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JAN 28 1986

Mr. Jack Fulton, Chairman
BWR Owners Group
Boston Edison Company
25 Brantree Hill Office Park
Brantree, Mass. 02184

Dear Jack:

SUBJECT: Proposed NUREG-1169 Concerning Generic Issue C-8, "MSIV Leakage and LCS Failures"

Enclosed is a copy of the proposed NUREG-1169 entitled "Resolution of Generic Issue C-8, An Evaluation of Boiling Water Reactor Main Steam Isolation Valve Leakage and the Effectiveness of Leakage Treatment Methods" for your review and comment. I would appreciate the Owners Group reviewing this document with respect to its technical content and its applicability to their plants.

Since we are anticipating publication of this NUREG by the end of February, we need to receive all comments by February 14, 1986. In order to expedite your review, I am sending a copy of the proposed NUREG directly to Elvis Hollins of TVA, Joseph Mollick of Philadelphia Electric Company, Jerry Burnett of General Electric and Richard Verbus of Cleveland Electric Illuminating Company. To expedite incorporation of the Owners Group comments into the NUREG, I request that each utility commenting provide me with a copy of their comments directly to me at mail P-1114.

John Ridgely, Project Manager
for Generic Issue C-8
Plant Systems Branch
Division of BWR Licensing

w/o enclosure:
bcc: R. Bernero
G. Lainas

RD-10-1
BWR
X RD-7
X RD-8-3
Pipe
Crack

OFC	PSB:DBL	PSB:DBL					
NAME	JRidgely	Lehman					
DATE	1/28/86	1/28/86					

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NUREG-1169

RESOLUTION OF GENERIC ISSUE C-8

An Evaluation of Boiling Water Reactor Main Steam Isolation Valve Leakage and the Effectiveness of Leakage Treatment Methods

Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

J. N. Ridgely and M. L. Wohl

January 1986

ABSTRACT

NUREG 1169 describes NRC staff and contractor efforts to resolve Generic Issue C-8, "Main Steam Isolation Valve Leakage and LCS Failure." This report describes efforts to determine the causes of excessive MSIV leakage and proposed solutions to the problem. A realistic fission product transport model was developed to assess the offsite dose consequences of alternate means of treating MSIV leakage using non-safety-grade systems that likely would be available for service following a design basis loss-of-coolant accident. The results of this assessment are presented in the report, together with conclusions regarding the prospects for reducing MSIV leakage, increasing the allowable MSIV leak rate, and the need to delete the requirement for a safety-grade leakage control system.

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ABBREVIATIONS

BWR	boiling water reactor
BWROG	BWR Owners Group
cfm	cubic feet per minute
Ci	curie
CRAC2	computer code
DST	Division of Safety Technology (NRC)
EAB	exclusion area boundary
ENS	a version of the TRAP/MELT computer code
EPG	emergency procedure guideline
FSAR	final safety analysis report
HEPA	high-efficiency particulate air
LCO	limiting condition for operation
LCS	leakage control system
LLI	lower large intestine
LLRT	local leak rate test
LOCA	loss of coolant accident
LPCI	low-pressure coolant injection
LPZ	low-population zone
LWR	light-water reactor
MSIV	main steam isolation valve
MSL	main steamline
MSLB	main steamline break
MWe	megawatt electric
MWt	megawatt thermal
NG	noble gas
NRC	U.S. Nuclear Regulatory Commission
NRR	(NRC) Office of Nuclear Reactor Regulation
PRA	probabilistic risk assessment
psig	pounds per square inch gage
PWR	pressurized water reactor
RPD	reference plant design
RPS	reactor protection system
RPV	reactor pressure vessel
RY	reactor year
scfh	standard cubic feet per hour
scfm	standard cubic feet per minute
SGTS	Standby Gas Treatment System
SJAE	steam jet air ejectors
SRV	safety relief valve
TACT III	computer code
TBV	turbine bypass valve
TCV	turbine control valve
TRAP/MELT	computer code

ACKNOWLEDGMENTS

The authors wish to acknowledge and express their appreciation to the following individuals and organizations for their assistance and contributions to the resolution of this Generic Issue C-8:

- Chairman M. E. Hollins and the members of the Boiling Water Reactor Owners Group Leakage Control Committee.

- The staff of the Washington Public Power Supply System for technical information.

- PNL staff members J. D. Jamison, D. L. Lessor, D. L. Strenge, W. E. Bickford, W. R. Krotiuk, A. Tabatabai, G. A. Sly, D. W. Faletti, S. H. Bian and P. C. Owczarski. A. Marshall and S. J. Sloot of PNL provided editorial and word processing assistance.

- General Electric Company staff and field representatives for information on the design and testing of MSIVs, the LCS, the offgas system, the SGTS and the main turbine stop and control valves.

EXECUTIVE SUMMARY

This NUREG report presents the results of the NRC staff and contractor efforts to resolve Generic Issue C-8, "MSIV Leakage and LCS Failure." This Issue deals with the inability of some main steam isolation valves (MSIVs) in boiling water reactors (BWRs) to meet the Technical Specification leakage rate limit, which is typically 11.5 scfh at 25 psig test pressure. This leakage rate was based on a large loss-of-coolant accident (LOCA), a specified design basis source term from the core (TID 14844), the worst single active failure, and no credit for any non-seismic Category I equipment, components, and structures. To limit offsite doses, a leakage control system (LCS) has been required to be installed on most BWRs to direct any leakage past the MSIV during the design basis LOCA to an area served by the Standby Gas Treatment System (SGTS). If the leakage rate through the MSIV is greatly in excess of the Technical Specification value, the LCS may not be effective because of limitations in its design.

As a result of these concerns and the potential consequences following a LOCA, the Division of Safety Technology (DST) prioritized the MSIV leakage and LCS failures as a high priority item in their reprioritization on January 20, 1983. Independent of the NRC efforts to resolve the Generic Issue, the BWR Owners Group (BWROG) formed the MSIV Leakage Control Committee to determine the cause of the high leakage rates associated with many of the MSIVs and to develop recommendations to reduce the leakage rate. The BWROG committee completed its effort and provided recommendations to the staff in February 1984.

The NRC staff's efforts to resolve this Generic Issue have focused on providing assurance that MSIV leakage will not be a significant contributor to offsite dose following a LOCA, using realistic assumptions concerning the equipment available to mitigate the effects of a LOCA. The specific elements of the effort were:

- To evaluate the BWROG recommendations associated with reducing leakage through MSIVs and assess the effectiveness of the recommendations as implemented by licensees.
- To evaluate the need for a safety-related LCS by comparing its effectiveness with that of other methods of handling the leakage that likely would be available following a LOCA.
- To perform a probabilistic risk assessment (PRA) to evaluate the reliability and relative risks associated with the different methods of mitigating the effects of a LOCA.

- To propose changes, as appropriate, to the current licensing requirements, including Standard Review Plan, Regulatory Guides and Standard Technical Specifications.

- To formulate recommendations regarding the use of alternate equipment to mitigate the effects of a LOCA, changes in allowable MSIV leakage, and the need for an LCS.

The findings and recommendations of the BWROG were reviewed and, for the most part, found acceptable by the staff. A thorough assessment of the effectiveness of the recommendations as implemented by licensees cannot be made at this time due to limited data.

The need for a safety-related LCS was assessed by comparing its effectiveness with the other methods of handling the leakage that would be available following a LOCA. It was concluded that several readily implemented leakage treatment methods which make use of the holdup volume of the main steamlines (MSL) and condenser are superior to the LCS in reducing offsite dose consequences.

A PRA of the reliability and relative risks associated with the different methods of mitigating the effects of a LOCA was performed. It was concluded that the overall risks from the accident sequences, in which MSIV leakage is a significant factor, were so low that a requirement to have an LCS could not be justified on a cost-benefit basis.

Changes to regulations, regulatory guides and technical specifications are proposed to acknowledge the realities of leak rate testing of these large valves and provide a leakage limit that is more likely to have some safety significance. A "standard" MSIV leak rate limit is not proposed. Rather, utilities are to propose plant-specific leak rate limits based on the total doses from all leakage sources not exceeding guidelines of 10 CFR 100.11 for the design basis LOCA. Based on our analyses, we anticipate that conservative plant-specific analyses will demonstrate that MSIV leakage rates of 300 scfh or more per valve will be acceptable if alternate leakage processing methods are used. This action should eliminate much unneeded, and perhaps detrimental, maintenance of MSIVs in service. Valves repaired or refurbished because of failure to meet this leak rate limit would be required to meet a lower limit of 5% of the Plant Technical Specification limit, or 15 scfh, whichever is greater, before being declared operational.

Finally, the staff concludes that a safety-grade LCS should not be required because alternate leakage processing methods result in reduced offsite consequences. Those plants with an LCS currently in operation should submit the results of an analysis that demonstrates a consequence reduction by using an alternate method before removing the LCS from service.

Although publication of this evaluation and of associated revisions to the Standard Review Plan, Regulatory Guides and the Regulations constitutes technical resolution of Generic Issue C-8 as delineated in the Task Action Plan, the technical resolution has not, at the time of publication, been reviewed by the Committee for the Review of Generic Requirements.

1. INTRODUCTION

This report presents the results of the NRC staff and contractor efforts to resolve Generic Issue C-8, "MSIV Leakage and LCS Failure." This issue deals with the inability of some main steam isolation valves (MSIVs) in boiling water reactors (BWRs) to meet the technical specification leakage rate limit, which is typically 11.5 scfh at 25 psig test pressure. This leakage rate was based on a large loss-of-coolant accident (LOCA), a specified design basis source term from the core (Ref. 1.1), the worst single active failure, and no credit for any non-seismic Category I equipment, components, and structures. To limit offsite doses, a leakage control system (LCS) has been required to be installed on most BWRs to direct any leakage past the MSIV during the design basis LOCA to an area served by the Standby Gas Treatment System (SGTS). If the leakage rate through the MSIV is greatly in excess of the technical specification value, the LCS may not be effective because of limitations in its design.

As a result of these concerns and the potential consequences following a LOCA, the Division of Safety Technology (DST) prioritized the MSIV leakage and LCS failure issue as a high priority item in their reprioritization on January 20, 1983. The NRR operating plan for FY83 included this item as Generic Issue C-8, "MSIV Leakage and LCS Failures," and authorized work to begin in FY83.

Independent of the NRC efforts to resolve Generic Issue C-8, the BWR Owners Group (BWROG) formed the MSIV Leakage Control Committee to determine the cause of the high leakage rates associated with many of the MSIVs and to develop recommendations to reduce the leakage rate to below the technical specification limit. The BWROG committee has completed their work effort and provided their recommendations to the NRC staff in February 1984. A review of the BWROG recommendations is provided in this report.

Resolution of this Generic Issue included verification that MSIV leakage will not be a significant contributor to offsite dose following a LOCA using realistic assumptions concerning the equipment available to mitigate the effects of a LOCA. The specific elements of the effort were:

- To evaluate the BWROG recommendations associated with reducing leakage through MSIVs and assess the effectiveness of the recommendations as implemented by licensees.
- To evaluate the need for a safety-related LCS by comparing its effectiveness with that of other methods of handling the leakage that likely would be available following a LOCA.
- To perform a PRA to evaluate the reliability and relative risks associated with the different methods of mitigating the effects of a LOCA.

- To propose changes, as appropriate, to the current licensing requirements, including Standard Review Plan, Regulatory Guides and Standard Technical Specifications.

- To formulate recommendations regarding the use of alternate equipment to mitigate the effects of a LOCA, changes in allowable MSIV leakage, and the need for an LCS.

To assist with the resolution of Generic Issue C-8, the NRC engaged the Pacific Northwest Laboratory (PNL) under FIN B2529.

The first task was the development of the baseline case, an assessment of dose consequences of a LOCA scenario with release through the LCS. The baseline case was later revised and additional calculations were run using two sets of release specifications for large direct atmospheric releases from containment.

A literature search was conducted to identify sources of technical data, procedures and event reports dealing with MSIV leakage, testing, maintenance and surveillance. Over 400 citations were reviewed and the documents were collected for those pertinent to the MSIV leakage issue. Efforts to review the documents and extract data for statistical analysis were started, but were suspended in February 1984 after the BWROG presented the results of their extensive data collection and analysis effort. Rather than attempting to duplicate the BWROG work, the staff determined that it would be better to examine and validate the BWROG methods and findings.

A method was developed for analyzing the transport of fission products from the reactor to the environment from the MSIVs via the LCS and the alternate leakage paths. This method assumes that all evolved radionuclides other than noble gases are in particulate form. A particle size spectrum in the source compartment [drywell and reactor pressure vessel (RPV)] is calculated for an early time (30 minutes after scram) and assumed constant thereafter. Assumptions appropriate to the scenario are made about thermal-hydraulic conditions in steamlines and leakage paths. Transport of fission products and depletion by deposition are calculated for the leakage paths to the environment.

Alternate leakage paths for treating MSIV leakage were selected from the model plant engineering drawings. Characterization of those paths (piping sizes, lengths, component characteristics) was done to provide inputs to the fission product transport calculations.

Utilizing the transport model thus developed, the releases of radioactive fission products to the plant environs were determined. The consequences of these releases, in terms of radiation dose to an individual, were then calculated using the CRAC2 computer code (Ref. 1.2) These calculated consequences provide a measure of the relative effectiveness of a given release pathway in

reducing the releases. By comparing the dose consequences of various leak rates and release pathways, the answers to the following questions can be determined:

- Is a safety grade LCS needed to minimize offsite doses following a design basis LOCA with MSIV leakage?
- What operational strategies relying on non-safety-grade equipment are preferable for reducing offsite dose consequences?
- What level of MSIV leakage could be acceptable based on a realistic analysis of offsite dose consequences?
- What changes in regulatory requirements are indicated by the results of this analysis?

This report presents the answers to these questions and describes the analysis upon which they are based.

2. BACKGROUND

2.1 Requirements for Control of MSIV Leakage and the LCS

The requirements for control of MSIV leakage are based on the General Design Criteria for Nuclear Power Plants, 10 CFR 50, Appendix A (Ref. 2.1). Specifically, Criterion 54 requires that:

> "Piping systems penetrating primary reactor containment shall be provided with leak detection, isolation, and containment capabilities having redundancy, reliability, and performance capabilities which reflect the importance to safety of isolating these piping systems. Such piping systems shall be designed with a capability to test periodically the operability of the isolation valves and associated apparatus and to determine if valve leakage is within acceptable limits."

Criterion 55 requires that:

> "Each line that is part of the reactor coolant pressure boundary and that penetrates primary reactor containment shall be provided with containment isolation valves - - - one automatic isolation valve inside and one automatic isolation valve outside containment."

The requirements for Primary Reactor Containment Leakage Testing for water-cooled power reactors are found in 10 CFR 50, Appendix J (Ref. 2.2). There, test requirements for BWR main steamlines (MSL) that penetrate containment are defined. As implemented, the Appendix J requirements result in MSIVs being leak tested every refueling outage by local pressurization to about 25 psig with air or nitrogen. The leak rate limit as specified in the plant specific technical specifications is generally 11.5 scfh, and is based on a conservative assessment of dose consequences.

Beginning about 1970, the staff's concern over the possible dose consequences of MSIV leakage at or above the 11.5 scfh limit led to the requirement that an LCS be installed in new plants. This regulatory position was set forth in Regulatory Guide 1.96, "Design of Main Steam Isolation Valve Leakage Control Systems for Boiling Water Reactor Nuclear Power Plants" (Ref. 2.3). Currently there are about ten BWR-4 and BWR-5 plants that have this system. All domestic and some foreign BWR-6 plants have LCSs.

2.2 MSIV Leakage Experience at BWRs

Many BWR licensees have reported difficulty meeting the allowable leakage rate limit for periodic local leak rate tests (LLRTs). One survey of the leakage rates of 400 MSIVs has shown that 46 valves exceeded the allowable leakage rate limit and required refurbishing to be brought within the allowable limit. Leakage rates as high as 3795 scfh have been reported. At one plant some valves were reported to consistently have a test leak rate well in excess of 11.5 scfh, some consistently above 1000 scfh.

Another survey of MSIV performance at BWRs for the years 1979 through 1981 found that 18 of 25 operating BWRs had MSIVs which failed to meet the limiting condition for operation (LCO), which specifies the maximum permissible leak rate, during one or more surveillance tests. During this time the number of MSIV test failures exceeded 150 with MSIVs supplied by all three MSIV vendors.

Measured leak rates that exceeded the LCO ranged up to 3427 scfh. Twelve licensees reported 57 MSIV tests with results of less than 100 scfh, and 4 licensees had 65 MSIV tests with results between 100 and 3500 scfh. Four other licensees had more than 24 test failures but did not measure, estimate, or report the magnitudes of the leak rates.

To return the valves to within the allowable leakage rate limits, different methods of refurbishment have been used. Most utilities grind or lap the valves. At least one utility has instituted a major refurbishment that includes increasing the actuator stem diameter, adding more guide rails for the valve plug, and increasing the force of the valve operator.

2.3 LCS Description and Principles of Operation

Two fundamentally different types of LCSs have been implemented by licensees to mitigate the effects of MSIV leakage. The first type uses a positive back-pressure of nitrogen or air in the steamline between the MSIVs to prevent outward leakage. This type of LCS exists at relatively few plants. While this type of LCS is not within the direct purview of this study because it prevents outward leakage from MSIVs rather than collecting and treating it, the dose results of this study would be applicable.

The second, more prevalent type of LCS uses blowers or "exhausters" to maintain a subatmospheric (negative) pressure in the steamlines between the MSIVs. Any leakage past the MSIVs is thereby collected, routed through a cleanup system, and discharged to the plant environment. Details of LCS system design differ from plant to plant. The design description and principles of operation presented here are based on the reference plant except where otherwise noted, and are typical of most systems in use today.

With both types of LCS design, two redundant trains are provided. one train services the space between the MSIVs and the redundant train services the space between the outboard MSIV and the main steam shutoff valve on the turbine stop valve. Each train is powered from a different diesel generator.

2.3.1 System Function

The function of the LCS is to minimize the release of fission products that would leak through the closed MSIVs after a LOCA. The system exhausts into the vicinity of the SGTS for processing. The system is capable of performing its function following any single component failure, including the failure of one MSIV to close, and will remain functional with a loss of offsite power. The LCS is manually initiated, controlled from the control room, and has system interlocks relating to the steamline pressure and would be placed in operation no sooner than twenty minutes following a LOCA. All valves and blowers in the LCS are testable during power operation.

2.3.2 System Description

2.3.2.1 Inboard Subsystem

Each MSL is provided with individual lines that tap off between the MSIVs. Each line contains two motor-operated isolation valves, an electric heater to boil off any condensate in the line, and a depressurization line to the main condenser for initial pressure reduction. The individual lines feed into a low-pressure manifold where the leakage is mixed with dilution air and exhausted by a 100 cfm blower. The blower discharges in the vicinity of the suction plenum of the SGTS.

2.3.2.2 Outboard Subsystem

The lines for the outboard subsystem tap off downstream of the outboard MSIVs. A combined depressurization line with two isolation valves directs any steam trapped in the steamlines to the main condenser for the initial pressure reduction. A 100 cfm blower then draws on the combined lines and discharges in the vicinity of the SGTS suction plenum.

2.3.3 System Operation

The LCS is initiated from the control room after reactor pressure is below 35 psig and no less than ten minutes after it has been determined that a LOCA has occurred (the time and pressure limits vary from reactor to reactor).

2.3.3.1 Inboard System

Provided the reactor pressure permissive interlock has been satisfied, when the control switch is positioned to ON, the depressurization valves will open, the heaters will energize, and the blower will start.

After the line pressure has been lowered, the depressurization valves will isolate and the bleedoff isolation valves will open. The blower will maintain the volume between the MSIVs at subatmospheric pressure. If the MSIVs in one line fail to isolate, the depressurization valves for that line will isolate one minute after the system actuates because the pressure in that steamline will not have dropped to 5 psig or less. If the MSL pressure shows that the MSIV has excessive leakage, the associated bleed valves will also isolate.

2.3.3.2 Outboard System

As described above, the reactor low-pressure permissive must be satisfied before the system is placed into service. The depressurization valves will open and the blower will start when the control switch is positioned to ON.

As the steamline pressure decreases to atmospheric, the depressurization valves will isolate and the bleedoff lines to the blower will open. If subatmospheric pressure is not established in five minutes, a timer will actuate an alarm and the operator must take corrective action, such as securing the system or reinitiating it.

As noted above, the LCS exhausts the MSIV leakage to the vicinity of the SGTS suction plenum. This means that the contaminated steam leaking through the MSIVs is discharged into the reactor building or secondary containment with the potential for contaminating that area and impairing accessibility. (The reference plant has the LCS discharge piped directly into the SGTS suction plenum, but this is not true at most plants.)

The SGTS high-efficiency particulate air (HEPA) and charcoal filters will remove a large fraction (99+%) of any fission products in particulate form but will have only a small effect on the noble gas isotopes. Finally, the LCS is designed to handle leakages only moderately in excess of the technical specification limits, so that the performance of the SGTS is not adversely affected. Thus the LCS would probably be inoperable in cases of MSIV leakage greater than a few hundred scfh.

3. EVALUATION OF BWROG RECOMMENDATIONS

The evaluation of the BWROG findings and recommendations is summarized in this section. The Technical Evaluation Report describing this evaluation in full is included as Appendix A.

3.1 Summary of BWROG Effort

In response to the MSIV leakage problem, the BWROG formed the MSIV Leakage Control Committee to determine the cause of the high leakage rates and develop recommendations for reducing them. The BWROG Committee completed their effort and provided their recommendations to the NRC on February 23, 1984.

The results of the BWROG MSIV Leakage Committee work was presented to the NRC as three separate reports. The three reports covered the collection and evaluation of MSIV leakage data, potential operator actions to control MSIV leakage, and an improved dose calculation method for consequence assessment.

3.1.1 Data Collection and Evaluation

The BWROG MSIV Leakage Committee solicited data on valve performance and maintenance history from its member licensees. The intent was to construct a data base from which conclusions could be drawn regarding the causes and likely solutions to the problem of excessive MSIV leakage. The data base included plant operational history and information on valve type, manufacturer, location, actuator type and other factors that the committee considered to have some bearing on MSIV performance.

A list of potential contributing factors was generated by the committee. Possible correlations between the reported valve data and the contributing factors were then examined.

The committee categorized the contributors into three groups: primary contributors, secondary contributors, and non-contributors. The primary contributors would most likely be the cause for large leakage rates. The secondary contributors would most probably be the cause for leakages of less than 500 scfh. The primary factors contributing to excessive MSIV leakage as indicated by failure of local leak rate tests (LLRTs) are as follows:

- improper maintenance,
- valve orientation,
- excessive clearance/seat-to-guide misalignment,

- lack of concentricity (seat-to-poppet),
- incorrect seat contact, and
- excessive coefficient of friction/corrosion.

The following were concluded to be secondary contributors, having a minor effect on leakage:

- seat geometry,
- inadequate actuator loading,
- sources other than the seat,
- valve damage,
- LLRT pressurization method,
- closing procedure, and
- poppet rotation.

The following were concluded not to be contributors to failure of the LLRT:

- pipe loading,
- thermal distortion,
- MSIV aging,
- actuator/stem binding,
- valve design differences, and
- foreign deposits.

The committee followed up these conclusions with recommendations that specific corrective and preventive actions be taken to counter the effect of the primary contributors. It recommended that specific actions be considered to deal with the secondary contributors, and that "no action beyond current practice" be taken for those factors judged to be non-contributors.

The BWROG submittal on the data collection and evaluation process is incorporated as Appendix B to this report.

3.1.2 Potential Operator Actions to Control MSIV Leakage

The General Electric Company report "Potential Operator Actions to Control MSIV Leakage" (Ref. 3.1) evaluated ten symptomatic conditions that could provide an indication of fuel failures and MSIV leakage. These conditions were categorized into three major groups:

Group 1: those indicating that MSIV leakage control <u>is</u> appropriate,

Group 2: those indicating that MSIV leakage control <u>may be</u> appropriate, and

Group 3: those indicating that MSIV leakage control <u>is not</u> appropriate.

Only Groups 1 and 2 were addressed by the BWROG Committee as being of any significance to the MSIV leakage problem. Three of the ten symptomatic conditions were in Group 3. While all were considered to be of great significance to overall plant safety and also were entry conditions for the emergency procedure guidelines (EPGs), they provided no direct correlation to MSIV leakage and were not evaluated for potential operator actions in this report by the BWROG. Of the remaining seven symptomatic conditions, two were in Group 1, (directly related to MSIV leakage) and the other five were in Group 2, (possibly related to MSIV leakage).

Next, the most probable leakage pathways were identified by the BWROG. They can be summarized in the following three major types:

(1) all intact systems and subsystems,

(2) steamline breaks in containment, and

(3) steamline breaks outside containment.

For each potential operator action, each of the above flow paths was considered, and the methods of radioactive release treatment were discussed.

Once the BWROG defined the important indications of MSIV leakage and the most probable flow paths for radioactive leakage, they proceeded to examine potential operator actions that would minimize the dose contribution from MSIV leakage. The BWROG defined nine potential actions that would reduce the dose consequences of MSIV leakage. Each potential operator action was evaluated for its effect on reduction of radioactive releases from the plant, feasibility of implementation, other benefits, drawbacks, and consistency with the EPGs.

Following the completion of the classification of the ten symptomatic conditions and nine operator actions, the BWROG provided direction for modifying the

existing general emergency procedure guidelines, (Ref. 3.2). The operator action guidelines were prioritized in three categories:

(1) control and treat any MSIV leakage,

(2) contain any MSIV leakage in the main steam system, and

(3) control the release of any MSIV leakage when containment is not possible.

3.1.3 Improved Dose Calculation Method

This method was developed by General Electric for the BWROG to provide a more realistic, yet conservative, evaluation of control room and offsite dose consequences compared to the methods used in previous FSAR analyses. It is expected that plant-specific analyses using this model will show that MSIV leakages significantly in excess of technical specifications do not constitute a safety problem.

The model was based on a nonbreak, isolation transient with all piping downstream of the MSIVs to the turbine-condenser assumed intact. Principal fission product attenuation mechanisms considered in this model that have not been previously considered are: 1) flow discharge through the safety relief valve (SRV), 2) plateout of particulates in the reactor vessel, steamlines, bypass lines, and condenser, and 3) decay of fission products while in transit.

The basic model employed is a three-compartment model for offsite dose calculations or a four-compartment model for a control room calculation. The model may also be divided into three areas of calculation: 1) reactor pressure vessel response, 2) ex-vessel transport, and 3) dose calculations. As derived, the model is a combination of empirical data and analytical equations. The empirical data can be changed without invalidating the model if more precise information becomes available.

3.2 Summary of PNL Evaluation

This section summarizes the PNL conclusions regarding the BWROG efforts to resolve the MSIV leakage problem. The full discussion of the PNL evaluation methods, findings and conclusions is contained in Appendix A.

3.2.1 Data Collection, Evaluation and Recommendations

Based on this evaluation, it was concluded that the BWROG data collection process was adequate with regard to the amount and type of data collected. The number of plants, plant classes, and the valves represented in the sampling give confidence in the validity of the data base.

Because little detail was provided on the data evaluation process, it was not possible to independently confirm the adequacy of the committee's data analysis. The analysis identified as primary contributors several factors that are intuitively believable causes of leakage (valve orientation, improper maintenance). It is therefore concluded that the data analysis is probably satisfactory.

Finally, the committee recommendations are generally consistent with their findings regarding the causes of MSIV leakage. If the classification of contributors is correct, implementing the committee recommendations should substantially reduce the incidence and magnitude of LLRT failure. The major unresolved issue surrounding the committee recommendations is the translation of the general recommendations into plant- and valve-specific recommendations and procedures. No information on this was provided by the committee.

We conclude that the BWROG Committee data collection effort provided an adequate basis for the solution of the MSIV leakage problem. The sample size, both in number of plants and valve history (operating years) represented gives confidence that the data is representative.

3.3 Assessment of Effectiveness of BWROG Recommendations

In February 1984, the Staff requested that the BWROG Leakage Control Committee provide a plan for implementing the committee recommendations and reviewing the results. At the time this report was prepared, only a few BWROG member utilities had implemented the recommendations. Since that time little data has been available on the effectiveness of the program. Appendix C summarizes the implementation actions taken by one licensee and the observed improvement in leak rate test performance.

4. EVALUATION OF NEED FOR LCS

4.1 Introduction to the Evaluation Method

One stated purpose of Generic Issue C-8 is to determine the need for a safety-related LCS by evaluating the dose consequences of using alternate means of controlling MSIV leakage. These alternate means make use of non-safety-related equipment and systems that could reasonably be expected to remain intact and serviceable following the LOCA. It should be noted that the only purpose of the LCS is to mitigate the effects of the recirculation line break LOCA and therefore only this LOCA needs to be considered when evaluating the need for the LCS.

The analysis described in this section uses a realistic fission product transport model to determine the quantities of radioactive material released by specific pathways in several time periods following the LOCA. By realistically modeling the depletion processes that would take place in plant piping and components, comparing the resulting offsite doses with those resulting from use of the LCS, and taking into account the likelihood that a given pathway would be available following the LOCA, the relative merits of using the LCS versus other installed equipment have been assessed. Problems associated with using the LCS to treat MSIV leakage with respect to contamination at the secondary contaminant are discussed in Section 5.5.

The essential elements of this analysis are:

- the baseline studies (LCS pathway),
- the realistic fission product transport model,
- the alternate leakage treatment methods, and
- the dose consequence calculations.

These will be discussed in detail in the following sections.

4.2 Baseline Studies

A baseline analysis was conducted to serve as a reference point against which to measure the effectiveness of the alternate methods of processing the MSIV leakage after a LOCA. This section presents the description and results of the baseline calculation of offsite doses using the TID source term. A discussion of the assumptions and methods used in the offsite dose calculations is provided in this section.

4.2.1 Baseline Case

This calculation is based on the current licensing design basis accident scenario involving a LOCA-induced core melt coupled with a complete break in the main steamline (MSL) downstream of the second MSIV and the failure of an inboard MSIV to close. Data for the analysis is based partially on the reference plant Final Safety Analysis Report (FSAR) (Ref. 4.1). The accident can be divided into two time periods; the first twenty minutes prior to operation of the LCS, and the time following initiation of the LCS. The flow of radioactivity from the reactor core to the exposure location is illustrated schematically in Figures 4.1 and 4.2 for the two periods. The primary baseline accident is assumed to proceed as follows:

- Immediately following the LOCA-induced core melt and steamline break, the primary coolant steam (24,960 lbs) is assumed to contain the TID source term activity. During the next 20-minute period, the primary steam is assumed to leak to the atmosphere through the MSIV and steamline break at a mass flow rate equivalent to 11.5 scfh at 25 psig. This leak rate corresponds to a fractional mass leak rate of the primary coolant steam of 0.068% per day. (Fig. 4.1)

- The release continues for 20 minutes, at which time the LCS activates and the leakage from all four MSIVs is directed through the SGTS. The SGTS filters reduce the iodine and particulate releases by 99%, but have no effect on noble gases. No delay in transit through the SGTS is assumed; the release from the MSIVs to the atmosphere (with filtration) is assumed to be immediate. The combined leak rate for the four MSIVs is 0.27% per day. (Fig. 4.2)

- The release continues at 0.27% per day indefinitely.

The release of material to the primary containment atmosphere following a postulated core melt accident is described in TID-14844 (Ref. 4.2). This source term postulates release of 100% of the core inventory of noble gases, 50% of the radioiodines, and 1% of the remainder of the radionuclides in particulate form. This release is assumed to be airborne in the steam phase of the primary containment atmosphere. No credit is taken for reduction in activity by plateout or settling.

During the first 20 minutes of the accident, the release is direct to the atmosphere and no credit is taken for filtration. After the first 20 minutes the release is through the SGTS, which contains charcoal and HEPA filters, resulting in an assumed removal of 99% of all radionuclides except noble gases (NGs).

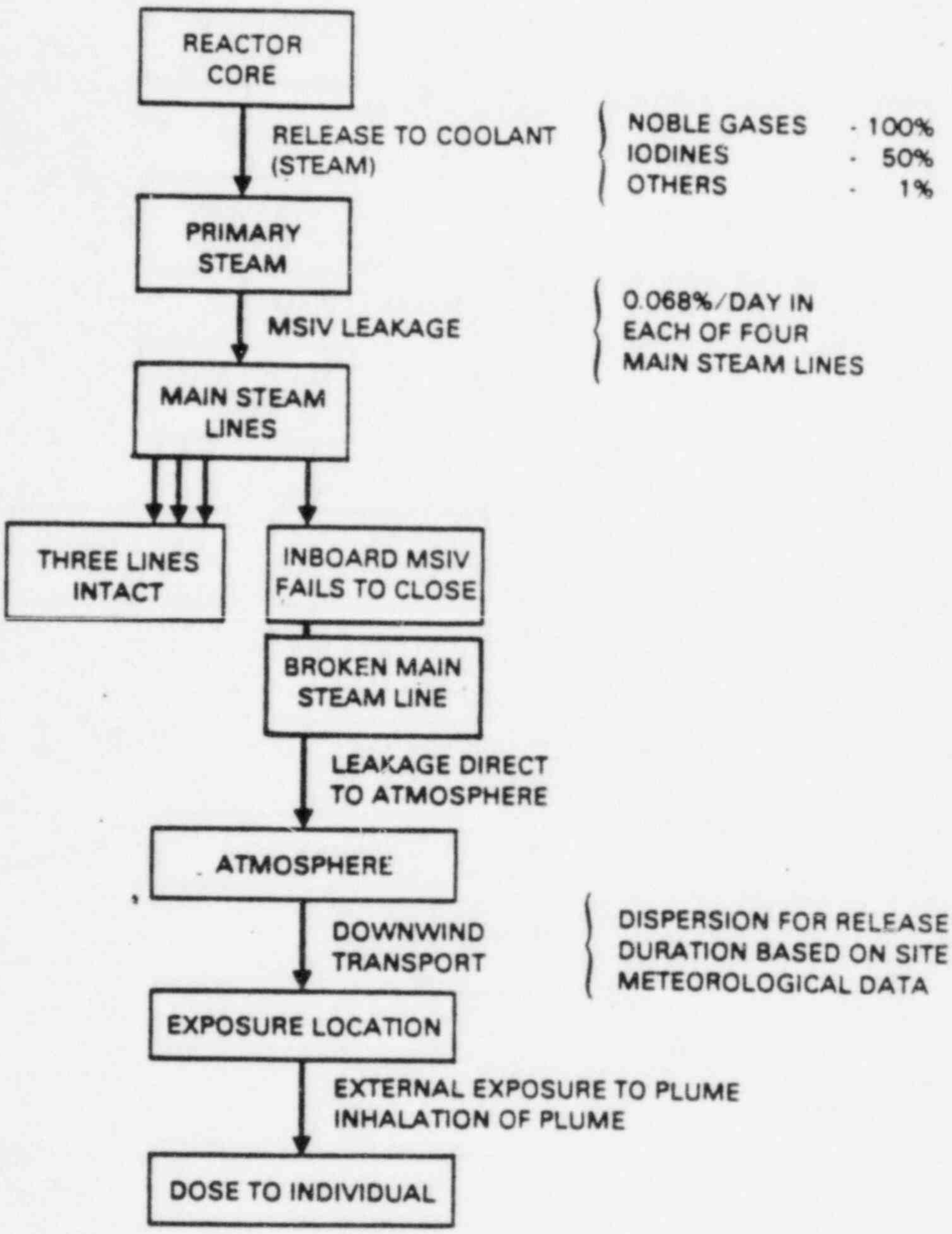

Figure 4.1. Release path for first twenty minutes

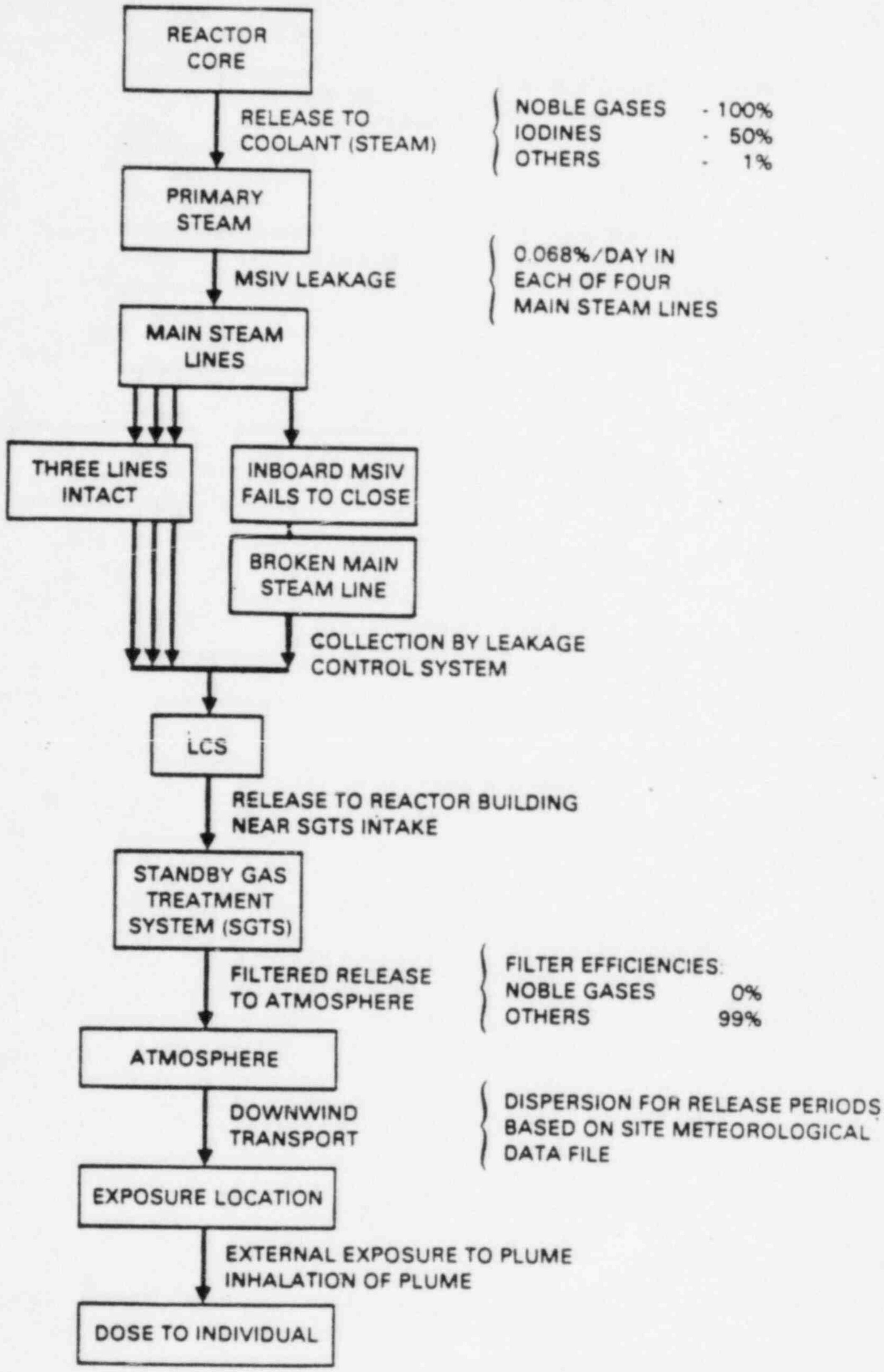

Figure 4.2. Release path after first twenty minutes

The calculations were performed using the CRAC2 computer program (distributed by Sandia National Laboratory, Ref. 4.3), modified slightly to print necessary dose tables. (Listing of the modification is in Appendix D.)

Comparison of the dose calculation results with 10 CFR 100 limits required that two time periods for release be considered: 2 hours [corresponding to dose estimates for the exclusion area boundary (EAB)] and 30 days [for dose estimates for the low-population zone (LPZ)]. To properly account for the initial 20-minute period of special release and the 2-hour and 30-day exposure times, the CRAC2 input had to be divided into 5 cases as described in Table 4.1. Section 4.4.3 describes the CRAC2 dose model.

4.2.2 Dose Calculation Results for the Primary Baseline Case

The radiation doses calculated for the base case are presented in the following tables. Table 4.2 presents results for the EAB for the 2-hour release. Included in the table are the average and maximum values expected assuming the accident can happen at any time during the year. The average values are calculated as an average over all directions from the site. The maximum values are the maximum observed doses for the start times sampled using the importance sampling procedure of the CRAC2 program.

Table 4.3 presents the radiation doses at the LPZ boundary for the 30-day release time. Average and maximum values are given in this table as for Table 4.2.

4.2.3 Alternate Baseline Cases

Several different alternate baseline cases were run to provide for comparison of the effectiveness of alternate leakage treatment methods, the effect of different source term assumptions, and the effect of the differences in the dose codes.

Table 4.1. Base case accident scenario representation for CRAC2

Period	Time After Start	Release Pathway	Filtration Considered	Breathing Rate (M^3/sec)
1	0 - 20 min	direct	none	3.47×10^{-4}
2	20 min - 2 hrs	SGTS	NG = 0, others = 99%	3.47×10^{-4}
3	2 hrs - 8 hrs	SGTS	NG = 0, others = 99%	3.47×10^{-4}
4	8 hrs - 1 day	SGTS	NG = 0, others = 99%	1.75×10^{-4}
5	1 day - 30 days	SGTS	NG = 0, others = 99%	2.32×10^{-4}

Table 4.2. Base case individual doses (rem) at the exclusion area boundary (6400 feet) for a two-hour release

	Whole Body	Organ of Reference Bone Marrow	Lungs	LLI*	Thyroid
<u>Average Dose</u>					
Period 1	1.9×10^{-2}	8.6×10^{-3}	2.5×10^{-1}	1.3×10^{-2}	2.2×10^{0}
Period 2	1.5×10^{-2}	1.5×10^{-2}	4.0×10^{-2}	1.1×10^{-2}	2.6×10^{-1}
Total	3.4×10^{-2}	2.4×10^{-2}	2.9×10^{-1}	2.4×10^{-2}	2.5×10^{0}
<u>Maximum Dose</u>					
Period 1	5.7×10^{-2}	2.6×10^{-2}	7.6×10^{-1}	4.0×10^{-2}	6.8×10^{0}
Period 2	7.3×10^{-2}	7.9×10^{-2}	1.8×10^{-1}	5.5×10^{-2}	8.1×10^{-1}
Total	1.3×10^{-1}	1.1×10^{-1}	9.0×10^{-1}	9.5×10^{-2}	7.6×10^{0}

*LLI - Lower Large Intestine.

Table 4.3. Base case individual doses (rem) at the low population zone boundary (three miles) for a thirty-day release

	Whole Body	Organ of Reference Bone Marrow	Lungs	LLI	Thyroid
<u>Average Dose</u>					
Period 1	4.8×10^{-3}	2.4×10^{-3}	5.9×10^{-2}	3.4×10^{-3}	5.3×10^{-1}
Period 2	5.0×10^{-3}	5.3×10^{-3}	1.1×10^{-2}	3.8×10^{-3}	6.4×10^{-2}
Period 3	6.7×10^{-3}	7.2×10^{-3}	2.2×10^{-2}	4.7×10^{-3}	1.5×10^{-1}
Period 4	6.1×10^{-3}	7.5×10^{-3}	2.6×10^{-2}	3.6×10^{-3}	1.7×10^{-1}
Period 5	3.4×10^{-3}	2.0×10^{-3}	4.2×10^{-2}	1.6×10^{-3}	1.1×10^{-1}
Total	2.6×10^{-2}	2.4×10^{-2}	1.6×10^{-1}	1.7×10^{-2}	1.0×10^{0}
<u>Maximum Dose</u>					
Period 1	1.5×10^{-2}	7.5×10^{-3}	1.8×10^{-1}	1.0×10^{-2}	1.6×10^{-0}
Period 2	1.8×10^{-2}	2.0×10^{-2}	3.6×10^{-2}	1.4×10^{-2}	2.0×10^{-1}
Period 3	2.4×10^{-2}	2.7×10^{-2}	7.0×10^{-2}	1.7×10^{-2}	4.5×10^{-1}
Period 4	2.3×10^{-2}	3.0×10^{-2}	8.2×10^{-2}	1.3×10^{-2}	5.3×10^{-1}
Period 5	1.1×10^{-2}	7.5×10^{-3}	1.3×10^{-1}	5.3×10^{-3}	3.4×10^{-1}
Total	9.1×10^{-2}	9.2×10^{-2}	5.0×10^{-1}	5.9×10^{-2}	3.1×10^{0}

4.2.3.1 Alternate Baseline Case 1 - CRAC2/BWR4

This case used the BWR4 release specification from WASH 1400 (Ref. 4.8), the CRAC2 code and the reference plant inputs. The doses are all calculated for the entire release period which ends at seven hours. The EAB and LPZ boundary doses are presented in Table 4.4.

4.2.2.2 Alternate Baseline Case 2 - CRAC2/BWR5

This case is identical to the above-described alternate baseline case 1 except that the WASH 1400 BWR5 release specification was used. The release period ends at 8.5 hours. Doses are presented in Table 4.5.

Table 4.4. Individual doses (rem) at the EAB and LPZ for release sequence BWR4

	Organ of Reference				
	Whole Body	Bone Marrow	Lungs	LLI	Thyroid
Average Dose					
EAB	4.3×10^{1}	4.2×10^{1}	3.7×10^{2}	4.4×10^{1}	4.5×10^{2}
LPZ	4.3×10^{1}	1.3×10^{1}	9.1×10^{1}	1.2×10^{1}	1.1×10^{2}
Maximum Dose					
EAB	1.7×10^{2}	1.9×10^{2}	1.2×10^{3}	1.6×10^{2}	1.4×10^{3}
LPZ	4.4×10^{1}	4.7×10^{2}	2.8×10^{2}	4.0×10^{1}	3.4×10^{2}

Table 4.5. Individual doses (rem) at the EAB and LPZ for accident sequence BWR5

	Organ of Reference				
	Whole Body	Bone Marrow	Lungs	LLI	Thyroid
Average Dose					
EAB	2.3×10^{-3}	2.7×10^{-3}	2.1×10^{-3}	1.7×10^{-3}	2.2×10^{-3}
LPZ	1.4×10^{-3}	1.7×10^{-3}	1.3×10^{-3}	1.0×10^{-3}	1.3×10^{-3}
Maximum Dose					
EAB	1.0×10^{-2}	1.2×10^{-2}	9.6×10^{-3}	7.6×10^{-3}	9.9×10^{-3}
LPZ	6.4×10^{-3}	7.8×10^{-3}	6.0×10^{-3}	4.7×10^{-3}	6.2×10^{-3}

4.2.2.3 Alternate Baseline Case 3 - TACT III/TID

Alternate baseline case 3 is the recalculation of the primary baseline case scenario using the TACT III code. The CRAC2 inputs were tailored to meet the input requirements of the TACT III code.

This case was done primarily to provide a comparison between CRAC2 and TACT III since TACT III has previously been used by the Staff in the review of plants applying for a license.

The doses appropriate for comparison are the thyroid dose and whole-body dose at the EAB and LPZ. These are the only doses reported by both programs. The calculated doses are compared in Table 4.6.

The primary differences in calculations and models which may result in discrepancies in the calculated doses are the source term definition, the release calculation, the dispersion calculation, and the dosimetry.

4.2.3.1 Source Term

Both calculations attempted to describe an LWR operating at 3462 MWt at the end of an equilibrium operating cycle. The core inventories at shutdown for this power level are indicated in Table 4.7. The inventories are quite similar, especially for the key radioiodines that contribute to the thyroid dose. The basic inventory does not appear to contribute significantly to the difference in doses.

4.2.3.2 Release Calculation

The CRAC2 release to the environment is described as leakage from a single volume at a fixed rate for each release period. The TACT III program is

Table 4.6. Comparison of calculated doses: TACT III and CRAC2 dose to an Individual (rem)

Organ of Reference	Dose to an Individual (rem) TACT III	CRAC2
Exclusion Area:		
Thyroid	35	7.6
Whole Body	1.7	0.13
Low-Population Zone:		
Thyroid	26	3.1
Whole Body	2.0	0.091

Table 4.7. Core inventory comparison for a 3462 MWt LWR

Radionuclide	Ci CRAC2	Ci TACT III
Kr-85	6.74×10^5	1.42×10^6
Kr-85m	3.17×10^7	4.49×10^7
Kr-87	5.78×10^7	8.08×10^7
I-131	8.87×10^7	8.68×10^7
I-133	1.87×10^8	1.95×10^8
I-135	1.76×10^8	1.77×10^8
Xe-133	1.87×10^8	1.95×10^8
Xe-135	3.86×10^7	1.86×10^8

designed to describe this system mathematically, and presents the total release during each period. The CRAC2 program does not calculate releases at a fixed rate, but requires the user to provide the total fraction released in a given period. For the base case calculation, special calculations were performed to determine the amount of each radionuclide released during each time period. These release inventories were entered directly into the CRAC2 program. A comparison of the total releases used in CRAC2 and calculated by TACT III is presented in Table 4.8 and does not appear to contribute significantly to the differences in doses.

4.2.3.3 Dispersion Calculation

The dispersion calculation for the TACT III calculation relies on user-supplied dispersion values. The values used in the present analysis were taken from the reference plant FSAR and are based on site meteorological observation data. The CRAC2 dispersion calculation is performed by the program using a sequential hourly observation data file based on data collected at the site. Because the dispersion values are not printed by the CRAC2 program, there is no sure way to compare the effect of differences in the dispersion calculation. However, the worst dispersion conditions are generally associated with stable atmospheric conditions at low wind speeds. The TACT III dispersion values are probably based on such conditions prevailing over the entire time of release, with added lateral dispersion for the longer release periods. The CRAC2 program uses the actual hourly observation sequences, which may not include the same level of persistence of stable, low wind speed conditions. This could result in lower dispersion estimates for the CRAC2 dispersion calculation.

Table 4.8. Comparison of calculated releases to the atmosphere

Radionuclide	Curies Released During Period	
	TACT III (calculated)	CRAC2 (input)
Period 1:		
Kr-85	1.57×10^{1}	6.40×10^{0}
Kr-85m	4.13×10^{2}	2.94×10^{2}
Kr-87	6.99×10^{2}	5.02×10^{2}
I-131	4.10×10^{2}	4.22×10^{2}
I-133	9.14×10^{2}	8.83×10^{2}
I-135	8.20×10^{2}	8.21×10^{2}
Xe-133	1.84×10^{3}	1.78×10^{3}
Xe-135	1.90×10^{3}	3.71×10^{2}
Period 2:		
Kr-85	5.67×10^{2}	1.27×10^{2}
Kr-85m	7.07×10^{3}	5.02×10^{3}
Kr-87	8.48×10^{3}	5.99×10^{3}
I-131	8.17×10^{1}	8.34×10^{1}
I-133	1.77×10^{2}	1.70×10^{2}
I-135	1.48×10^{2}	1.47×10^{2}
Xe-133	3.66×10^{4}	3.52×10^{4}
Xe-135	4.08×10^{4}	7.91×10^{3}
Total All Periods:		
Kr-85	8.45×10^{5}	5.28×10^{4}
Kr-85m	3.07×10^{4}	2.24×10^{4}
Kr-87	1.51×10^{4}	1.04×10^{4}
I-131	1.28×10^{4}	1.31×10^{4}
I-133	4.20×10^{3}	4.01×10^{3}
I-135	1.75×10^{3}	1.73×10^{3}
Xe-133	3.97×10^{6}	4.01×10^{6}
Xe-135	3.51×10^{5}	1.51×10^{5}

4.2.3.4 Dosimetry Calculations

The thyroid and whole-body doses presented in Table 4.1 are not calculated identically by the two programs. The TACT III thyroid dose includes only contributions from radioiodines and is based on a 50-year inhalation dose commitment factor. The CRAC2 thyroid dose includes contributions from most radionuclides inhaled, plus external exposure from the passing cloud and deposited material.

The differences are not significant because the external exposure is a small fraction of the internal exposure for thyroid. The dose conversion factors used by the two programs are presented in Table 4.9.

The TACT III calculation of whole-body dose is based on the dose received from the passing cloud. A semi-infinite plume model is used. The CRAC2 whole-body dose calculation includes the cloud dose based on the finite plume model, plus external exposure to deposited material and inhalation exposure received within two days of uptake. Because of the large amount of noble gases released, the major contribution to whole-body dose is probably the cloud exposure. An estimate of the differences in calculational methods between the finite plume and semi-infinite plume models can be obtained from the finite plume correction used by CRAC2. The CRAC2 program applies a correction factor to the semi-infinite plume dose based on the current weather conditions. For stable conditions, the correction factors at distances of 6400 feet and 3 miles are approximately 0.2 and 0.3, respectively. This could be a significant source of differences in calculated whole-body doses. The external dose conversion factors used by the two programs are nearly identical and are not presented here. In summary, the CRAC2 code calculates more realistic doses compared with those calculated by the deterministic and extremely conservative approach used in TACT III.

4.3 Alternate Leakage Treatment Methods

This section describes the alternate methods of treating MSIV leakage using non-safety grade systems and equipment that likely would be available for use following the LOCA.

4.3.1 Isolated Condenser

This leakage treatment mode uses the large volume of the main condenser to hold up the release of fission products leaking from the MSIV and down the MSL. The

Table 4.9. Comparison of thyroid dose conversion factors

	Dose Conversion Factor (rem/Ci inhaled)	
Radionuclide	TACT III	CRAC2
Iodine-131	1.5×10^6	1.1×10^6
Iodine-132	5.4×10^4	6.6×10^3
Iodine-133	4.0×10^5	1.8×10^5
Iodine-135	1.2×10^5	4.4×10^4

condenser would be isolated from the turbine building atmosphere to the extent possible, however, leakage of condenser contents would occur from the low-pressure turbine seals, primarily from changes in atmospheric temperature and barometric pressure. This mode has two variations. The first is the case where the turbine bypass valves are opened to ensure free communication from the steamlines to the condenser. The second is the case where the turbine bypass valves remain closed but the MSL condensate drains are opened to the condenser. The latter mode provides less holdup time in the MSL because the steamline condensate drain bypass lines are much smaller in diameter than the lines from the turbine bypass valve manifold to the condenser and higher leakages through the turbine valves. This lower hold-up time leads to slightly higher releases because of the reduced depletion of particulate matter by gravitational settling.

Some plants have the MSL drain valves fail open on a loss of power. For these plants, this approach qualifies as completely passive because no power or operation action is required to use this pathway.

4.3.2 Isolated Steamline

This leakage treatment mode is completely passive in that it relies on no off-site powered equipment or operator action. Following MSIV closure and turbine trip, the turbine bypass valves likely will be in the closed position, isolating the MSL from the main condenser. This has the effect of restricting the flow out of the MSL. However, the turbine bypass, turbine stop and turbine control valves will all leak substantially because of their size and design (e.g., fast acting, modulating or throttling). It is shown in Appendix E that if all three of these valves have approximately the same leakage characteristics, the division of flow between the two leakage paths will be such that approximately 59% goes through the turbine bypass valves to the condenser, and the balance through the turbine stop and control valves to the high-pressure turbine. The fraction that passes into the high-pressure turbine will be subject to less holdup and gravitational settling of the entrained particulates than will the 59% that goes into the main condenser. Thus, the releases to the turbine building by way of the turbine seals, particularly from the high pressure turbine, will be substantially greater than the releases in the isolated condenser cases described in the previous section. Credit has been taken for holdup and gravitational settling of particulate material in the high pressure turbine. This is still a conservative treatment of the turbine because no credit was taken for particulate losses by impaction or other processes in the extremely tortuous flow path that the leakage stream would be forced to take through the turbine blading.

4.3.3 Mechanical Vacuum Pump

This leakage mode uses the mechanical vacuum pump or gland exhausters to maintain a slight vacuum in the main condenser. This would ensure that the flow of MSIV leakage down the steamline would enter the condenser, as opposed to leaking through the turbine stop and control valves and out past the high-pressure turbine seal. As a practical matter, the gland exhausters are more likely to be used in this mode, maintaining positive control over leakage past the turbine seals while maximizing holdup in the condenser volume. If optimized, this mode could result in flow rates out of the condenser that approach the minimum achieved by barometric "breathing." The gland exhauster would, however, exhaust the fission products to an elevated release point with the attendant offsite dose benefits over a ground level release, and minimize contamination and radiation levels in the turbine building.

4.3.4 Steam Jet Air Ejector - Offgas System

This highly desirable mode of operation takes advantage of the volumetric holdup of the condenser as well as the cleanup capability of the offgas system and enhanced atmospheric dispersion of an elevated release. However, this mode is generally not available at plants now in operation because the auxiliary steam supply to drive the air ejectors is lost when the MSIVs close. Even in those plants capable of providing an alternate supply of auxiliary steam from auxiliary boilers or another reactor on the same site to the air ejectors, it is unlikely that the steam supply could be restored in time to prevent loss of condenser vacuum. Therefore, the consequences of using this mode have been assessed by two different scenarios.

The first scenario reflects the more prevalent case where auxiliary steam (and hence condenser vacuum) is lost when the MSIVs close. It is assumed that the MSIV leakage into the steamlines and condenser continues until an alternate steam supply for the air ejectors and turbine seals is made operable some hours later. Then vacuum is re-established in the condenser by use of the mechanical vacuum pumps, which discharge the condenser contents, unfiltered, to the environment via the elevated release point. The air ejectors are then placed in service to exhaust the condenser contents via the offgas system, with its characteristic particulate filtration and noble gas holdup.

The second scenario is one in which the air ejectors and offgas system remain in service throughout the event. This scenario presupposes that auxiliary steam is supplied from some source other than the main steam system at the time of the LOCA, and that it is not interrupted. This is highly unlikely given the current operating practices at BWRs.

4.4 Dose Consequences of Releases by Alternate Methods

4.4.1 Source Term Description

The source term used in this comparison of leakage treatment methods is based on the postulated release of radioactive material from the core following a LOCA-induced core melt accident described in Ref. 4.2. This TID inventory, consisting of 100% of the noble gases, 50% of the radioiodines and 1% of the other fission products in particulate form, was assumed to be distributed in the steam phase of the primary containment atmosphere (24,960 pounds of steam) at 8 minutes following the reactor scram. The radionuclides other than noble gases are assumed to be in particulate form. The particle size distribution used was generated using the European Nuclear Society version of the TRAP/MELT code and a large recirculation pipe break scenario. Specifically, the particle size distribution characterized by agglomeration and settling of particles in the drywell for a period of thirty minutes was taken as a conservative representation of the particulate source term. By allowing deposition inside the drywell, the particle size distribution is tilted in the direction of smaller sizes, which are removed less rapidly by gravitational settling in the steamlines, thus giving a larger release to the environment for a given mass leak rate.

4.4.2 Transport Model

4.4.2.1 Scenarios of Interest

The scenario of interest for constructing this model is the recirculation line break LOCA without containment failure or other radionuclide release paths that would overshadow MSIV leakage. A recirculation line break could conceivably produce sufficient loss of reactor water to the drywell to uncover fuel for a period long enough to give core damage and hence to give a significant radionuclide concentration in whatever steam leaks past the MSIVs. The blowdown to the drywell will result in a dramatic pressure and temperature reduction for the reactor. Hence the steam challenging the MSIVs will be cooler and at lower pressure than the steam there under normal operation. The uncovered fuel would necessarily have undergone a positive temperature excursion to have released significant quantities of radionuclides.

4.4.2.2 Steamline Temperature Transient

The MSL in this recirculation line break scenario will initially be at normal operating temperature (550°F). Following MSIV closure, the MSL will begin to cool by:

- conduction through pipe hangers, condensate drains, instrumentation taps, and other penetrations through the insulation,

- convective transfer by ambient air of heat conducted through the insulation, and

- cooling by lower temperature steam leaking through the MSIVs and down the steamlines.

Two observations about the third of these mechanisms should be noted: 1) at long times after the break, steam would be cooled and at least partially condensed by heat transfer to the pipe and 2) even at early times, the initially cool sections of the turbine bypass line (beyond the turbine bypass valves) would have a cooling effect on the leakage system.

Using pipe sizes, insulation values and hanger configurations from the reference plant, it was confirmed that the non-uniform cooldown of the MSL leads to axial temperature gradients sufficient to produce convective mixing of the gases in the steamlines. It was determined that the convective flow velocities associated with the calculated axial temperature gradients will be large compared to the bulk flow velocity in a MSL at low MSIV leakage rates. This implies that the steamline can reasonably be modeled as a series of well-mixed volumes. Appendix E presents the analysis of the pipe temperature transient, development of the axial convective velocities, the effects due to compartment size variations, and the division of leakage flow between the turbine bypass and high-pressure turbine flow paths. The effects on the transport processes of condensation in the steamlines was analyzed to determine if a detailed thermal transient analysis of the steamline was needed to accurately model the mass movement down the lines. Appendix F presents the analysis, which concluded that by not accounting for condensation in the lines, a small and acceptable conservatism was introduced.

As shown in Appendix E, an estimate of the MSL cooling by direct conduction through insulation and natural convection by exterior air after shutdown gives 47 hours with 2 inches of insulation or 83 hours with 4 inches of insulation for the temperature difference (pipe temperature minus ambient air temperature) to drop to 1/e or 37% of its initial value. These figures are for a 30-inch diameter steamline with 1-3/8 inch wall thickness. Additional, non-uniform cooling occurs through the pipe supports, condensate drains, and instrumentation taps. This means that for a significant period of time after the MSIVs close, the pipe walls will actually be hotter than the gas mixture inside. This temperature gradient could produce thermophoretic repulsion, which would prevent small particles from settling onto the wall surface. To conservatively account for this uncertainty, no credit was taken for gravitational settling of particles in the initially hot parts of the steamline for the first 48 hours.

4.4.2.3 Main Steamline Filling and Deposition Model

This model represents flow through a succession of pipe sections or compartments at a volume flow rate determined by the total leakage rate into the first volume. The mixture from the preceding compartment is mixed with the contents of the present compartment in a time that is short compared with the time to fill or drain it at the net volume flow rate. It is shown in Appendix E that anticipated axial convective velocities are much larger than this mean linear (bulk) velocity. Hence the mass of steam leakage that has reached a region of the MSL is expected to be mixed and diluted within a compartment (convective cell) in which there is a significant convective circulation. Flow into and flow out of a compartment occurs continuously, as do the mixing, deposition of precipitatable radionuclides, and radioactive decay. The radionuclide quantity balance is that the mass of a radionuclide that has flowed into a compartment is equal to the sum of the mass that has flowed out, the mass still retained in the vapor within the compartment, the mass that has deposited on walls, and the mass that has decayed.

These considerations can be embodied in differential equations that describe the change of the quantity N_i of a radionuclide in compartment i:

$$\frac{dN_i}{dt} = \underbrace{\dot{t}_i^{(1)}\, C_{i-1}}_{\text{flow in}} - \underbrace{\dot{t}_i^{(2)}\, C_i}_{\text{flow out}} \quad \underbrace{-\ \lambda N_i}_{\text{radioactive decay}} \tag{4.1}$$

$$+\ k_{i-1,i}\, A_{i-1,i}\, (C_{i-1} - C_i) - k_{i,i+1}\, A_{i,i+1}\, (C_i - C_{i+1})$$

diffusional or mixing interchanges between compartments

$$-\sum_m k_i^m\, A_i^m\, (C_i - C_{e,i}^m)$$

deposition on surfaces

The symbols are as follows:

N_i = quantity in compartment i

$\frac{dN_i}{dt}$ = rate of change with time of quantity in compartment i

C_i N_i/V_i = concentration in compartment i, which has volume V_i

$\dot{\tau}_i^{(1)}$, $\dot{\tau}_i^{(2)}$ = volume flow rate into and out of compartment i

k_i^m = deposition transport coefficient (dep. velocity) for m-th process in compartment i

A_i^m = effective area for deposition by process m in compartment i

$C_{e,i}^m$ = equilibrium concentration for process m at deposition surface in compartment i

$k_{i,i+1}$ = mass transfer coefficient for transfer from compartment i to compartment i+1

$A_{i,i+1}$ = area of contact between compartment i and compartment i+1 ($k_{i-1,i}$ and $A_{i-1,i}$ are similarly defined)

Note that the intercompartmental mass transfer coefficients have dimensions of velocity or of D/L, where D is a diffusion coefficient, and L is an intercompartment boundary layer thickness.

The flow out is assumed to carry the radionuclide at the concentration $N_i V_i$, and that deposition on walls occurs as if driven by a concentration N_i/V_i. This is equivalent to the assumption that mixing within a compartment is complete and fast compared with the filling time $V_i/\tau_i^{(1)}$ or draining time $V_i/\tau_i^{(2)}$.

The analytic solution to the set of equations for volumes i = 1,2,...,N was obtained on the assumption that the source concentration C for flow into Volume 1 is piecewise constant and diffusional, or mixing, interchange between compartments is minimal. This analytic solution is coded for calculation of the fission product transport. A second version of the computer code used numerical integration of the system of equations to treat mixing interchange. The mixing interchange was only significant for gaseous radionuclides and low flow rates. Appendix G contains the full analysis of the mixing interchange terms. The program listings and input descriptions used to calculate the transport of fission products from the MSIVs to the environment are provided as Appendix H.

4.4.3 Dose Models

The calculations were performed using the CRAC2 computer program distributed by Sandia National Laboratory (Ref. 4.3), modified slightly to print necessary dose tables (Appendix D). The core inventory used with the CRAC2 input stream provides the radionuclide activity in a 1120 MWt PWR. The reference reactor is

an 1145 MWe BWR. A correction for the power level difference is made by ratio of the power levels. No correction was made for the reactor type.

Comparison of the dose calculation results with 10 CFR 100 limits required that two time periods for release be considered: 2 hours (corresponding to dose estimates for the EAB) and 30 days (for dose estimates for the LPZ). To properly account for the initial 20-minute period of special release and the 2-hour and 30-day exposure times, the CRAC2 input had to be divided into 5 cases as described in Table 4.1.

The downwind dispersion of activity was estimated using the probabilistic meteorological bin sampling method of the CRAC2 program. This method requires a data file containing one year of hourly sequential meteorological observations. Data from the reference site was used for the calendar year 1975 (year of the most complete available data) with precipitation rate data included. Using this method, the CRAC2 program estimates an average value for each organ dose requested. The average and maximum doses (from all start times sampled) are reported as a function of distance from the reactor. The CRAC2 computer program employs a straight-line Gaussian dispersion model with a three-sigma top hat approximation. The concentrations (and doses) predicted by the top hat approximation are a factor of 0.84 lower than the bivariate Gaussian model centerline concentrations. The doses presented in this report are as calculated by the CRAC2 program using the top hat approximation.

The release to the atmosphere is assumed to be through the reactor building elevated release duct. Because this vent is near the building roof as opposed to being a separate stack, the release was modeled as a ground-level release with a nominal height of 33 feet.

Because the dispersion model in the CRAC2 program is limited to release times of 10 hours or less, special consideration was given to dispersion for times greater than 8 hours (periods 4 and 5). For periods 4 and 5 the release times were set to 8 hours and a correction factor was applied to the release times (16 hours for period 4 and 696 hours for period 5). The correction factors were based on dispersion parameters presented for the design basis accident analysis (Ref. 4.1, pages 15.6-37). The period 4 correction factor was set to unity because the 8-hour and 16-hour dispersion values were similar. The period 5 correction factor was calculated as the ratio of the 26-day dispersion value to the 8-hour dispersion value. This factor is 0.039.

Offsite dose estimates were made using the external and inhalation dose conversion factors in the CRAC2 dose conversion factor file. These factors were calculated with an early version of methodology used in recent International Commission on Radiological Protection publications (Ref. 4.4 and 4.5). Because the CRAC2 program was designed to estimate the acute health effects, the acute doses are calculated for organs for which acute effects are most likely. These

organs are whole body, bone marrow, lungs, and lower large intestine (LLI). The dose to the thyroid is also calculated because of the large releases of radioiodines.

Dose contributions to these organs are calculated for both submersion in the passing plume and inhalation of the plume. Average doses received by individuals during cloud passage and dose commitments received within seven days are included in the dose calculations. Special consideration for internal organ exposures extend this time in some cases. For bone marrow, the internal dose received over the duration of the accident plus one-half of the dose received between the end of the accident and the thirtieth day after inhalation of radionuclides are used to estimate acute health effects. Dose to lungs includes the internal dose received within one year from inhalation of radionuclides. To make the calculated dose more comparable with 10 CFR Part 100 limits, the CRAC2 program was modified to provide the 50-year dose commitment from the acute inhalation exposure.

The doses resulting from the 2-hour release were calculated for a receptor at the EAB for the reference plant. This exclusion area is defined as a circle of radius 6400 feet from the center of the reactor building vent (Ref. 4.6). The doses from the 30-day release were calculated for a receptor at the LPZ boundary, a distance of 3 miles (Ref. 4.1).

Breathing rates were taken from Regulatory Guide 1.3 (Ref. 4.7). The values used are shown in Table 4.1.

4.4.4 Dose Consequences versus Leak Rate for Different Treatment Methods

Using the transport model described in Section 4.4.2, Appendices E and G, and the CRAC2 dose model described in Section 4.4.3, offsite dose consequences were calculated for a number of different MSIV leakage rates. This was done with two objectives. The first objective was to compare and rank the various treatment methods on the basis of dose consequences from a 11.5 scfh MSIV leakage rate. Based on this ranking the most favorable active (requiring offsite power) and passive (not requiring offsite power) methods were to be evaluated further. This further evaluation was to fulfill the second objective, which was to determine for the most favorable active and passive methods. The MSIV leakage rate would then be increased to determine the leakage rate at which the offsite dose consequences would approach those of the baseline case. For this analysis, the baseline case consequences, derived from a conservative licensing-type scenario, are taken to represent the MSIV contribution to the 10 CFR 100 siting criteria limit, or a "maximum acceptable" offsite consequence from MSIV leakage.

The results of the comparison of methods at the 11.5 scfh leak rate are summarized in Table 4.10.

Table 4.10. Dose comparison of treatment methods at 11.5 scfh per valve

Method	Doses (maximum) (rem)			
	0 - 2 hr (EAB)		0 - 30 days (LPZ)	
	Whole Body	Thyroid	Whole Body	Thyroid
Steam Jet Air Ejector/ Offgas System (a)	(b)	(b)	$<10^{-5}$	$<10^{-5}$
Mechanical Vacuum Pump (Gland Exhauster)(c)	(b)	(b)	4.1×10^{-4}	4.7×10^{-4}
Isolated Condenser (Turbine Bypass Valves Open) (d)	(b)	(b)	7.8×10^{-4}	8.9×10^{-4}
Isolated Condenser (Steamline Condensate Drains Open) (e)	(b)	(b)	8.2×10^{-4}	1.2×10^{-3}
Isolated Steamline (Turbine Bypass Valves Shut) (d)	(b)	(b)	1.3×10^{-2}	5.8×10^{-1}
LCS/SGTS (Baseline Case)	1.3×10^{-1}	7.6×10^{-0}	9.1×10^{-2}	3.1×10^{-0}

(a) This case is of little practical interest because it would not be available for most plants now in operation without major modifications and changes in operating practice.
(b) Doses negligible in the 0-2 hour time period.
(c) This is an "optimized" gland exhauster scenario in which flow from the gland exhauster is throttled to approximately the same flow rate as the barometric breathing rate used in the isolated condenser and isolated steamline scenarios.
(d) Opening turbine bypass valves following the LOCA sequence will require operator intervention (to defeat an interlock). Although it could probably be accomplished in a relatively short time under ideal conditions, the advisability of diverting plant staff to do this under accident conditions is questionable, especially in view of the other means of opening up the MSL to the condenser (condensate drains, LCS bleedoff lines) that could be employed quickly and with little penalty in offsite dose.
(e) MSL condensate drains are opened to the main condenser hotwell during steamline heatup and could serve to ensure that the MSIV leakage into the MSL is routed preferentially to the condenser.

It can be seen from Table 4.10 that the steam jet air ejector - offgas system treatment method is extremely effective in reducing the offsite doses from MSIV leakage. However, several factors weigh against its being considered as the treatment method of choice for most plants. First, closure of the MSIVs shuts off the supply of steam to the air ejectors and turbine gland seals, meaning condenser vacuum will be rapidly lost. Most plants, for which information was available, did not have sufficient auxiliary boiler capacity to supply the air ejectors and gland seal steam. Further, cross connecting systems to make auxiliary boiler steam available to the air ejectors is not a normal operation and would likely require installation of spool pieces or temporary piping. For plants at multiple-unit sites, auxiliary steam may be available from the companion unit if it is steaming at the time. The practicality of this method would be highly dependent on the specific plant design. This strategy is classified as "active" because it depends on offsite power, and it also requires substantial operator intervention to accomplish.

The gland exhauster treatment method should be available at most plants and is quite effective in reducing the offsite dose consequences of MSIV leakage. This strategy is "active" because it depends on offsite power and operator intervention is also required. It should be noted that the offsite doses cited in Table 4.10 are based on a volumetric "exhaust rate" from the condenser that equals the barometric breathing rate used for the isolated condenser cases. This implies that some preplanning has been done, so that the plant staff can quickly implement the gland exhauster strategy with a near-optimum flow rate. Therefore, the only difference in the offsite doses between the optimized gland exhauster strategy and the isolated condenser (turbine bypass valves open) strategy is the difference in release height and the subsequent atmospheric dispersion that is achieved. The gland exhauster, discharging to an elevated release point, will achieve greater dispersion and lower doses at the EAB and LPZ. It also has the benefit of minimizing radioactive releases into the turbine building, which should keep post-accident occupational exposure rates lower, improving accessibility to plant equipment.

The isolated condenser cases differ only in the amount of holdup (and therefore deposition of particles and radioactive decay) that takes place in the steamlines. If the turbine bypass valves can be opened, the turbine bypass steamlines provide the pathway to the condenser. If the condensate drain bypass lines are open, the 1 1/2 inch to 2 1/2 inch lines will vent the main steam piping to the condenser. The smaller piping implies a higher flow velocity and thus a shorter transit time.

There is a possibility that the turbine bypass valves could be opened at some plants, even during an interruption of offsite power, thereby making this a "passive" method (not requiring offsite powe~). However, the bypass valves are

interlocked shut when the condenser vacuum is lost to protect the condenser from overpressure. An interlock may have to be defeated to implement this treatment method.

The case of MSL condensate drain bypasses open achieves nearly the same holdup and dose reduction as with the turbine bypass valves open, but could probably be implemented much more easily. In fact, the reference plant (and perhaps others) would fail to this condition upon loss of offsite power (loss of control air, air-operated condensate drain bypass valves fail open). Because it has not been established that all operating BWRs would respond this way to a loss of offsite power, this treatment method can be classified as either "passive" or "active." In view of the fact that the condensate drain bypasses are likely to be more easily opened than the turbine bypass valves, the condensate drains probably are the basis for a more timely and feasible operational strategy to minimize offsite doses.

The isolated steamline case is the only strictly passive case examined here. With the turbine bypass, control and stop valves shut, pressure would have to build up in the steamlines to force any flow past the leaking valves. The smaller volume and settling area of the high pressure turbine (as compared to the main condenser) would produce releases that are relatively high when compared with the leak treatment paths discussed previously. However, even these dose consequences compare favorably with the baseline case.

Because of the differences in individual plant designs dictating which of the strategies may be "passive" and "active," four strategies were evaluated further to determine what MSIV leak rate limit could be accepted. The results of these sensitivity calculations are presented in Section 4.4.5.

4.4.5 Comparison of Dose Consequences with Baseline Case Limits

The radioactive releases and dose consequences for several different MSIV leak rates were calculated for each of the leakage treatment methods of interest. The doses were then plotted to determine the leak rate at which the most limiting baseline case dose value would be exceeded. This data is presented in Tables 4.11 to 4.14 with the estimated "cross over" point, the leak rate at which the corresponding baseline case dose would be exceeded identified.

Table 4.11. Mechanical vacuum pump (gland exhauster) Leak rate versus Dose

Leak Rate (scfh/Valve)	Doses (maximum) rem			
	0 - 2 hr (EAB)		0 - 30 days (LPZ)	
	Whole Body	Thyroid	Whole Body	Thyroid
11.5	--	--	4.1×10^{-4}	4.7×10^{-4}
300	1.6×10^{-4}	5.4×10^{-3}	1.4×10^{-2}	7.4×10^{-2}
1000	3.2×10^{-3}	1.0×10^{-1}	4.5×10^{-2}	4.4×10^{-1}
1840*			9.1×10^{-2}	
2000	1.1×10^{-2}	3.4×10^{-1}	1.0×10^{-1}	1.2×10^{0}

* Leak rate calculated to produce maximum LPZ whole-body dose of 9.1×10^{-2} rem, equal to baseline case scenario.

Table 4.12. Isolated condenser (turbine bypass valves open), Leak rate versus dose

Leak Rate (scfh/Valve)	Doses (maximum) rem			
	0 - 2 hr (EAB)		0 - 30 days (LPZ)	
	Whole Body	Thyroid	Whole Body	Thyroid
11.5	--	--	7.8×10^{-4}	8.9×10^{-4}
1000	6.4×10^{-3}	1.6×10^{-1}	6.6×10^{-2}	4.1×10^{-1}
1500*	--	--	9.1×10^{-2}	
2000	2.1×10^{-2}	5.4×10^{-1}	1.4×10^{-1}	1.1×10^{-0}

* Leak rate calculated to produce maximum LPZ whole-body dose of 9.1×10^{-2} rem.

Table 4.13. Isolated condenser (steamline drains open), Leak rate versus dose

Leak Rate (scfh/Valve)	Doses (maximum) rem			
	0 - 2 hr (EAB)		0 - 30 days (LPZ)	
	Whole Body	Thyroid	Whole Body	Thyroid
11.5	--	--	8.2×10^{-4}	1.2×10^{-3}
300	6.2×10^{-4}	2.2×10^{-2}	2.0×10^{-2}	1.1×10^{-1}
1000	7.4×10^{-3}	2.1×10^{-1}	6.5×10^{-2}	4.9×10^{-1}
1300*	--	--	9.1×10^{-2}	

* Leak rate calculated to produce maximum LPZ whole-body dose of 9.1×10^{-2} rem.

Table 4.14. Isolated steamline (turbine bypass and steam drain line isolation valves shut), leak rate versus dose

Leak Rate (scfh/Valve)	Doses (maximum) rem			
	0 - 2 hr (EAB)		0 - 30 days (LPZ)	
	Whole Body	Thyroid	Whole Body	Thyroid
11.5	--	--	1.3×10^{-2}	5.8×10^{-1}
13.5*				$3.1 \times 10^{+0}$
50	1.5×10^{-5}	4.7×10^{-4}	7.8×10^{-1}	$4.7 \times 10^{+1}$
100	2.7×10^{-3}	1.8×10^{-1}	2.3×10^{0}	$1.4 \times 10^{+2}$
300	1.3×10^{0}	$9.0 \times 10^{+1}$	9.2×10^{0}	$5.7 \times 10^{+2}$

* Leak rate calculated to produce maximum LPZ thyroid dose of 3.1 rem.

5. A PROBABILISTIC ANALYSIS OF MSIV LEAKAGE PATHWAYS IN CORE-MELT ACCIDENTS

5.1 Reference Design and Base Case Assumptions

The reference plant used for this analysis is an 1100 MWe GE BWR-5, with a Mark II type containment. The assumed pathways of interest for leakage past the MSIVs are the baseline case and the alternate leakage treatment methods (refer to sections 4.2 and 4.3).

5.2 Frequency of Initiating Accidents

5.2.1 Recirculation Line Break in the BWR-5 Design

The MSIVs and LCS are included in BWR designs to ensure: 1) isolation of the primary containment, given pipe breaks within the drywell or steamline breaks outside the drywell and 2) prevention of release of radionuclides to the environment. A large pipe break loss of coolant accident (LOCA) within the coolant recirculation system of the BWR that is coupled with the failure of one MSIV to close typically has been used to bound the analysis of MSIV and LCS performance (Reference 5.1).

The recirculation line LOCA is the reference design basis accident that was used for this program. The resulting pressure histories are used to model steam leakage past the MSIVs and travel down the steamlines. This may be representative of a bounding case for analyzing LCS performance. Other initiating events, such as transients, also can lead to core-melt where leakage past the valves may be of concern. A reliability analysis must then consider the frequency of other accidents that may contribute to the MSIV leakage problem as well as the LOCA base case event.

The MSIV leakage term will be of safety interest only for those cases where core damage or core-melt has occurred, yet the containment is still intact. The standard specification for leakage past the MSIVs is 11.5 scfh down the steamlines, so any leakage at all through containment could easily make MSIV leakage insignificant. Many of the core-melt scenarios of interest, such as the recirculation line LOCA, have significant probabilities for containment failure if the accident progresses to core-melt as is necessary for the source term to be present. In the design basis accident, the recirculation line fails and the reactor vessel blows down to the drywell and suppression pool. Pressures rapidly degrade to only several psig; however no radionuclides are present at this time in the steam. The source term of interest is generated after the accident progresses to core-melt, and is brought about when adequate water fails to inject and remove heat from the core. At this point, fuel

begins to fail, and the pressure histories in the containment will rise dramatically. In this program, the value of 25 psig is assumed for the driving pressure for modeling release past the MSIVs.

The pressures in containment can be significant during this period, with the probability of containment failure due to overpressure typically put at 0.95 in probabilistic risk analysis (PRA) studies. The pressures assumed necessary for containment failure are typically on the order of 2 times the design pressure, or approximately 45 psia. Recent studies at Sandia have demonstrated that the containment failure pressure may be much higher than anticipated.

Partial failures and leakage terms, such as MSIV leakage, may then become of interest as possible release pathways.

5.2.1.1 Frequency of LOCAs in the BWR-5

The ability of the plant safety injection systems to respond to a LOCA is highly dependent on the specific plant design. Previous plant designs located the low pressure coolant injection (LPCI) on the pump discharge side of the recirculation loops; thus, they were vulnerable to partial loss of the LPCI capacity, given a pipe break on the discharge side. The reference plant design has 3 separate loops of low pressure injection to inject directly into the vessel.

The reference plant does not have a probabilistic risk assessment (PRA) associated with it, but a recently-licensed BWR-6 plant does (Reference 5.2). Although this plant is a BWR-6, the layout of the reactor heat removal systems is similar to the reference plant and the PRA of this plant is used here to model the response to a LOCA. The event tree that was developed was adequate to model the response to both large LOCAs and smaller LOCAs in the BWR-6. This simple event tree includes only the functions of the reactor protection system, the vapor suppression system, the emergency coolant injection function, and the reactor heat removal function.

The frequency of LOCA in the PRA study was based on the WASH-1400 (Reference 5.3) frequencies for pipe break, but was restructured slightly to reflect the impact of modified systems in the BWR-6 where response to small and intermediate break sizes would be similar. This gave the following frequencies:

S = frequency of break sizes less than 13.5 inches effective hydraulic diameter = 1.4×10^{-3}/plant year (PY).

A = frequency of break sizes greater than 13.5 inches effective hydraulic diameter = 1.0×10^{-4}/PY.

The resulting dominant accident sequences (i.e. frequency greater than $1x10^{-10}$/PY) from the event tree are given in Table 5.1, giving a total estimated frequency of large and small LOCAs leading to core-melt of $4.89x10^{-6}$/PY. The PRA study did not call out steam-line breaks specifically, however, it can reasonably be assumed that approximately 50% of this total represents breaks in the recirculation piping only.

5.2.1.2 Frequency of Transients in the BWR-5

Leakage past the MSIVs may also play a role in defining the eventual release of radionuclides for other core-melt scenarios beside the design basis recirculation line break. The dominant transient sequences identified in the PRA are given in Table 5.2. The T1 transients represent loss of off-site power, and T23 transients represent any other transient requiring emergency reactor shutdown.

5.2.1.3 Containment Failure Modes in the BWR-5

As mentioned earlier, the existing PRAs assume that a significant fraction of the LOCAs (including ruptures in the recirculation line) and transients that lead to core-melt progress to failure of the containment. In such cases, the contribution from MSIV leakage would add insignificantly to risk. The containment failure modes are represented by the following:

- α = containment rupture due to steam explosions,
- β = containment leakage due to failure to isolate,

Table 5.1. LOCA Dominant Sequences Leading to Core-Melt

Large LOCAs		Small LOCAs	
Sequence	Frequency, 1/PY	Sequence	Frequency, 1/PY
AI	$2.6x10^{-7}$	SI	$4.6x10^{-6}$
AE	$5.0x10^{-9}$	SC	$1.1x10^{-8}$
AC	$7.7x10^{-10}$	SE	$8.2x10^{-9}$
		SDI	$3.0x10^{-10}$
Total	$2.66x10^{-7}$		$4.62x10^{-6}$

Table 5.2 Core-melt frequencies for transient sequences per plant year

Sequence dominant	Frequency/PY
T1PQI	1.6×10^{-6}
T23PQI	3.7×10^{-6}
T1PQE	2.4×10^{-7}
T23PQE	5.4×10^{-7}
T1QW	6.2×10^{-6}
T23QW	1.2×10^{-5}
T23C	5.4×10^{-6}
T1QUV	1.9×10^{-6}
non-dominant	4.1×10^{-7}
Total	3.20×10^{-5}

This totals 3.20×10^{-5}/PY for transient-induced core-melt in the BWR-5.

- γ = containment failure due to hydrogen burning, and
- δ = containment rupture due to overpressurization.

The probabilities assigned to these failure modes in the PRA and the associated release categories assigned to these failure modes are given in Table 5.3 for LOCAs and Table 5.4 for transients. Note that only the dominant LOCA frequencies are given as presented in the PRA study.

In the PRA study, as was the case in the WASH 1400 Reactor Safety Study, (Reference 5.3) analysis found that none of the sequences involving containment leakage were found to be among the dominant contributors to risk. This resulted from the combination of low probability of the sequences together with the relatively modest consequences associated with them. As a result, no containment isolation failure sequences were explicitly evaluated for the PRA. That small fraction of core-melts predicted (0.007) where massive containment failure was prevented by leakage was associated with the BWR Release Category 4, with releases significantly below those of Release Category 1 and 2.

The importance of containment failure in the role of MSIV leakage is discussed further after the presentation of core-melt frequencies for the BWR-4 design.

Table 5.3. Containment failure mode probabilities and release categories for LOCA

Sequence	Frequency/PY	Release Category 4	2	3	4
AI (1)	2.6×10^{-7}	α = 0.01		$\gamma+\delta$ = 1	β = 0.007
AI (2)		α = 0.01	δ = 1		β = 0.007
AE	5.0×10^{-9}	α = 0.01		$\gamma+\delta$=0.8	δ = 0.2 (3)
AC (1)	7.7×10^{-10}	α = 0.01		$\gamma+\delta$=1	β = 0.007
AC (2)		α = 0.01	δ = 1		β = 0.007
ADI		α = 0.01	δ = 1		
ADE		α = 0.01	δ = 1		
ACD		α = 0.01	δ = 1		
Total	2.66×10^{-7}				
SI (1)	4.6×10^{-0}	α = 0.01		$\gamma+\delta$=1	β = 0.007
SI (2)		α = 0.01	δ = 1		β = 0.007
SC (1)	1.1×10^{-8}	α = 0.0001		$\gamma+\delta$=1	β = 0.007
SC (2)		α = 0.01	δ = 1		β = 0.007
SE	8.2×10^{-9}	α = 0.01		$\gamma+\delta$=0.8	δ = 0.2 (3)
SDI	3.0×10^{-10}	α = 0.01	δ = 1		β = 0.007
SCD		α = 0.01	δ = 1		β = 0.007
SDE		α = 0.01	δ = 1		β = 0.007
Total	4.62×10^{-6}				

(1) For ECCS failure due to high suppression pool temperature preceding containment failure.
(2) Assuming ECCS failure due to pump activation following containment failure.
(3) Early overpressure failure resulting from interaction of core debris with water in reactor cavity.

5.2.2 Core-Melt Scenarios in the BWR-4 Design

Of the earlier GE designs, the BWR-4 is representative of the largest class of plants that were built. This design has 2 recirculation loops, with low pressure core injection (LPCI) being delivered into the pressure side of the recirculation piping (i.e. on the discharge side of the pumps). Four BWR-3 plants also use this design. In such a design, a break on the discharge side results in the partial failure of the emergency coolant injection function. Distinct event trees must be developed to consider these plants' response to LOCAs in

Table 5.4. Core-melt frequencies and containment failure mode probabilities for transient sequences

Sequence	Frequency/PY	Release Category 1	2	3	4
T1PQI	1.6×10^{-6}	$\alpha = 0.01$	$\delta = 1$		
T23PQI	3.7×10^{-6}	$\alpha = 0.01$	$\delta = 1$		
T1PQE	2.4×10^{-7}			$\gamma = 0.5$	$\delta = 0.5$
T23PQE	5.4×10^{-7}			$\gamma = 0.5$	$\delta = 0.5$
T1QW	6.2×10^{-6}		$\delta = 1$		
T23QW	1.2×10^{-5}		$\delta = 1$		
T23C	5.4×10^{-6}		$\delta = 1$		
T1QUV	1.9×10^{-6}			$\gamma = 0.5$	$\delta = 0.5$
non-dominant	4.1×10^{-7}				
Total	3.20×10^{-5}				

various piping locations, as opposed to the single event tree considered sufficient for the BWR-5 design. A BWR-4 PRA (Reference 5.4) is used below to estimate the frequency of the accidents of interest.

5.2.2.1 Frequency of LOCAs in the BWR-4

The probability of pipe rupture by size--1×10^{-3}/yr for small, 3×10^{-4}/yr for intermediate, and 1×10^{-4}/yr for large--was based on the median pipe rupture probabilities from WASH-1400.

Note that the design basis scenario for this program again is assumed to deal specifically with a recirculation line break. In the BWR-4 design, the location of the break plays an important role in possible recovery options due to the location of emergency injection on the recirculation plumbing. This frequency was estimated by observing the percentage of piping in the recirculation system compared to the primary coolant safety-related piping for the entire plant. This was put at the following:

- discharge side of recirculation piping, 348.4 ft, 38.5% of total
- suction side of recirculation piping, 89.3 ft, 9.9% of total
- steamlines, 466.5 ft, 51.6% of total.

It was then assumed that the probability of pipe break was random anywhere in the system. As a result, the frequency of pipe breaks on the recirculation

system would represent only 48.4%, or approximately 50% of the total frequency for pipe break. The frequency of a large break on the discharge side of the recirculation piping was then estimated as $(1\times10^{-4}/yr)(0.385) = 3.9\times10^{-5}/yr$. Similarly, a break on the suction side of the recirculation piping was put at $9.9\times10^{-6}/yr$, and the frequency of a large steamline break was put at $5.2\times10^{-5}/yr$.

Event trees to core-melt were then developed to evaluate plant response to the following events:

- LS - large suction side break on recirculation piping
- LD - large discharge side break on recirculation piping
- LV - large steam break
- IL - intermediate liquid break
- IV - intermediate steam break
- S - small liquid or steam break.

The estimated core-melt frequency associated with the above initiating events is given in Table 5.5.

Assuming that 50% of the S-initiated sequences deal with liquid breaks, then the total frequency of core-melt for recirculation line breaks is $(2.80\times10^{-8} + 1.09\times10^{-8} + 1.40\times10^{-7} + 9.8\times10^{-7}/2) = 6.69\times10^{-7}/PY$.

Table 5.5. LOCA core-melt frequencies for BWR-4 greater than $1\times10^{-8}/PY$

Sequence	Total Frequency, 1/PY
LS Initiated Sequences	2.80×10^{-8}
LD Initiated Sequences	1.09×10^{-8}
LV Initiated Sequences	none greater than 10^{-8}
IL Initiated Sequences	1.4×10^{-7}
IV Initiated Sequences	6.8×10^{-8}
S Initiated Sequences	9.80×10^{-7}
	1.23×10^{-6}

5.2.2.2 Frequency of Transients in the BWR-4 Design

The transients considered for BWR-4 design include the following:

- TP - loss of off-site power
- TU - transients where PCS is unavailable
- TA - transients where PCS is available
- TK - transient induced stuck open relief valve.

The resulting predicted frequency of transient initiated core-melt sequences is given in Table 5.6.

5.2.2.3 Containment Failure Modes for the BWR-4

The containment failure modes predicted in the BWR-4 PRA for LOCAs and transients are as follows:

- α = in-vessel steam explosion, = 0.0001 (LOCAs)
- α' = in-vessel steam explosion, = 0.01 (transients)
- γ = release through annulus, = 0.8
- γ' = direct release to atmosphere, = 0.2.

Table 5.6. Transient core-melt frequencies for a BWR-4 greater than 1×10^{-8}/PY

Sequence	Total Frequency, 1/PY
TU Initiated Sequences	1.53×10^{-4}
TP Initiated Sequences	2.92×10^{-5}
TP Initiated LOCAs	1.61×10^{-6}
TA Initiated Sequences	3.7×10^{-6}
TK Initiated Sequences	9.3×10^{-6}
	1.97×10^{-4}

As with the BWR-5 design discussed earlier, the leakage through the MSIVs is important only for those core melts where the containment remains intact. However, the net probability of containment failure for the above core-melt sequences is again set at 1 for the PRA. Again, this is thought to be a conservative assumption from the standpoint of measuring public risk in the original PRA; but accidents such as TMI-2 indicate that there are core-melt type accidents where the containment remains relatively intact.

5.2.3 Probability of MSIV Leakage

A review of the MSIV reliability information being generated by the BWR Owner's Group (BWROG) indicates that a number of improvements have been and continue to be implemented to improve reliability. The "as found" reliability of the valves predicted by the BWROG is given in Table 5.7. One value is given for seating under pressure, with a probability of leakage greater than 11.5 scfh at 0.0541. Seating under pressure lowered the observed failure probability by a factor of 5.41/37.84 = 0.143. This same ratio was applied to the 90 and 500 scfh failure probabilities to estimate the failure probability for leakage under pressure.

No data has yet been found to support common mode failures of both valves, so the BWROG currently assume that independent failures would be required to result in leakage past both valves in a steamline. Note, however, that during closure, only the inboard valve may likely take credit for improved closure under pressure. The outboard valve would not likely see the higher pressure as the inboard valve begins to close.

The reliability of two valves to close will then be expressed as:

$$
\begin{aligned}
R(2\ \text{valves}) &= R(\text{inboard}) \text{ or } R(\text{outboard}) \\
&= R(\text{inboard}) + R(\text{outboard}) - R(\text{inboard})R(\text{outboard}).
\end{aligned}
$$

Table 5.7. MSIV reliability reported by BWROG

Leakage Less Than, scfh	% of Valves	Leakage Greater Than, scfh	% of Valves	Total %
11.5	62.16	11.5	37.84	100
90	78.34	90	21.66	100
500	94.59	500	5.41	100
(seating under pressure)				
11.5	94.59	11.5	5.41	100
90	96.90	90	3.10	(estimated)
500	99.23	500	0.77	(estimated)

The reliability of a system with four steamlines, each containing two valves is then:

$$R(\text{system}) = R(2 \text{ valves}) \text{ and } R(2 \text{ valves}) \text{ and } R(2 \text{ valves}) \text{ and } R(2 \text{ valves}) = R(2 \text{ valves})^4.$$

The failure probability is 1-R. Table 5.8 presents the results of the reliability of steamline closure. Again, these results do not consider the potential improvements in valve performance.

The number of interest for this accident scenario is then thought to be the probability of leakage greater than 11.5 scfh for valves closing under pressure, with failure probability for four steamlines given as 1.15 percent or 0.0115 above.

The capacity of the LCS is estimated at 400 scfh, so the probability of exceeding this limit is approximately 0.024% or 0.0002 (see Table 5.8). The probability of leakage within the capacity of the LCS is then p(greater than 11.5 scfh) - p(greater than 400 scfh) or 0.0113.

Leakage past both MSIVs in one steamline can also occur if one of the MSIVs fails to close, and the other valve closes but leaks. The failure of a motor-operated valve to respond to the closure signal is estimated at 1×10^{-3}/demand. Leakage past two valves in excess of 11.5 scfh would be estimated to occur with a demand frequency of $(1 \times 10^{-3})(0.0541) = 5.41 \times 10^{-5}$/demand, assuming that valve failure to close would not effect the performance of the remaining valve. Given that there are two valve pairs per steamline and 4 steamlines, the net probability of leakage greater than 11.5 scfh out of any one line is put at $(4)(5.41 \times 10^{-5}/\text{demand}) = 2.16 \times 10^{-4}$/demand.

Table 5.8. Estimated Probability of Steamline Leakage

Leakage Greater Than, scfh	1 MSIV No %	1 MSIV Yes %	2 MSIVs No %	2 MSIVs Yes %	4 Steamlines No %	4 Steamlines Yes %
(no pressure)						
11.5	62.16	37.84	85.68	14.32	53.89	46.11
90	78.34	21.66	95.31	4.69	82.52	17.48
500	94.59	5.41	99.71	0.29	98.85	1.15
(under pressure)						
11.5	95.59	5.41	99.71	0.29	98.85	1.15

Thus, leakage is considered a higher probability than leakage plus valve failure to close.

For simplicity, the approximate value of 0.01 for leakage in the steamlines greater than 11.5 scfh but less than 400 scfh was used here.

Note also that the BWR-6 design includes an additional main steamline shutoff valve downstream of the MSIVs. The leakage performance of these slow closing valves is thought to at the very least equal that of an MSIV. This would effectively lower the probability of steamline leakage in a BWR-6 by at least one order of magnitude below the estimate used here for 2 MSIVs per steamline. The presence of such valves will be ignored in this analysis to determine the need for any leakage control measure downstream of two MSIVs per steamline.

5.2.4 Implications of Containment Failure on Importance of MSIV Leakage

MSIV leakage could play an important role in leakage if the containment remains intact, and if there is a source term available for release under such conditions. The source term available for release depends on the accident scenario. Some sequences result in a direct blowdown to the suppression pool with subsequent entrainment of fission products in the pool. Other scenarios result in substantial aerosol generation in the drywell atmosphere, which is available for release. Any calculation of the importance of the MSIV leakage must consider the following items:

(1) recognition that source terms will vary with core-melt scenario due to plate-out and entrainment of fission products in the suppression pool,

(2) the existing probability of containment failures that would compete with or exceed any MSIV leakage,

(3) the potential that MSIV leakage might reduce the probability of containment failure given core-melt, and

(4) the likelihood that core-melt will result in containment failure that would make MSIV leakage irrelevant.

In item (1) we must recognize that the source term present in the steamlines that is available for release past the MSIVs will be a function of the core-melt scenario. The recirculation line break bypasses a direct path to the suppression pool would likely have a higher fraction of the fission product inventory remain in the drywell region compared to scenarios that allow a direct flow path to the suppression pool. This effect is characterized in

Table 5.9, which gives the results of CsI fission product distribution for several representative core-melt scenarios in a BWR Mark III containment (Reference 5.5).

In all cases, most of the inventory ends up in the suppression pool. The inventory in the RCS that may leak past the MSIVs can vary by up to a factor of 3 compared to a TC scenario (transient with failure to SCRAM). The frequency of this scenario is very low, however, and plays a relatively insignificant role in overall plant risk. The distribution in the RCS for the other scenarios is quite similar.

Item (2) introduces the potential for other containment failures that may already be in existence at the time of the core-melt scenario that would compete with the MSIV leakage. A review of past experience in LWRs (Reference 5.6) indicates that the probability for leakage on the order of several percent of containment volume per day is approximately 0.01, or roughly the same probability as having two MSIVs in the same steamline leak. Thus frequency of a core-melt with containment leakage is thought to be approximately the same as core-melt with MSIV leakage. However, with these events being independent, it could be assumed that only 1% of core-melts with MSIV leakage also would have containment leakage from an existing failure. As a result, existing failures may be comparable to, but would not reduce appreciably the role of MSIV leakage.

Item (3) brings up the possibility that containment leakage, such as through the MSIVs, can act as a pressure release and possibly reduce the probability of massive containment failure in some scenarios. A review of containment failures however indicates that gross containment failure is currently assumed for leakage rates approaching 100% volume per day (Reference 5.5). This represents penetration failures with effective hole diameters up to approximately 6 in. With leakage past the MSIVs from 11.5 to 500 scfh, or approximately $2x10^2$ to $1x10^4$ scfd, this represents from 10% to 1% of the containment volume

Table 5.9. Distribution of CsI in the BWR mark III containment for various core-melt scenarios

		Fraction of CsI Core Inventory by Location			
Sequence	RCS	Drywell	Pool	Containment	Environment
TC	0.19	$3.6x10^{-2}$	0.77	$1.9x10^{-4}$	$6.8x10^{-3}$
TPI	$8.4x10^{-2}$	$3.9x10^{-3}$	0.91	$7.5x10^{-7}$	$2.4x10^{-4}$
TQUV	$6.3x10^{-2}$	$3.8x10^{-6}$	0.94	$6.8x10^{-4}$	$8.4x10^{-4}$
SE	$9.1x10^{-2}$	$1.2x10^{-2}$	0.89	$2.0x10^{-3}$	$3.3x10^{-3}$

per day for plants with 1×10^5 and 1×10^6 cubic feet of volume, respectively. Further, leakage through such failures is currently not thought to affect in any appreciable way, the dynamic behavior of systems, such as action of the suppression pool vents and delivery of water to sumps during the accident. As a result, it is not thought at this time that MSIV leakage plays any role in avoiding massive containment failure due to pressure relief at the leakage rates of interest.

Item (4) introduces the fact that current PRAs assume that there is a probability of that containment will suffer a gross failure as a result of core-melt. This would make any contribution from MSIV leakage negligible to overall risk. The earlier PRA studies are considered conservative because they give little credit to the ability of the containment structures to withstand pressures that are significantly over the design pressure. More recent studies have indicated a trend toward higher sustainable pressures. Recent tests at Sandia showed containment pressures of over 5 times the design pressure before failure; however, failures would still be predicted to occur in a majority of core-melt scenarios.

Current estimates are that containment will survive in less than 4% of core-melts in the Mark I containment plant that is used by most BWR-4 plants, and in less than 6% of core-melts in Mark III containment plants.

MSIVs could play a more important role for non-core-melt accidents of higher frequency where containment failure is less likely; however, the overall contribution to risk from non-core-melt scenarios is small when compared to core-melt scenarios.

5.2.5 Summary of Core-Melt Frequencies Where MSIV Leakage is of Interest

There are several factors that affect core-melt frequency with respect to the role of MSIV leakage. The effective core-melt frequency of interest is modified for the BWR-4 and BWR-6 values that were presented earlier to reflect the potential for other containment failures that make MSIV leakage irrelevant. It is assumed that the better Mark III survival probabilities are characteristic of the Mark II containment that is found at the reference plant. The factors developed earlier are as follows:

- probability of no pre-existing containment failures = 0.99,
- probability of no gross containment overpressure failure for the BWR-4 with Mark I containment = 0.04,
- for the BWR-6 with Mark III containment = 0.06, and
- probability of MSIV leakage greater than 11.5 scfh = 0.01.

When MSIV leakage may play an important role, the effective core-melt frequency of interest then must be modified by the factor (0.99)(0.04)(0.01) = 3.96×10^{-4} for the BWR-4 and (0.99)(0.06)(0.01) = 5.94×10^{-4} for the BWR-6. This factor is incorporated in Table 5.10.

The total predicted core-melt frequency where the MSIV leakage term would be of interest is then predicted to be 2.19×10^{-8}/PY for the BWR-6 plant, and assumed to be representative of the newer Mark II and Mark III containments. The estimate for the BWR-4 plant with the Mark I containment is put slightly higher at 7.85×10^{-8}/PY.

The major contribution to the above estimates is not due to recirculation line break, but rather to transient-initiated core-melt scenarios that typically involve eventual loss of coolant injection or decay heat removal functions,

Table 5.10. Summary of BWR core-melt frequencies where MSIV leakage may play an important role

	Base Case Core-Melt Frequency 1/PY	Correction Factor	Effective Core-Melt Frequency Were MSIV Leakage is of Concern 1/PY
BWR-5		5.94×10^{-4}	
Recirculation Line Break	2.45×10^{-6}		1.46×10^{-9}
Steamline Break	2.45×10^{-6}		1.46×10^{-9}
Transients	3.20×10^{-5}		1.90×10^{-8}
Total	3.69×10^{-5}		2.19×10^{-8}
BWR-4		3.96×10^{-4}	
Recirculation Line Break	6.69×10^{-7}		2.65×10^{-10}
Steamline Break	5.68×10^{-7}		2.25×10^{-10}
Transients	1.97×10^{-4}		7.80×10^{-8}
Total	1.98×10^{-4}		7.85×10^{-8}

which has no bearing on the question of the need for an LCS. Consideration of the recirculation line break alone would reduce the above estimates of core-melt frequency where MSIV leakage may be of importance by over an order of magnitude.

5.3 MSIV Leakage Control Pathways

This section presents a discussion of the availability of MSIV leakage control pathways. For the purposes of this study the MSIVs are assumed to leak following a core-melt accident. Only those core-melt accidents in which the containment integrity is intact are of interest. If containment integrity is lost, then the amount of radioactive gases leaking via the MSIVs is insignificant in comparison to the overall release to the atmosphere. The frequency of core-melt accidents derived in the previous chapter already take this factor into consideration.

Following a LOCA and the reactor trip, the MSIVs are expected to close. The same condition applies to the turbine bypass valve (TBV) and the turbine control valve (TCV). The configuration of valves for the reference plant, the BWR-5 Mark II containment, was determined from the plant final safety analysis report (FSAR) and in discussions with licensee's operator training personnel. Steamline drain isolation valves must also be considered. These air-operated valves will fail open on loss of offsite power (LOOP) and eventual loss of compressed air supply. The system consists of 4 TBVs, 2 TCVs and 1 steamline drain isolation valve (IV) that must be properly aligned for the pathway of interest. The "closed" state of the MSIVs, TBV, and the TCV indicates that, theoretically, no leakage through the steam system should occur. Experience has shown, however, that the MSIVs do leak and this leakage might exceed the standard 11.5 scfh leakage limit.

In the following sub-sections, a detailed discussion of each of the leakage control pathway discussed in Sections 4.2 and 4.3 is provided. An availability assessment of these pathways is also presented by the means of fault tree analysis. The probability of successful operation (availability) of the leakage control pathways, frequency of initiating event, and total public risk estimates are also provided. An attempt has also been made to point out the benefits and the limitations associated with each one of the leakage control pathways.

5.3.1 Role of Loss of Offsite Power During DBA

Of particular concern to this program is the potential availability of leakage control pathways during the design basis accident (DBA). This again consists

of recirculation line break initiated LOCA leading to core-melt. Such conditions in the plant will lead to turbine trip and loss on on-site load generation, with the real potential for subsequent loss of off-site power supplies (LOOP) as well in the early stages of the accident. Several of the proposed pathways are however highly dependent on this power source. As a result, the performance of the various leakage control pathways under loss of offsite power conditions becomes important.

The general approach in establishing regulatory requirements for control of radionuclide release is to insure that the proposed system will perform its intended function under all possible accident conditions. This "deterministic" approach then sets performance standards under presumed conditions, such as loss of offsite power in this case. A probabilistic evaluation of the issue however must take into consideration in its evaluation the probability of such additional failures in support systems. As a result, the potential for plant shutdown initiating loss of offsite power will be reviewed here along with its impact on the leakage control pathways.

5.3.2 Loss of Offsite Power

The most recent review of loss of offsite power events by the Electric Power Research Institute (EPRI) (Reference 5.7) indicates that up through 1983 there have been 47 reported LOOP events at 52 plant sites. With 533 site-years observed, this represents an average of 0.088 events per site year, with this number falling to 0.027 events per site year for the years 1981 through 1983 due to specific site improvements in electrical switchyard reliability. The median duration for the loss of power was approximately 1/2 hour, with the longest recorded put at approximately 9 hours. The average of 0.049 events per site year was given for outages exceeding 1/2 hour.

This however represents an industry average, with actual incidents being very site specific. Of the 52 plant sites, 1/2 (26 of 52) have never experienced a loss of offsite power. Fifteen sites have had only one event, indicating that the remaining 11 sites experienced 32 loss of offsite power events. As a result, several of the sites discussed in the report have undertaken equipment upgrades to improve power reliability. This again is reflected in the improved performance in recent years.

The particular failure mode of interest in this case is the potential for plant shutdown after LOCA to initiate grid instabilities leading to loss of offsite power. There have been several recorded instances of such events, most notably at Turkey Point (two 666 MWe Westinghouse units). This plant has experienced 6 events, with grid instability problems and interactions between the two units at Turkey point contributing to the outages. A major switchyard upgrade is expected to eliminate interactions between the units.

The experience at Turkey Point would then represent an upper bound on the potential for inducing loss of offsite power following plant trip.

A review of the transient shutdown data for plants operating at between 26 and 110% power (Reference 5.8) gives a historical shutdown frequency of 6.01/PY for PWRs and 6.61/PY for BWRs. The two Turkey Point units went into operation in 12/72 and 9/73, giving a total operational history of 11 and 10.25 or 21.25 plant years up to the end of 1983. The total number of trips during this period using the average PWR trip frequency at power is then (6.01 trips/yr) (21.5 years) = 129.22 trips. It will be further assumed that all of the 6 recorded loss of offsite power events at the site were due to plant shutdowns. The conditional probability of loss of offsite power given plant shutdown at Turkey point can then be estimated as (6/129.22) = 0.05.

The potential for plant shutdown leading to loss of offsite power is thus highly site dependent and ranges historically from 0 to 0.05, with the probability put at 0.05/shutdown at the site which has historically displayed the highest tendency to cause grid instabilities on plant shutdown. The true industry average is therefore somewhere between these extremes.

The value of 0.05 for loss of offsite power on plant shutdown will be used here as a measure for the potential states of plant equipment after a LOCA induced shutdown.

5.3.3 Power Recovery

Several of the leakage control pathways under consideration here will utilize equipment downstream of the MSIVs that will be powered by non-safety grade electric buses. As such, this equipment will be vulnerable to loss of offsite power events with the plant shutdown and no longer maintaining normal house loads. The potential for recovery of offsite power during the course of the accident then becomes of interest. As reviewed above, the median time for recovery of offsite power has been on the order of 1/2 hour. Recovery on this time frame will mean that the systems in question would be available within 1/2 hour from the time of trip with a probability of approximately 0.5. Progression of accidents to core-melt on time frames less than 1/2 hour following a loss of offsite power event will essentially make the systems available for leakage control measures. This is more conservative than the recovery factor typically quoted in Reference 5.9 and in PRAs such as Reference 5.2 which put this value at 0.2. The net effective probability of unavailability due to loss of offsite power of (0.05)(0.5) = 0.025 will be used in the following development of availabilities of the leakage control options.

5.3.4 Impact of Loss of Offsite Power on Leakage Control Options

In the leakage control options to follow, some of the valves and equipment to be utilized will not be available given a LOOP. This will include compressed air supplies of the balance of plant which may effect air powered valve positions, vacuum pumps, steam supplies, etc. To account for the potential unavailability due to LOOP, the 0.025 term estimated above will be included in any estimate of unavailability due to mechanical failure.

5.3.5 Leakage Control System (LCS) Pathway

The main steamline isolation valve leakage control system (MSIV-LCS) is designed to minimize the fission products that could escape to the environment without treatment after a LOCA. This is accomplished by directing the leakage past the closed MSIVs to a bleedline using a blower that directs the leakage into the reactor building and eventually through the standby gas treatment system. Thus, leakage through the MSIV is processed by the SGTS prior to release to the atmosphere.

Use of this pathway provides some treatment and holdup of the radioactive gases by the SGTS charcoal beds and HEPA filters. It also provides an elevated release from the plant.

One drawback associated with this pathway is the limited capacity of the system that isolates at flows exceeding 100 scfh per main steamline (MSL). Therefore, when a large MSIV leakage occurs, this pathway is not available. The conditional probabilities of MSIV leakage that were developed in the previous section reflect this limited capacity of the LCS. The availability data on MSIV failure to close does indicate that the probability of exceeding 100 scfh is quite small. As a result, the probability of leakage past the valves on any steamline being greater than 11.5 scfh but less than 400 scfh for the four lines essentially is equal to the probability of leakage greater than 11.5 scfh. It will be assumed that the LCS is a safety related system, and all associated equipment will be unaffected by a LOOP.

The potential release flow path for operation of MSIV-LCS is presented in Figure 5.1. The leakage passes through the inboard and outboard MSIV-LCS, the SGTS system, and the stack before it is finally released to the atmosphere. A success tree illustrates the successful operation of this leakage control pathway (Figure 5.2).

The top event of this fault tree is a core-melt with successful operation of the LCS. For this to occur, five main conditions must be met. These are:

- containment integrity should be intact,

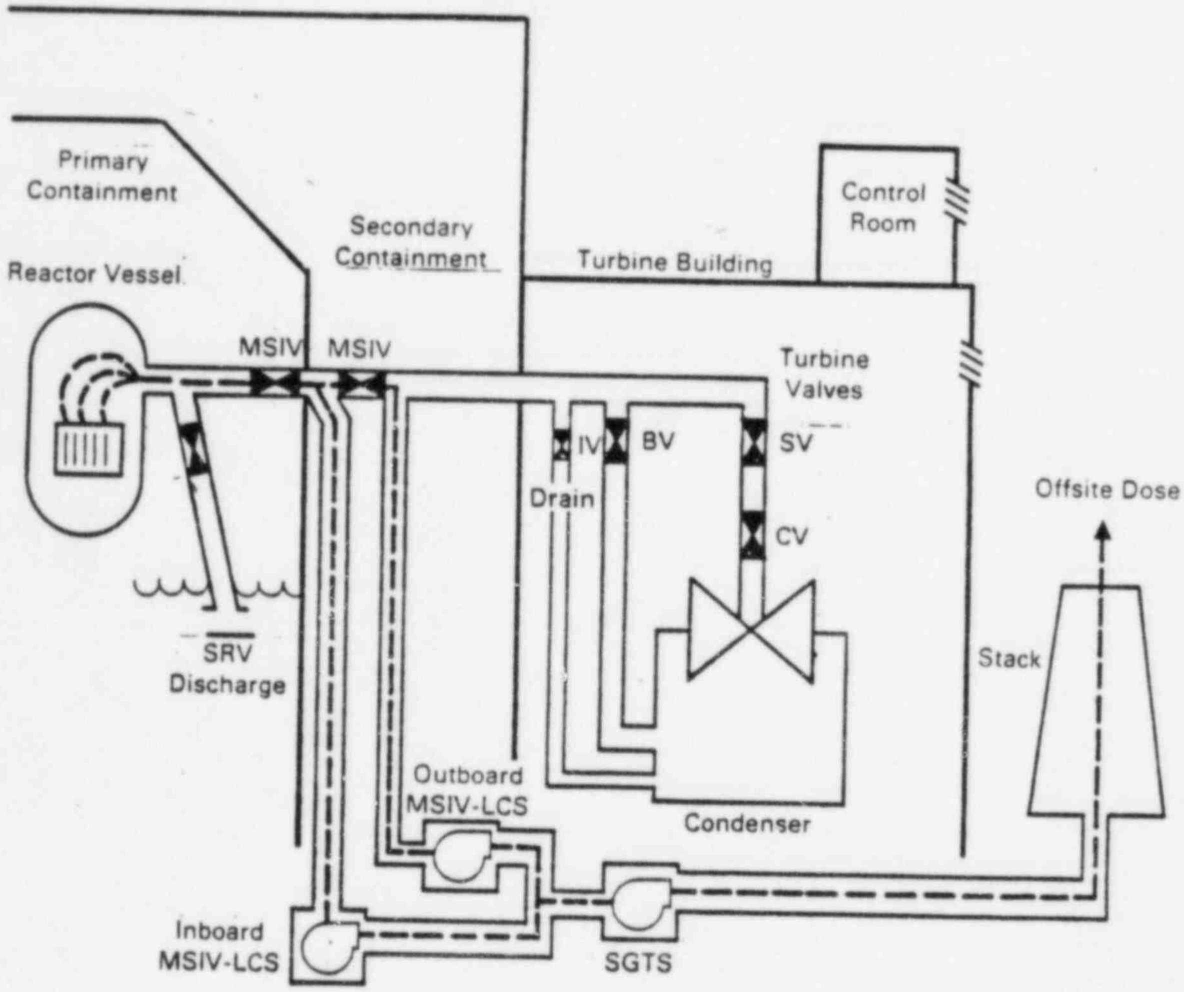

Figure 5.1 LCS flow path

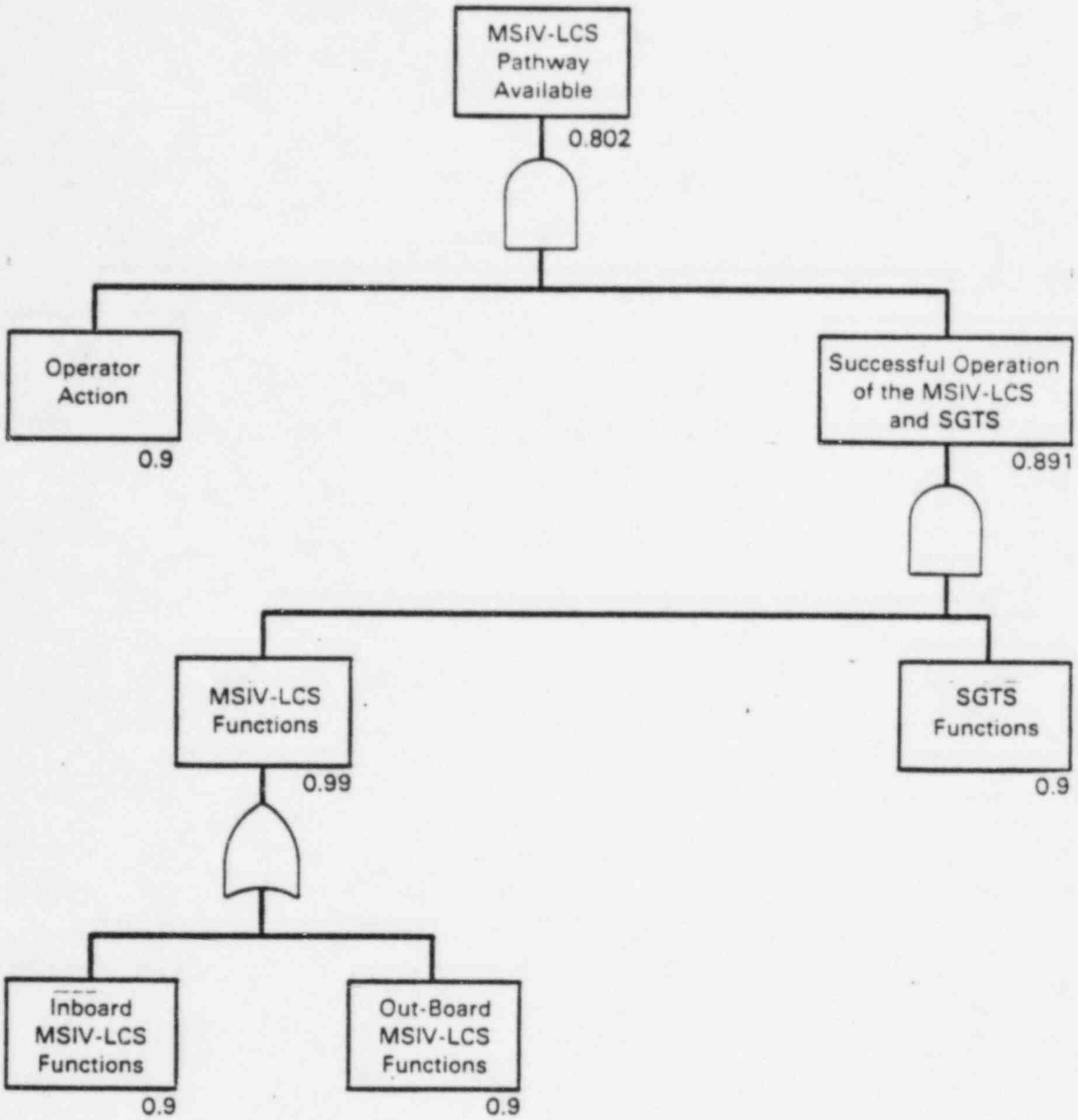

Figure 5.2. LCS availability success tree

* closure of the MSIVs with leakage within the LCS capacity,
* operator action to initiate LCS operation,
* successful mechanical operation of the LCS components, and
* proper alignment of valves.

In this analysis, the containment integrity is maintained. The core-melt frequencies developed in the previous chapter have already incorporated a probability factor for containment failure. For fuel damage scenarios, the availability of containment would likely be much higher. Therefore, a probability of 1.00 is assumed for the containment integrity remaining intact in this event tree.

The second condition that must be fulfilled in this analysis is that the MSIVs must leak within the capacity of the LCS. If 100 scfh per MSL limit is exceeded, the LCS will isolate and this pathway will not be available. This factor addressed in a previous section, and this condition was accounted for in the initiation frequency of this accident. Therefore, to avoid double counting, a probability of 1 is assigned to this condition.

The third condition in this analysis that needs to be met is the operator interaction. (Not all of the pathways identified require some operator action.)

During the scenario progression to core-melt, operator action to initiate LCS operation is unlikely. Discussions with the reference plant operator trainers indicate that responding to the system demands to prevent core damage will require most of the operator's time and attention. On detection of radiation in the steamlines however, the existing procedures would dictate use of the LCS. The operator will attempt to control MSIV leakage with a high probability at some time after core-melt, but given the continued confusion and demands on operator it is uncertain if the LCS system would be demanded immediately after leakage and the presence of radiation in the steamlines. Since the identified MSIV leakage control pathway will be documented in the emergency procedures guide, a probability of 0.9 is assigned that the operator will take some action, and that he will do it correctly.

The fourth condition that must be met for successful operation of the LCS is successful operation of the MSIV-LCS and the SGTS system. The LCS consists of a mechanical blower, power supply, and switching components. In the absence of any specific availability data, a value of 0.9 is used for availability on demand of the blower for the inboard and outboard LCS. If operation of only one LCS is required for success, each having a reliability of 0.9, the overall

probability of success for the inboard or outboard LCS is then (0.0 + 0.9) - (0.9)(0.9) = 0.99. The same basic value of 0.9 is also used for the SGTS system. Therefore, the total probability of availability of the MSIV-LCS leakage control pathway is estimated to be (0.9)(0.9)(0.99) = 0.802 as shown in Figure 5.2.

5.3.6 SJAE and Offgas System Pathway

The use of the steam jet air ejectors (SJAE) to reduce offsite releases maintains the main condenser vacuum. Operation of the SJAEs sweeps non-condensables to the offgas system. Any MSIV leakage would then be processed through the offgas system by opening the main turbine bypass valves to the main condenser. The steamline valves must then be configured to direct MSIV leakage to the main condenser. Figure 5.3 illustrates this leakage control pathway.

Once the MSIV leakage is in the main condenser the non-condensable radioactive gases are evacuated from the main condenser by the SJAE and processed through the offgas system recombiner, condenser, charcoal beds or delay tanks, and high efficiency particulate absolute (HEPA) filters. Finally, they go out the main stack. This option provides the optimum treatment of the radioactive gases prior to release from the plant when there is no large steamline break. By using this pathway, any MSIV leakage is evacuated to the main condenser, thus precluding or minimizing any leakage from elsewhere in the main steam system.

This flow path also permits the cold-trapping of iodine and volatiles, and gives the added benefit of condensation, scrubbing and plateout that would occur in the MSL and main condenser. Further plateout and holdup continues in the offgas system, the charcoal adsorbers, and HEPA filters. This pathway also maximizes the holdup time of the radioactive gases prior to their release from the plant at an elevated point.

The SJAEs use a high velocity jet of steam to create a low pressure for the removal of non-condensable gases from the main condenser shells. Main steam, reduced to 125 psig, is supplied through a strainer to each SJAE nozzle. The nozzle accelerates the steam to a high velocity so that it passes through the diffuser throat as it begins to expand. Gas molecules present in the suction chamber are entrained in the steam and carried by the steam.

This control pathway relies on a flow path to the main condenser that is intact. For steamline break scenarios, this pathway becomes ineffective. For other scenarios involving radiation in the steamlines, the MSL are closed, and the steam supply for the SJAEs is not available. An auxiliary source of steam for operation of SJAEs and establishing turbine seals, therefore is needed. This steam source will be assumed to be lost on LOOP, reflected by an additional 0.025 unavailability factor.

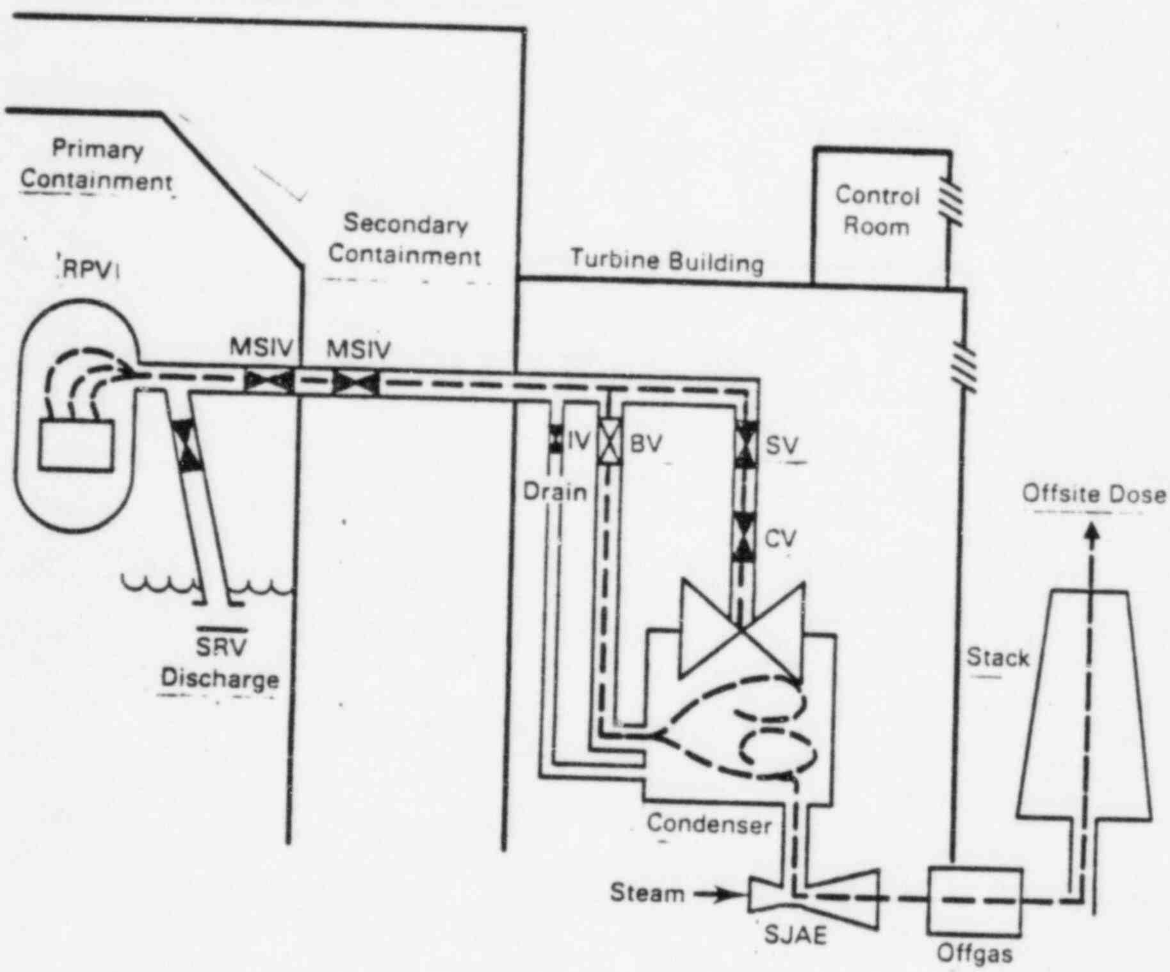

Figure 5.3. SJAE and offgas system flow path

A success tree analysis of the availability of this leakage control pathway is illustrated in Figure 5.4. Similar to the success tree presented in Figure 5.2, there are six main conditions that must be met for the top event, release via the SJAEs and offgas system in Figure 5.4, to occur. These are:

- containment integrity,
- no steamline break,
- operator selection of this control pathway,
- turbine bypass valve opened, or main steamline drain isolation valves open
- availability of steam supply and mechanical operation of SJAEs,
- mechanical operation of the offgas treatment system.

The first two conditions are accounted for in the initiation frequency that was developed earlier.

The third condition to meet this analysis requires that the operator select this control pathway. This requires opening the TBV or TSV and aligning valves for delivery of the steam supply. Currently, this is not a standard emergency procedure, and the probability of this selection is negligible; however, the procedures could be modified to reflect this potential. A probability of 0.5 is suggested if such procedures are implemented. This is consistent with the assumptions made in MSIV-LCS analysis. Again, this value is assumed to include both the probability of operator action and the probability that the operator acts correctly once the decision is made.

In the fourth condition for using the SJAEs and offgas pathway, the turbine bypass valve (TBV) or main steamline drain line isolation valve must open on demand to open the pathway to the condenser. Depending on the initiating event that led to plant shutdown, the TBV could be in the open or closed position. For scenarios that open the TBV after shutdown, the TBV may remain open on closure of the MSIVs. No automatic closure signal is generated for the TBV on closure of the MSIVs. A review of Table 5.6 for transients in the BWR-4 plant indicates that TBV opening could be expected for loss of off-site power and transients where the PCS is available. These contribute (2.92×10^{-5}/PY + 3.7×10^{-6}/PY) out of a total frequency of 1.97×10^{-4}/PY, or 17%. This is rounded off to 20% here for simplicity. A similar percentage is obtained for the BWR-6. LOCA scenarios are not thought to open the TBV, so the total core-melts with the TBV left open when the MSIVs close is estimated to be 20%. For 80% of the core-melt scenarios, the operator must then properly align the valve. As a

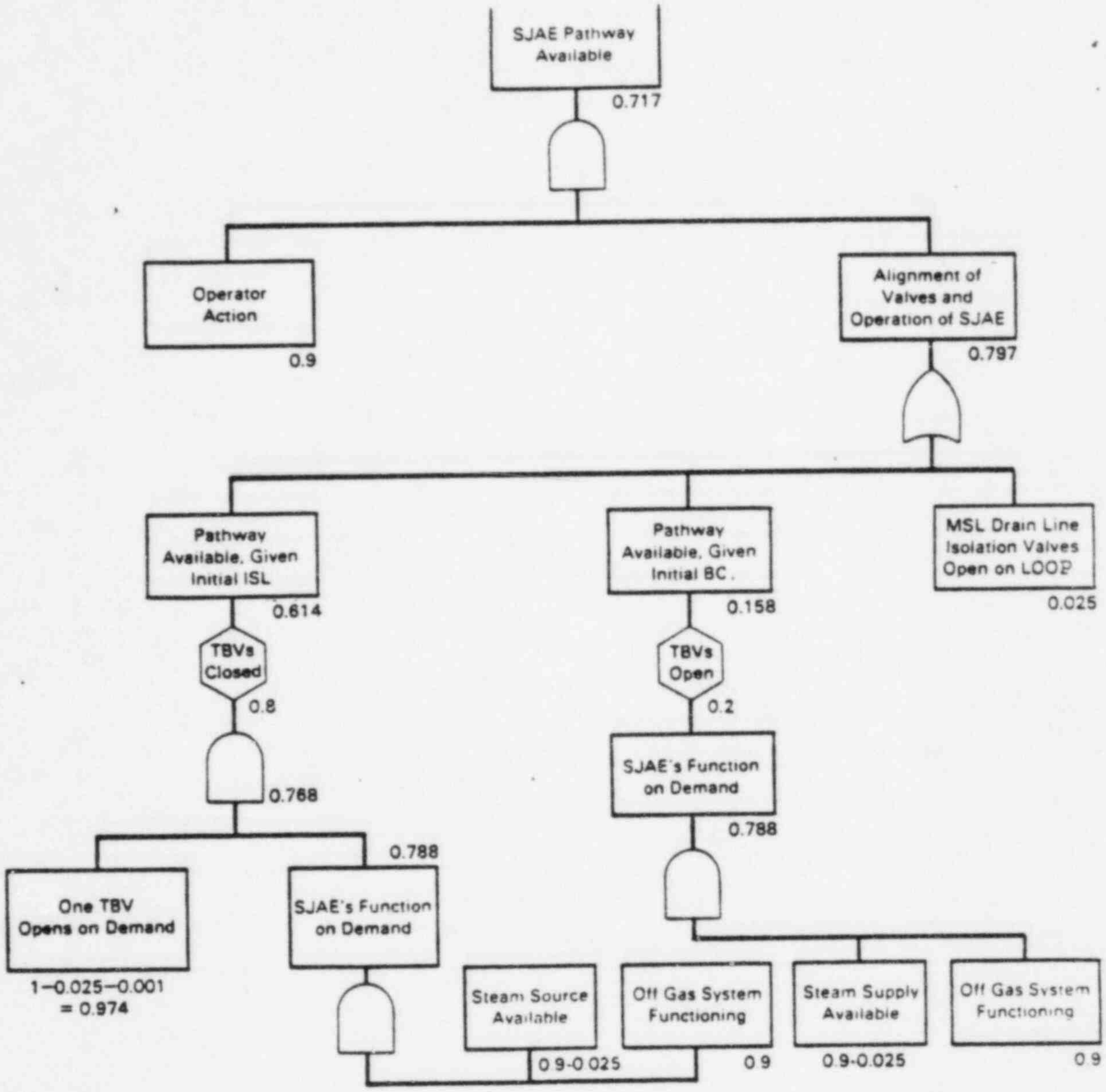

Figure 5.4. SJAE and offgas availability success tree

result, the probability of the TBV failing to open on demand must be considered. This value is typically put at $1x10^{-3}$/demand. Unavailability due to loss of offsite power of 0.025 is included here, for an availability of 1-0.001 - 0.025 = 0.974. The drain line isolation valve could also fail open on LOOP. The potential for this was put at 0.025 for all shutdowns.

The next condition deals with the availability of steam for the SJAEs. Again, it is assumed that the plant in question has an auxiliary steam supply available. It is highly uncertain if adequate steam would be available from the auxiliary source after several hours into a core-melt scenario; however, if no other systems are consuming steam, the availability may result from operator selection and alignment of the proper valves.

The probability of operator action to open the steam pathway is assumed to be synonymous with the overall decision to use this pathway, starting with the selection to open the TBV. Thus, a high probability of 0.8 is assumed for successful operator action. The mechanical success or failure of the SJAE function then is thought to result from the operation of valves that are used to isolate the SJAEs from the steam source. Several valves may be required to open to complete the steam pathway. To reflect the uncertainty in the steam supply and its maintenance after shutdown as well as the uncertainty in the valving and power supply arrangement, an availability value of 0.9 will be used.

Finally, the probability of availability of the gas treatment system focuses on the operation of a blower because the rest of the components have basically a passive function. This availability is put at 0.9, with a 0.1 probability of unavailability.

The last three conditions for using the SJAE and offgas pathway deal with the proper alignment of valves. The basic discussion is the same as the one presented in the MSIV-LCS analysis. Based upon the values given in Figure 5.4, the probability of proper valve alignment is estimated to be 0.797. Combined with operator interaction probability of 0.9, this will yield a total probability for the SJAE availability of 0.717.

5.3.7 Condenser Vacuum Pumps Pathway

The condenser vacuum pumps pathway is similar to the previous leakage control pathway (option) where the SJAEs are used to maintain main condenser vacuum. In this option, mechanical vacuum pumps are used to maintain condenser vacuum. This flow path is presented in Figure 5.5. MSIV leakage is drawn through the turbine bypass valves and into the main condenser. It is then pumped directly to the main stack. In the previous option, the leakage was processed through the offgas system before going through the main stack.

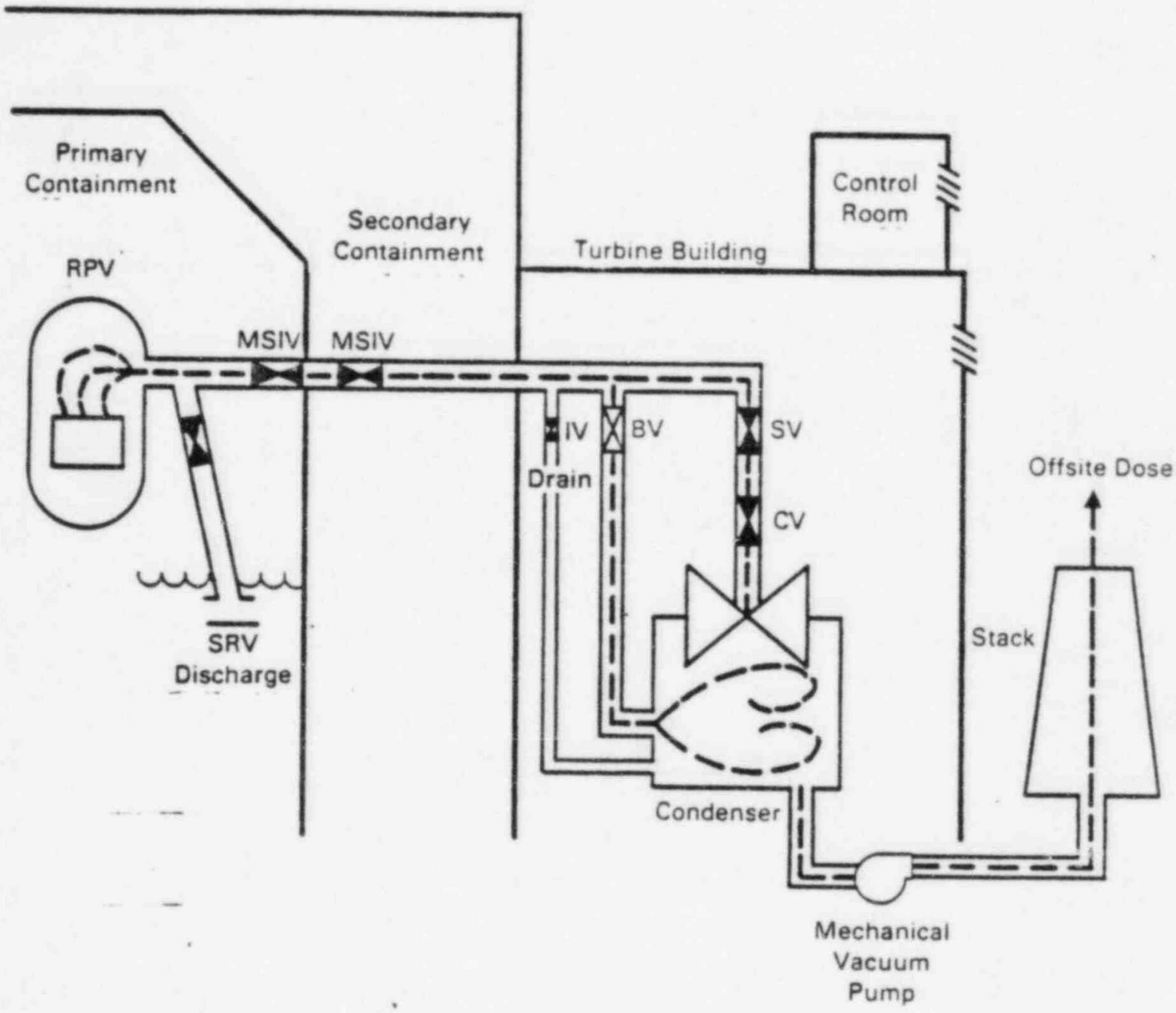

Figure 5.5. Condenser vacuum pump flow path

All plants are equipped with mechanical vacuum pumps, so this leakage control pathway is an option for all plants. In this pathway, the radioactive gases are evacuated from the main condenser by the mechanical vacuum pumps and pumped through a holdup volume and out the main stack for the plant. These mechanical vacuum pumps also are used to remove air and non-condensables from the main condenser during startup when steam pressure is less than 260 psig, and they can operate as roughing pumps. The two pumps are vane-type centrifugal, pumps rated at 2350 scfm. Each pump is driven by a 100 hp motor.

The mechanical vacuum pumps isolate on high steamline radiation. Direct operator action is required to initiate pump action when MSIV leakage control is needed. There is essentially no holdup time (about 2 minutes); and there also are no condensers, filters,or charcoal adsorbers in the flow path to reduce the radioactive release from the plant.

This pathway is similar to the previous leakage control pathways; if there is a large steamline break (outside the capacity of the vacuum pumps), it becomes ineffective. A success tree analysis of the availability of this pathway is presented in Figure 5.6. There are five conditions that need to be met before the vacuum pump pathway is available:

- containment intact,
- steamline intact,
- availability of the pathway,
- mechanical operation of the vacuum pumps, and
- proper alignment of valves.

As with the previous leakage control options, the first two conditions are incorporated into the initiating event frequencies (see Table 5.6). The failure probability of mechanical operation on demand for the pumps is also estimated to be much smaller than any operator error in aligning the valves and selecting the option itself.

This leakage control pathway requires that the TBVs or drain line isolation valves be open. As discussed in the analysis of the SJAEs and the offgas system, the initial plant condition following normal reactor trip is for the TBV to remain closed, 80% of the time. The drain lines open only on LOOP.

With MSIV closure, the TCV closure also is assured; however, for some core-melt scenarios, the initiating events could result in turbine trip and TCV closure before any demand signal for MSIV closure. In such cases, the TBV opens to bleed steam pressure directly to the condenser, and the pathway already is

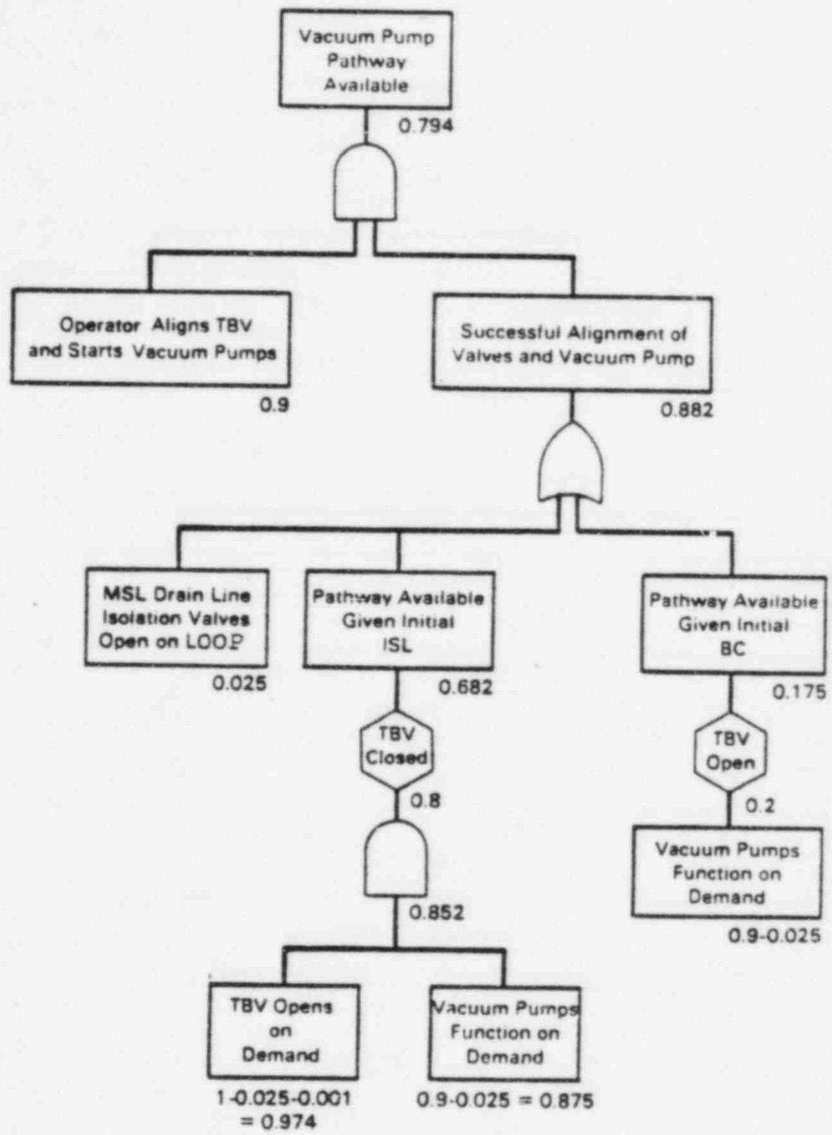

Figure 5.6. Condenser vacuum pump availability success tree

aligned properly. Rather than make a detailed study of scenarios, it is assumed that the TBV is open with MSIVs closed in 20% of the cases. As a result, the operator has to decide to use this leakage control pathway, requiring the demand of the TBV and vacuum pumps. This is shown in Figure 5.6 for the availability of the pathway. The discussion for proper valve alignment is similar to previous release pathways.

A probability of failure to open on demand for the TBV valve is 1×10^{-3}. The same value typically is used for pumps. Electric motors have a slightly lower value for failure to start of 3×10^{-4}/demand and failure to run of 1×10^{-5}/hr to 1×10^{-3}/hr for extreme environments. The addition of power supplies and switching for the motors makes a 0.9 value for availability, as used for the SGTS system, more reasonable. Unavailability factors of 0.025 due to LOOP are also added to both components.

Applying the data given in Figure 5.6 yields a total probability for the availability of mechanical vacuum pumps of 0.794.

5.3.8 Containment Within the Main Steam System Pathway

This leakage control option isolates the main steam system by closing the main turbine stop, control, and bypass valves as well as all branch line valves that connected to the MSL. Figure 5.7 illustrates this leakage control pathway. The TBV is assumed to be closed in 80% and open in 20% of the scenarios, with the latter requiring operator action to close the valve. A 0.9 value for operator action, and successful completion of that action is used to allow direct comparison to other pathways.

The net availability estimated in Figure 5.8 is 0.962.

To contain any possible leakage past the main turbine valves, the main condenser vacuum breakers are closed to isolate the main condenser. Turbine seals are established with an auxiliary steam source. This pathway then essentially becomes the isolated condenser pathway discussed in Section 5.3.9.

5.3.9 Isolated Condenser Pathway

In this leakage control pathway, illustrated in Figure 5.9, MSIV leakage is directed to a sealed or isolated condenser; leakage into the secondary containment and treatment by the SGTS system is not considered.

The leakage from the turbine building depends on its leakage constraints; therefore, any leakage from the turbine building would constitute a direct, untreated release from the plant.

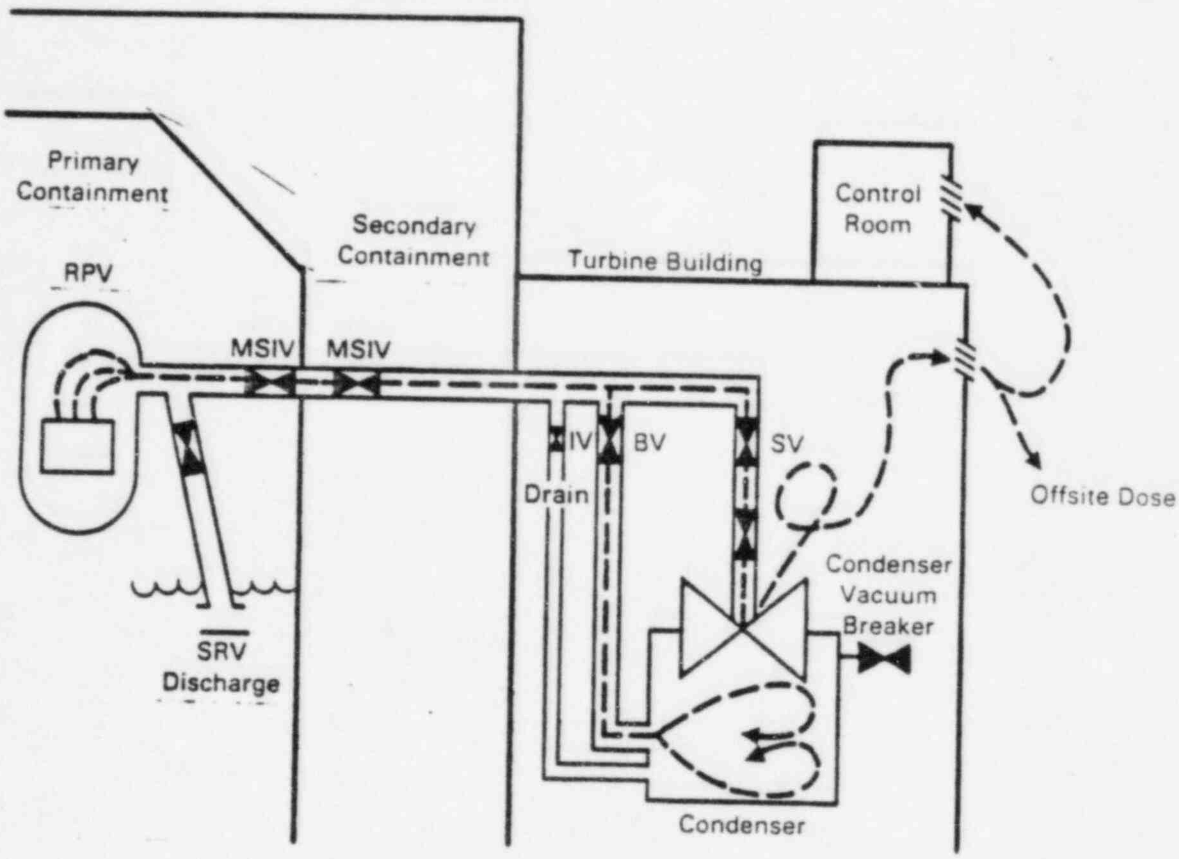

Figure 5.7. Isolated steamline flow path

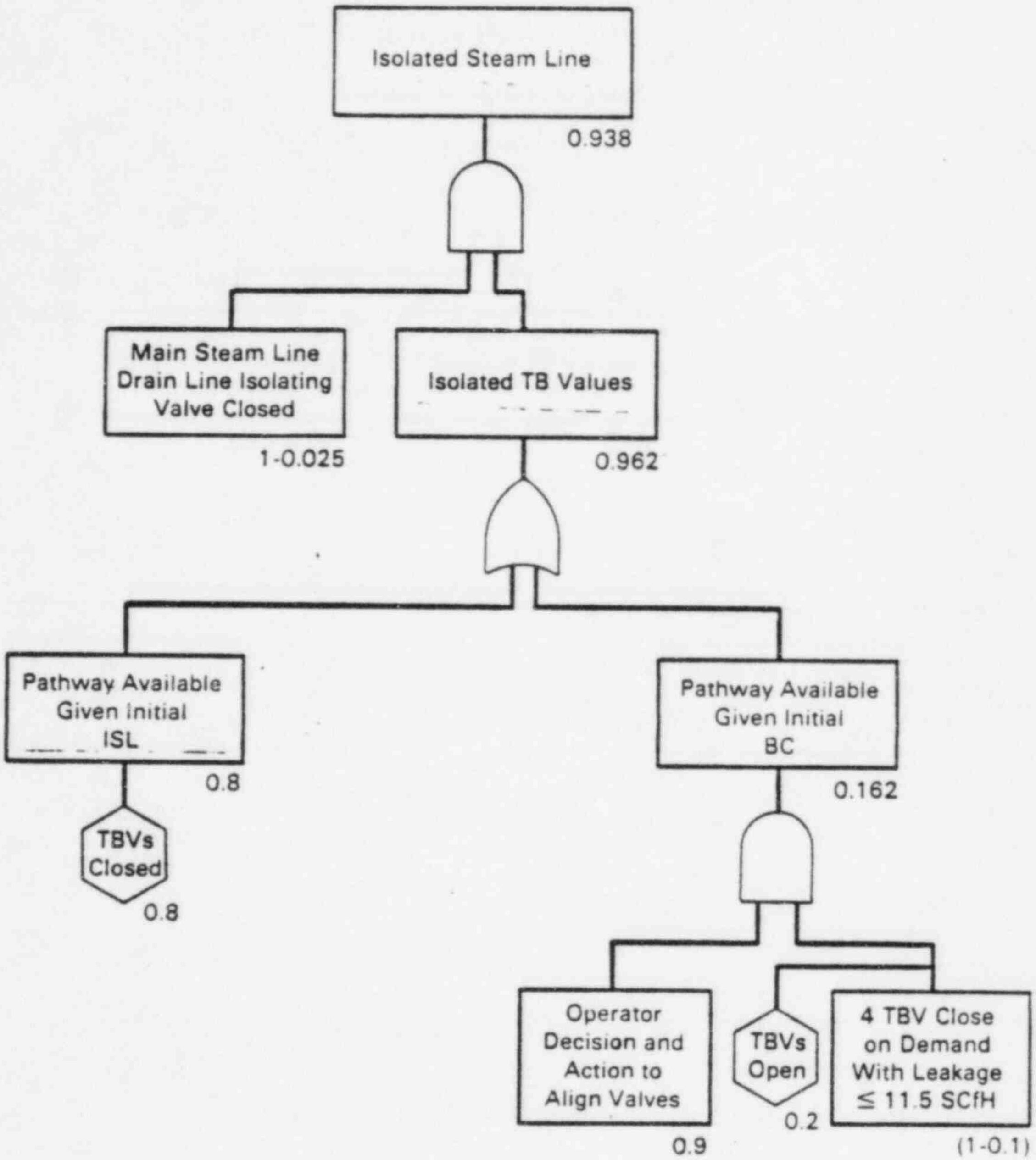

Figure 5.8 Isolated steamline flow path availability success tree

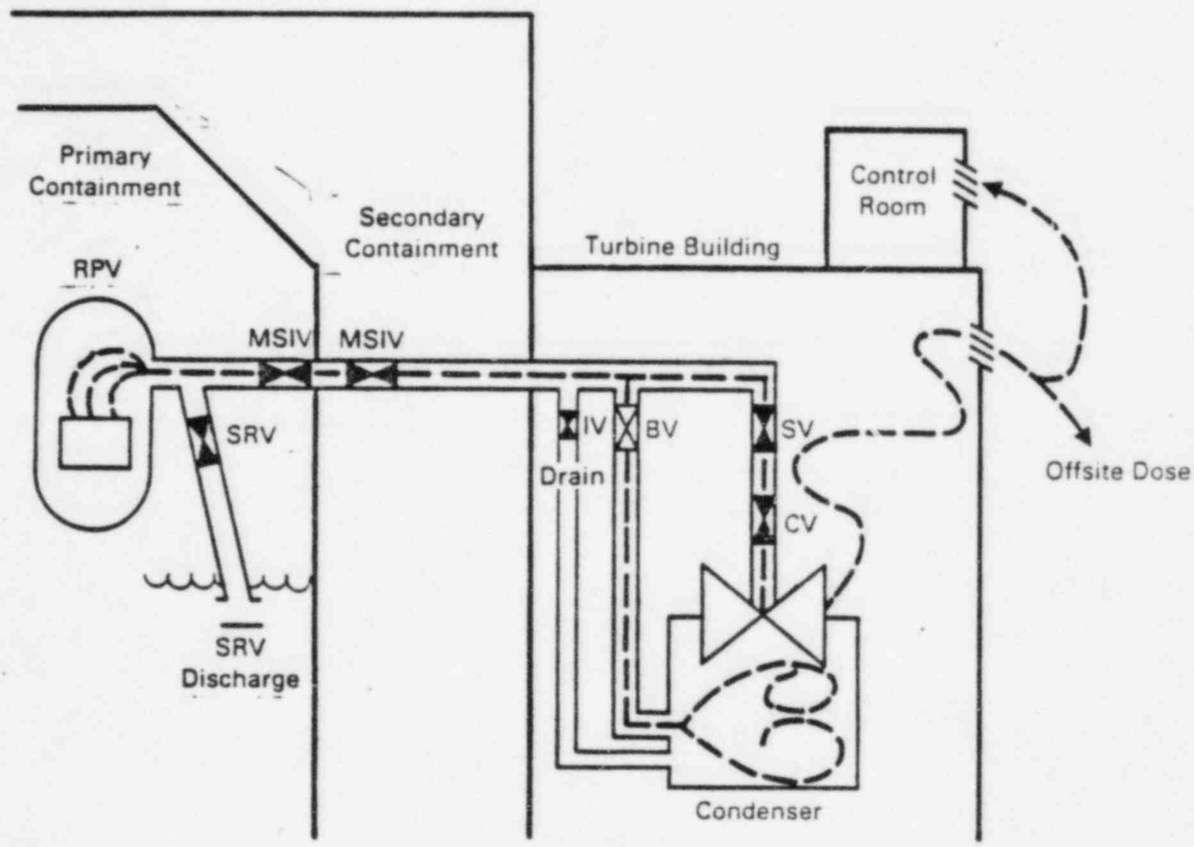

Figure 5.9 Isolated condenser flow path

This flow path allows the cold-trapping of iodine and volatiles, plus the scrubbing and plateout that occurs in the MSL and main condenser [provided TBVs or the main steamline drain line isolation valves (IV) are open].

Containment within the turbine building provides some holdup within the turbine building prior to release from the plant. This might be the only release control pathway for radioactive gases if there is a steamline break outside the primary containment.

A success tree analysis of the availability of this leakage control pathway is presented in Figure 5.10. Operator action with a probability of 0.9 to open TBVs is used as before to allow direct comparisons between the options.

The net result from Figure 5.10 is an estimated availability of the isolated condenser pathway of 0.926.

5.3.10 Summary of MSIV Leakage Control Pathways

The estimated availability of the five leakage control pathways is summarized in Table 5.11. The exact configuration of these systems has a pronounced effect on these the estimates, as does the assumed initial condition of loss of offsite power. The operation of all of the leakage control pathways, however, relies on relatively simple mechanical components, such as blowers, valves, switches, and power supplies.

Again, it was assumed that the plant would configure itself with closed TBVs 80% of the time. This would be lowered slightly by the potential for steamline drain line isolation valves opening on LOOP (0.025). Without any operator action, the plant is expected to be in the isolated steamline configuration for (0.80-0.025), or 77.5% of the time and in the isolated condenser configuration for 22.5% of the time. If operator action is considered, the potential availability of all pathways improve, but the isolated steamline configuration still has the highest availability estimate.

The potential for equipment unavailability due to loss of offsite power was again included in these estimates, but in a probabilistic sense. The probability of LOOP on shutdown without recovery within 30 minutes was put at 0.025. The reliance on these pathways for a safety grade leakage control option would thus require assumed power supplies in addition to procedural changes. The availability of these pathways could then be expected to improve, but only slightly.

After shutdown with the MSIVs closed, the plant is expected to be in either the isolated condenser or isolated steamline condition. The above analysis considers the potential for re-alignment of val es by the operator, and the availability of equipment necessary for the other pathways.

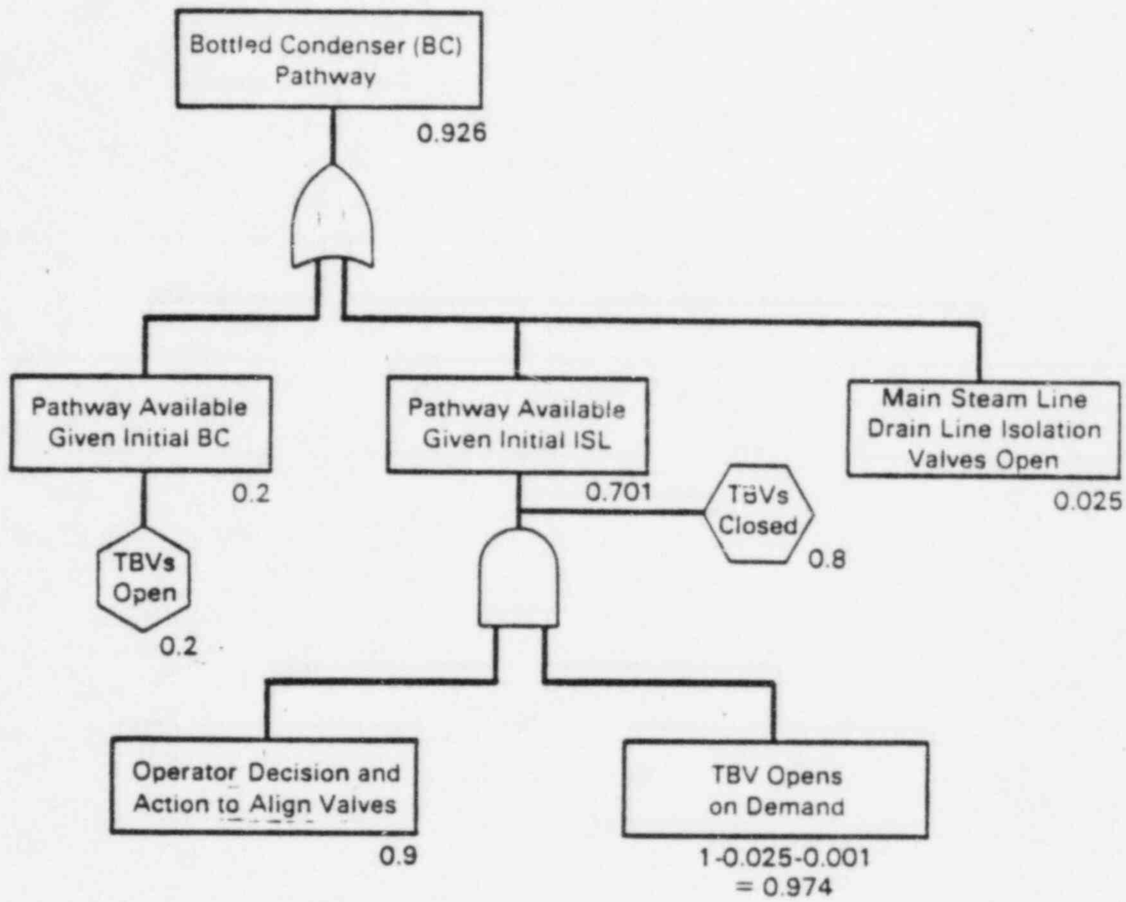

Figure 5.10. Isolated condenser availability success tree

Table 5.11. Summary of availability of leakage pathways

	Probability of Configuration on Plant Shutdown	Net Availability with Operator Action
Leakage Control System (LCS)	--	0.802
Steam Jet Air Ejectors (SJAE) and OffGas System	--	0.717
Condenser Vacuum Pumps	--	0.794
Isolated Main Steam System	0.775	0.938
Isolated condenser (no HVAC required)	0.225	0.926
	1.0	

5.4 Effective Frequency of Public Dose

This section presents the correlation between man-rem of public dose per event (i.e., core-melt with leakage past the MSIVs) and frequency of the event, giving an estimate of the frequency of man-rem/PY that is expected for this issue.

The following factors were used to reflect core-melt scenarios with MSIV leakage and without containment failure:

- probability of no pre-existing containment leakage = 0.99
- probability of no gross containment failure
  --for BWR-4 with Mark I containment = 0.04
  --for BWR-6 with Mark III containment = 0.06
- probability of MSIV leakage greater than 11.5 scfh = 0.01
- net effective reduction in core-melt frequency
  --for BWR-4 with Mark I containment = 3.96×10^{-4}
  --for BWR-6 with Mark III containment = 5.94×10^{-4}

The summary of core-melt frequencies is given in Table 5.12. The factor for net effective reduction in core-melt frequency (given above) is incorporated

Table 5.12. Summary of BWR core-melt frequencies where MSIV leakage will play an important role

	Base Case Core-Melt Frequency 1/PY	Effective Core-Melt Frequency With MSIV Leakage Greater Than 11.5 scfh, 1/PY
BWR-4		
Recirculation Line Break	6.69×10^{-7}	2.65×10^{-10}
Steamline Break	5.68×10^{-7}	2.25×10^{-10}
Transients	1.97×10^{-4}	7.80×10^{-8}
Total	1.98×10^{-4}	7.85×10^{-8}
BWR-5		
Recirculation Line Break	2.45×10^{-6}	1.46×10^{-9}
Steamline Break	2.45×10^{-6}	1.46×10^{-9}
Transients	3.20×10^{-5}	1.90×10^{-8}
Total	3.69×10^{-5}	2.19×10^{-8}

into the second column in Table 5.12, reflecting the 0.01 probability that was used for leakage greater than 11.5 scfh past the MSIVs.

5.4.1 Public Dose Due to MSIV Leakage

The dose consequence modeling effort presented in Chapter 4 included a calculation of total whole body dose commitment to the public as a result of MSIV leakage. These calculations assumed a population density of 340 people per square mile out to 50 miles, the value used in the probabilistic evaluation of other NRC safety issues. The public exposure as a function of MSIV leakage rate is summarized in Table 5.13, along with the estimate of the frequency of such releases where MSIV leakage is still of concern (i.e. containment still intact). Public exposure for each of several MSIV leakage rates was calculated. All estimates of public risk then were calculated using a probability of MSIV leakage past two valves in any one steamline of 0.01, based on data for leakage at 11.5 scfh.

Incorporated into Table 5.13 is the availability of the leakage control pathway, which was summarized in Table 5.11. The system is expected to be in an isolated steamline or condenser configuration after shutdown.

The maximum predicted public exposure is 2.58×10^{-6} man-rem/PY for leakage at 11.5 scfh in a BWR-4 with an isolated steamline. Using the same probability of MSIV leakage (i.e. 0.01) at 1000 scfh leakage, the public exposure increases to 2.06×10^{-3} man-rem/PY for an isolated steamline in a BWR-4.

The public exposure for the Mark III containment is predicted to be less, due to the smaller core-melt frequency.

Table 5.13. Summary of BWR public exposures due to MSIV leakage with containment intact following core-melt

Leakage Pathway Scenario	Availability of Leakage Pathway Function	Leak Rate, scfh	Man-Rem per event	Public Exposure, man-rem/PY BWR-4	BWR-5
Isolated Condenser	0.926	11.5	6.4×10^{0}	4.65×10^{-7}	1.30×10^{-7}
		300	1.8×10^{2}	1.31×10^{-5}	3.65×10^{-6}
		1000	4.8×10^{2}	3.49×10^{-5}	9.73×10^{-6}
		2000	9.3×10^{2}	6.76×10^{-5}	1.89×10^{-5}
Isolated Main Steam Line	0.938	11.5	3.5×10^{1}	2.58×10^{-6}	7.19×10^{-7}
		100	1.3×10^{3}	9.57×10^{-5}	2.67×10^{-5}
		300	4.5×10^{3}	3.31×10^{-4}	9.24×10^{-5}
		1000	2.8×10^{4}	2.06×10^{-3}	5.75×10^{-4}
Mechanical Vacuum	0.794	11.5	6.1×10^{0}	3.80×10^{-7}	1.06×10^{-7}
		300	1.6×10^{2}	9.97×10^{-6}	2.78×10^{-6}
		1000	4.3×10^{2}	2.68×10^{-5}	7.48×10^{-6}
		2000	8.3×10^{2}	5.17×10^{-5}	1.44×10^{-5}
		5000	2.3×10^{3}	1.43×10^{-4}	4.00×10^{-5}
Leaking Condenser	0.717	11.5	6.7×10^{0}	3.77×10^{-7}	1.05×10^{-7}
		1000	4.6×10^{2}	2.59×10^{-5}	7.22×10^{-6}
Leakage Control System	0.802	11.5	1.31×10^{2}	8.25×10^{-6}	2.30×10^{-6}
		100	1.14×10^{3}	7.17×10^{-5}	2.00×10^{-5}
		*			

* LCS pathway not available for leak rates much in excess of 100 scfh.

Note again that the probability of leakage past two MSIVs for some discreet value like 1000 scfh is expected to be significantly less than the probability of leakage simply exceeding 11.5 scfh. Given the lack of observational data, the probability of leakage at 1000 scfh will not be estimated here. The dose rates associated with this leakage will be used here however as a conservative upper bound for public dose commitment due to leakage past the MSIVs.

The total public dose commitment that is estimated for this generic issue is bounded by using the exposure estimate at 1000 scfh of 2.06×10^{-3} man-rem/PY for 30 years with 44 BWRs, giving a total dose of (2.06×10^{-3} man-rem/PY) (44 plants)(30 years) = 2.72 man-rem. This is the dose that is expected to result from leakage past the MSIVs following a core-melt that leaves the containment intact. In any scenario involving containment failure, the contribution from MSIV leakage to public dose is insignificant.

5.5 Conclusions

The estimate of low public risk that is represented by leakage past the MSIVs is insensitive to the assumptions used in this calculation. The selection of variables that are thought to overestimate the frequency of events assumed here include:

- using all core-melt scenarios rather than core-melts initiated by recirculation line breaks, for which the LCS was originally designed,
- assuming 4% to 6% containment survival, compared to 100% failure in all PRA calculations of other NRC safety issues,
- using releases at 1000 scfh and associated public dose/event without reducing the probability of leakage past the MSIVs at these higher rates.

A more rigorous probabilistic analysis would result in a further decrease in the low public dose estimates made here. Because of these low dose estimates, a full value/impact analysis to identify associated costs was not needed to conclude that public risks represented by leakage past the MSIVs are too low to justify the imposition of equipment additions or modifications for leakage control.

A full value/impact analysis of the leakage control issue for future BWRs would include costs associated with equipment design, installation, operation, testing and maintenance. These costs are expected to be substantial, resulting in a value/impact ratio far below the 1 man-rem/$1000 figure of merit that is used to evaluate potential modifications to reduce public exposure. Other negative aspects of LCS operation as it is now designed include occupational exposures

during maintenance, testing, and cleanup in secondary containment. Contamination of equipment in secondary containment due to LCS operation could also potentially hinder accident recovery and maintenance operations. These all contribute negatively to any perceived benefits of a LCS, and would further strengthen the conclusion that the requirement for a safety grade LCS cannot be justified on a value/impact basis.

6. SUMMARY AND CONCLUSIONS

6.1 Reduction of MSIV Leakage

Based on the findings of the BWROG described in Section 3 and the appendices of this report, it is concluded that the major causes of excessive MSIV leakage probably have been identified. Efforts by the BWROG members and valve vendors to improve maintenance practices and repair or modify valves that regularly fail the leak rate test are significant aspects of the long-term solution. However, two or more operating cycles of maintenance and test experience may be needed to establish the effectiveness of the improved practices. The experience of some licensees confirms the belief of some valve vendors that improper field maintenance techniques or equipment may create valve leakage problems that, in turn, necessitate further maintenance.

As regards leak test methods, it is concluded that there may be substantial benefit to testing the valves after closure under conditions that simulate as closely as possible those of a valve in actual use. The success experienced by one utility in having all MSIVs pass the leak rate test for a number of operating cycles appears to bear this out. That utility reportedly tested the valves hot after closing them with several psi of steam pressure on them and experienced no leak rate test failures in the first seven years of commercial operation. By not having to open the valves and refurbish them for minor leakage, the utility may have avoided introducing the root causes of recurrent leakage problems. A conclusion that is suggested by industry experience is that by attempting to maintain these large, fast-acting valves to such a stringent leakage specification, utilities have conducted numerous disassembly and refurbishment operations on valves that had no substantive defects. By attempting to correct nonexistent defects in the valves under less-than-optimum field maintenance conditions, it is likely that some actual defects have been introduced that led to later leak test failure.

6.2 Allowable MSIV Leakage Rate

As can be seen from Tables 4.13, 4.14, and 4.15, any MSIV leakage strategy that takes advantage of the main condenser as a holdup volume is extremely effective for mitigating the offsite consequences. All three strategies examined here can be either active or passive, and it is quite likely that some variation of one of these three would be feasible at most plants, even if offsite power is lost.

The passive strategy of leaving the MSL isolated compares favorably with the baseline case treatment mode but yields doses that are one to three orders of

magnitude higher than the three active modes. This passive mode can be transformed into one of the more effective active modes by opening one or more MSL condensate drain bypass valves. If the valves fail to the open position upon a LOCA signal or loss of offsite power, or the action can be taken before a significant concentration of fission products arrive at the turbine bypass valve/stop valve bifurcation, the release can be substantially reduced. The time available for operator action would, of course, depend on the MSIV leakage rate and numerous plant-specific factors, but should be on the order of tens of minutes to a few hours for MSIV leakage rates in the hundreds of scfh.

Given that the time required to implement one of the active strategies could be as little as a few seconds to a few minutes even without offsite power, it appears reasonable to base a leak rate specification on the dose consequences from one of the alternate treatment modes. Leak rates of 1300 to 1840 scfh per valve have been shown by a realistic analysis to produce offsite dose consequences comparable to those calculated for the 11.5 scfh limit using the very conservative licensing-type analysis.

It is therefore concluded that a leak rate limit on the order of 10 to 100 times higher than the current limit should be implemented, with licensees to propose plant-specific values and provide analyses to substantiate them. The higher limit would have the following positive impact on BWR operational reliability and safety:

- By formulating and proposing an operational strategy for dealing with MSIV leakage rates that are greater than the capacity of the LCS, licensees can ensure that they are in fact better prepared for occurrences of extremely high MSIV leakage, an event of true safety significance.

- By setting the leakage limit for individual valves at a value shown to be indicative of some real hardware problem that can be identified and repaired, a major reduction in nonproductive repair and refurbishment effort can be realized. This should lead to reductions in outage time, occupational radiation exposure, and defects introduced by disassembling and refurbishing valves that are basically in good condition.

6.3 Need for a Safety-Grade LCS

To examine the need for a safety-grade LCS from a probabilistic risk assessment (PRA) perspective, the PRAs of two representative BWRs were examined, a BWR-4 with Mark I containment and a BWR-6 with Mark III containment.

The core-melt frequency was slightly lower for the BWR-6, because of improved response to recirculation line breaks, steamline breaks, and transients. The core-melt frequency from all causes was put in the PRAs at 1.98×10^{-4}/plant year (py) and 3.69×10^{-5}/py for the BWR-4 and BWR-6 respectively. The recirculation line break used as the reference accident in this study contributed only a core-melt frequency of 6.69×10^{-7}/py and 2.45×10^{-6}/py to the BWR-4 and BWR-6 respectively. The entire core-melt frequency was used here, however, to give a maximum estimate of the potential frequency of MSIV leakage contributing to public dose.

An examination of containment failure modes in PRAs indicates that containment failure is assumed for all core-melt scenarios. As such, MSIV leakage control would play no role in minimizing public exposure when considered with a core-melt scenario and subsequent source term. For this examination, however, the probability of no containment failure was examined in more detail. The probability of no containment failure was then put at 0.04 and 0.06 for BWR-4 and BWR-6 containments, respectively.

Finally, the probability of MSIV leakage was examined. Based on the data compiled by the BWROG, the probability of MSIV leakage past two valves in any one steamline was put at 0.01 for leakage greater than 11.5 scfh. The trend for the valve leakage when tested following closure with no differential pressure across the valves indicated that the probability of leakage at higher values would be much less than 0.01. For tests conducted following closure under differential pressure, the only reliability figure given was for "leakage greater than 11.5 scfh." No data were provided concerning the probability of higher leakage rates, and the value for 11.5 scfh following closure under differential pressure was used.

The net result was a predicted core-melt frequency where MSIV leakage control would be important (i.e., no containment failure and independent MSIV leakage) of 7.85×10^{-8}/py and 2.19×10^{-8}/py for BWR-4 and BWR-6, respectively. This then would represent the frequency of events where public exposure via MSIV leakage during a core-melt accident would be of concern.

The highest public exposure predicted per release for the alternate leakage pathways examined was on the order of 35 man-rem for leakage at 11.5 scfh through the MSIVs using the isolated steamline strategy. This represents a public exposure frequency of 2.45×10^{-6} and 6.82×10^{-7} man-rem/py for BWR-4 and BWR-6, respectively. Over a 30-year plant life, this represents 7.35×10^{-5} and 2.05×10^{-5} man-rem/plant. With such a low public exposure there is no justification for retaining the requirement for a safety-grade LCS.

The predicted public exposure increases with an assumed increase in leakage past the MSIVs, but the probability of such leakage decreases. Increasing the assumed leakage by two orders of magnitude to 1000 scfh, increases the public

dose roughly three orders of magnitude to $2.8 \times 10^{+4}$ man-rem/event. Even at the leakage frequency for 11.5 scfh, however, the dose comes to only 6.6×10^{-2} and 1.8×10^{-2} man-rem/plant for BWR-4 and BWR-6, respectively. Actual frequencies would be less due to the lower probability of leakage at 1000 scfh. Again, the requirement for an LCS could not be defended on a valve-impact basis using a value of $1000/man-rem saved.

6.4 Anticipated Impact of the New Source Term on These Conclusions

The dose consequences of MSIV leakage scenarios were calculated using source terms based on TID 14844 (Ref.6.1). The TID inventory, representing a conservative estimate of the release to containment from a "maximum credible" core-melt accident, was assumed to be distributed uniformly throughout the containment atmosphere at a time corresponding to the beginning of core melting.

For modeling the transport and depletion processes that determine the release to the environment, certain physical, chemical and temporal characteristics had to be assigned to the inventory in containment. The principal assumptions concerned particle agglomeration and size distribution, time history of the accident, and chemical form of the radioiodines. The source term research results available at the time were carefully reviewed to determine the best-estimate values or conditions. In each case, values were selected that were consistent with the available data, but that tended toward conservatism. For example, the particle size distribution was weighted in the direction of smaller, more transportable particles by "turning off" the agglomeration function after about 20 minutes. Similarly, the continuation of the particulate release for the entire 30-day release duration implies a continuing generation of aerosols from the core, a condition that is very unlikely.

Finally, based on thermodynamic considerations, it was assumed that the radioiodine released from the core would be in the form of cesium iodide, a particulate. The most recent indication of the nature of a "new source term" described in NUREG-0956 (Ref.6.2) is that the iodine in the reactor coolant system will continue to be treated as cesium iodide, and the balance of the cesium will be treated as cesium hydroxide. It is therefore concluded that based on the reassessment of the Technical Bases for Estimating Source Terms, NUREG-0956 (draft), the character of the "new source term" is not likely to invalidate the work documented in this report. In fact, the probable ultimate impact of the source term work will be the refinement of some release assumptions used in this project, making possible the reduction of some of the uncertainties and conservatisms.

7. RESOLUTION OF GENERIC ISSUE C-8

7.1 Changes to Regulations, Regulatory Guides and Standard Review Plans

7.1.1 Regulations

In order to increase the allowable MSIV leakage rate by any significant amount, 10 CFR 50 Appendix J.III.C.3 should be changed to exclude MSIV leakage from the requirement that "the combined leakage rate from all penetrations and valves subject to Type B and C tests shall be less than 0.60 La." This is clearly preferable to granting individual exemptions to the Appendix J requirement.

The exclusion of MSIV leakage from the total could be accomplished by changing the definition of Type C tests found in Appendix J.II.H, or, preferably by changing Appendix J.III.C.3 to read as follows:

> "3. Acceptance Criterion. The combined leakage rate for all penetrations and valves, except boiling water reactor main steam isolation valves, that are subject to Type B and C tests shall be less than 0.60La." (Remainder of text unchanged).

Type C test methods, J.III.C.1, should be revised to allow cycling MSIVs and increasing actuator loading to attempt to get the valves to seal if an initial test indicates leakage exceeding the limit. Increasing actuator loading has been shown to overcome frictional forces between disk and seat, in many cases achieving a much lower leak rate. There is little doubt that an MSIV closing in response to a containment isolation signal at high steam flow would be effectively seated with a much greater force than the closing operator provides. If a valve can be made to seat satisfactorily by cycling it and increasing the operator loading to simulate closure with steam flow, there would appear to be little benefit to disassembling that valve.

The proposed change is to add the following statement to the end of the current Appendix J.III.C.1.:

> "Before leak rate testing, boiling water reactor main steam isolation valves may be closed using increased actuator loading to simulate closure under steam flow."

7.1.2 Regulatory Guides

The only existing regulatory guide with direct bearing on the MSIV leakage question is Regulatory Guide 1.96, "Design of Main Steam Isolation Valve Leakage Control Systems for Boiling Water Reactor Nuclear Power Plants." The analyses documented in this report indicate that alternate means of treating

MSIV leakage are likely to be available following a large LOCA and will be more effective than the LCS in mitigating offsite doses for the scenario examined. Therefore, Regulatory Guide 1.96 should be revised to incorporate the options proposed in the revised Standard Review Plan Section 6.7. A revised Regulatory Guide 1.96 is provided as Appendix I.

7.1.3 Standard Review Plans

Standard Review Plan Section 6.7 should be changed to provide an alternative to using an LCS. A proposed revised Standard Review Plan Section 6.7 is provided as Appendix J.

7.2 Changes to Technical Specifications

Technical specifications concerning the MSIV leak rate limits should be changed to reflect the conclusions of this investigation. Specifically, the leak rate specification should consider the potential offsite dose impact of MSIV leakage at the maximum allowable leakage rate. Several points that must be considered in setting the value are:

- When an MSIV fails a leak test by a modest amount (e.g., leak rate less then ~50 scfh) the licensee's report of maintenance required to restore the valve to its specified leak rate limit is frequently non-specific (such as "normal valve wear, lapped seat and disk," or "minor surface defects"). Reports on valves that failed with leak rates of more than 100 scfh more frequently cite specific defects (such as "debris under the seating surfaces" or "erosion of the stellited seat").

- The BWROG members reported that increased actuator loading frequently can provide an acceptable leakage rate for those valves that have a leakage rate less than 500 scfh. This implies that many LLRT failures at less than 500 scfh are due to the failure of the disk to seat fully when closed without steam flow or pressure, a condition that is not representative of those under which the valve would be challenged.

- Finally, the leakage specification for newly repaired or refurbished valves should be at or near the current 11.5 scfh. This value has been shown to be readily achievable and is indicative of a high quality repair and re-assembly effort. To substantially increase this limit would invite relaxation of maintenance standards and would remove the impetus for vendor and licensee efforts to improve the overall performance and reliability of the valves.

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APPENDIX A

Technical Evaluation Report
Review of BWR Owner's Group Recommendations
On MSIV Leakage

TECHNICAL EVALUATION REPORT
REVIEW OF BWR OWNER'S GROUP
RECOMMENDATIONS ON MSIV LEAKAGE

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September 1985

Prepared for
U.S. Nuclear Regulatory Commission
under FIN B25?9, Generic Issue
C-8, MSIV Leakage and LCS Failure

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CONTENTS

1.0 INTRODUCTION

1.1 PURPOSE OF REVIEW

This Technical Evaluation Report documents a review of data and analyses presented to the NRC by the Boiling Water Reactor Owner's Group (BWROG). The purpose of the review was to provide the NRC staff with an independent technical assessment of the BWROG data and recommendations concerning MSIV leakage and determine its relevance to the NRC's efforts to resolve Generic Safety Issue C-8.

1.2 BACKGROUND

Generic Safety Issue C-8 deals with the inability of some boiling water reactor (BWR) main steam isolation valves (MSIVs) to meet the technical specification leakage rate limit, which is typically 11.5 SCFH. This leakage rate limit was based on limiting the offsite dose consequences of MSIV leakage following a large Loss of Coolant Accident (LOCA).

In accordance with General Design Criterion 55 (Reference 1.2.1) the MSIVs in the main steam lines of a Boiling Water Reactor (BWR) are designed to isolate the Reactor Pressure Vessel (RPV) in the event of a steam line break downstream of the MSIVs, a design basis Loss of Coolant Accident (LOCA), or any event that would warrant containment isolation. The closure of the MSIVs should terminate any undue release of radioactivity from the RPV and ensure that the offsite radiological consequences do not exceed the guidelines of 10 CFR Part 100, "Reactor Site Criteria" (Reference 1.2.2).

Even though the MSIVs are designed to be leak tight they have experienced some leakage. In order to limit offsite doses, a leakage control system (LCS) has been required on most BWRs to collect leakage past MSIVs and direct it to the Standby Gas Treatment System. If the MSIV leakage is substantially above the technical specification limits, the LCS may not be effective because it is typically designed for flow rates only moderately in excess of the technical specification limits.

The NRC has contracted with Pacific Northwest Laboratory (PNL) to assist in the resolution of this Generic Issue. One aspect of the original PNL effort was to perform a literature search and to analyze the information collected to develop a correlation between valve design and maintenance practices, and the high leakage rates being observed. However, in response to the leakage problem the BWROG formed the MSIV Leakage Control Committee to determine the cause of the high leakage rates and develop recommendations for reducing them. The BWROG Committee completed their effort and provided their recommendations to the NRC on February 23, 1984. Because the BWROG initiated this effort independent of any suggestion from the NRC, and because the committee had access to documents which might not be available to PNL or the NRC, it was decided that the Committee's data base was probably better than could be developed by PNL and NRC. Therefore, PNL was directed to utilize the information already collected through the literature search to perform a review of the Committee's data base, methods and conclusions and provide a report to the NRC staff.

2.0 EVALUATION

The results of the BWROG MSIV Leakage Committee work was presented to the NRC as three separate reports. The three reports covered the collection and evaluation of MSIV leakage data, potential operator actions to control MSIV leakage, and an improved dose calculation method for consequence assessment. Each of the three reports is evaluated in this section. To objectively evaluate the reports, each has been divided, where possible, into topics or issues and the review of each topic is presented.

2.1 MAIN STEAM ISOLATION VALVE HISTORICAL DATA EVALUATION AND ASSESSMENT

2.1.1 Summary of the BWROG Work

The BWROG MSIV Leakage Committee solicited data on valve performance and maintenance history from its member licensees. The intent was to construct a data base from which conclusions could be drawn regarding the causes and likely solutions to the problem of excessive MSIV leakage. The data base included plant operational history and information on valve type, manufacturer, location, actuator type and other factors which the committee considered to have some bearing on MSIV performance.

A listing of potential contributing factors was generated by the committee. Possible correlations between the reported valve data and the contributing factors were then examined.

The committee concluded that the following were primary factors contributing to excessive MSIV leakage as indicated by failure of Local Leak Rate Tests (LLRTs):

1. improper maintenance,
2. valve orientation,
3. excessive clearance/seat-to-guide misalignment,
4. lack of concentricity (seat-to-poppet),
5. incorrect seat contact,
6. excessive coefficient of friction/corrosion.

The following were concluded to be secondary contributors, having a minor effect on leakage:

1. seat geometry,
2. inadequate actuator loading,
3. leakage sources other than the seat,
4. valve damage,
5. LLRT pressurization method,
6. closing procedure,
7. poppet rotation.

The following were concluded not to be contributors to failure of the LLRT:

1. pipe loading,
2. thermal distortion,
3. MSIV aging,
4. actuator/stem binding,
5. valve design differences,
6. foreign deposits.

The committee followed up these conclusions with recommendations that specific corrective and preventive actions be taken to counter the effect of the primary contributors. It recommended that specific actions be considered to deal with the secondary contributors, and that "no action beyond current practice" be taken with regard to those factors judged to be noncontributors.

2.1.2 Approach

The BWROG committee work was viewed as having three major aspects. They are:

1. data collection,
2. data assessment, and
3. recommendations.

To evaluate the data collection and assessment program and recommendations described in the BWROG report, PNL developed a checklist (Attachment 1) of

important evaluation parameters to structure the evaluation and yield the most objective overall judgment of the validity of the BWROG findings and recommendations.

2.1.3 Evaluation

2.1.3.1 Data Collection

Description. The committee sent summary data sheets to the BWR Owners Group for input to the data base. A total of four forms were requested. These forms called for plant contact information, valve description, and maintenance history.

The data base consisted of 18 plant contact records, 136 valve description records, and 586 maintenance history records.

The 586 maintenance history records documented repairs, in some cases dating from the early 1970s. The following is a list of plants and their owners that provided data.

Utility	Plant(s)
Boston Edison Company	Pilgrim 1
Detroit Edison Company	Fermi 2
Georgia Power Company	Hatch 1, 2
GPU Nuclear Corporation	Oyster Creek 1
Iowa Electric Light and Power Company	Duane Arnold
Long Island Lighting Company	Shoreham
Mississippi Power & Light Company	Grand Gulf 1
Niagara Mohawk Power Corporation	Nine Mile Point 1, 2
Northeast Utilities	Millstone 1
Northern States Power Company	Monticello
Pennsylvania Power & Light Company	Susquehanna 1, 2
Philadelphia Electric Company	Peach Bottom 2, 3; Limerick 1, 2
Public Service Electric and Gas Company	Hope Creek 1
Tennessee Valley Authority	Browns Ferry 1, 2, 3
Washington Public Power Supply System	WNP-2

PNL Findings. At the time of the data collection, there existed 26 BWR units with operating history in the United States. Although the Committee report states that the data base consists of "18 plant contact records," apparently only 14 of these plants had significant operating history at the time the data was collected.

A breakdown by BWR class type indicates that of the plants with operating history at the time of data collection, only the BWR-2, 3 and 4 classes were represented (2 of 2 BWR-2's, 3 of 7 BWR-3's and 9 of 16 BWR-4's).

The data base includes ten (10) utilities with plants operating during the data collection period. They had a total of three operating multiple (BWR) unit sites. Six utilities with operating BWRs which were not represented in the BWROG data base have an additional three multiple-unit sites.

Evaluation. Of the plants with significant operating history at the time of data collection, 14 of 26 units (54%) were represented in the data base. Although no BWR-1 class units are included in the data base this does not appear to be a significant shortcoming because of the small number of operating BWR-1 units (two), their small size and first-generation design. The first BWR-5 entered commercial operation during the data collection period and the owner utility was not a BWROG member. No BWR-6 units were in operation at the time of data collection. The three classes represented in the data base account for nearly 90% of the operating history (both in number of reactors and reactor years) at the time of data collection. The inclusion of data from three of the possible six operating multiple-unit sites in the data base is a positive attribute, because evaluation of leakage data for multiple unit sites provides an opportunity to assess the effects of consistent testing, maintenance and operating procedures.

From the committee's report, it is not entirely clear that the data base includes a representative sample of all valve vendor types. Nor is it clear that the valve description records and maintenance histories for all MSIVs were included in the data base, even if the valves consistently passed the LLRT. However, it can be inferred from the committee's conclusions and recommendations that valves from all three major vendors were included in the data base.

Conclusions. Based on this evaluation, it is concluded that the BWROG data collection process was adequate with regard to the amount and type of data collected. The number of plants, plant classes and the valves represented in the sampling give confidence in the validity of the data base.

2.1.3.2 Data Assessment

Description. The committee tabulated and sorted the data by plant, valve type, size, leakage performance, and corrective action taken in the past by plant personnel. The data base was reviewed and expanded through further requests for information and contacts with plant personnel.

Where feasible, plant personnel were interviewed to clarify questionable data and to gain a more thorough understanding of actual plant experience.

With the data collection and review completed, the technical group made use of the Kepner-Tregoe technique for analysis of the information.

This approach explored what the problem was, when it occurred, and how various aspects could be related. Potential causes were listed and analyzed, and a most likely cause (or causes) was determined. Corrective actions resulting from this analysis were then recommended.

The following is a list of potential contributors to MSIV leakage that was reviewed by the technical group.

1. seat geometry
2. pipe loading
3. thermal distortion
4. inadequate actuator loading
5. MSIV aging
6. leakage sources other than seat
7. actuator/stem binding
8. valve damage
9. valve design differences
10. LLRT pressurization method
11. closing procedure
12. foreign deposits
13. poppet rotation

14. improper maintenance
15. valve orientation
16. excessive clearances/seat to guide misalignment
17. lack of concentricity
18. incorrect seat contact
19. excessive coefficient of friction/corrosion

PNL Findings. The data assessment method used by the committee appears to a relatively straightforward correlation of observed valve leakage with other observed conditions (potential causes). Without a more detailed knowledge of the data base contents it is not possible to determine if other means of data analysis would have been more applicable.

Based on the reviewer's understanding of the Kepner-Tregoe technique, it may be appropriate to this application. However, the committee did not describe why this technique was selected instead of other analysis methods, what data was manipulated, or how the Kepner-Tregoe method was used. Thus no finding can be made regarding the reasonableness of this particular aspect of their analysis.

It is not clear from the report how the list of potential contributors was developed from the data base. Without a list of any other potential contributors that were considered and the technical justification for discounting them, there will always be some question about the completeness of the list.

Conclusions. Because little detail was provided on the data evaluation process, it is not possible to independently confirm the adequacy of the committee's data analysis. The fact that the analysis identified as primary contributors several factors that are intuitively believable causes of leakage (valve orientation, improper maintenance), suggests that the process yielded satisfactory results. It is therefore concluded that the data analysis was probably satisfactory, and that there is a good probability that the primary contributors to excessive MSIV leakage were identified. However, because of the nature of the data and the analysis described in the committee report, there is a significant likelihood that only a small amount of additional data might have provided the basis for elevating a noncontributor to secondary

contributor status, or even a secondary contributor to primary. For this reason, the classifications should not be considered "frozen" but should be re-evaluated as further information is available.

2.1.3.3 BWROG Recommendations

With regard to Category 1, Noncontributors, the committee recommended that no action be taken beyond current practice.

With regard to Category 2, Secondary Contributors, the committee recommended that the following actions be considered.

1. Seat Geometry
   Care should be taken to maintain the as-manufactured seat geometry. Any contemplated changes should be carefully assessed and analyzed to ensure that the changes will not be detrimental to valve performance.

2. Inadequate Actuator Loading
   Care should be taken to ensure that the design operating pressure for the actuator is maintained properly. Further, consideration should be given to increasing actuator operating pressure for valves exhibiting marginal LLRT failures.

3. Leakage Sources Other Than Seat
   Care should be taken to correct or isolate any identifiable leak paths before LLRTs are performed.

4. Valve Damage
   For those failures related to maintenance, attention should be devoted to careful maintenance supervision and inspection to reveal any incipient failures.

5. LLRT Pressurization Method
   Wherever feasible, consideration should be given to applying the LLRT test pressure in the direction of steam flow for all valves being tested or compensating for decreased seat loading on the inboard valves when pressurizing between valves.

6. Closing Procedure

Inasmuch as it may be beneficial to close the MSIVs with some steam flow and reactor pressure prior to cold shutdown, the individual plants should review the feasibility of this operation and justify that this condition bounds postulated to occur during operation.

7. Poppet Rotation

Considerati , should be given to preventing possible poppet rotation by installing an appropriate anti-rotation device to preclude possible guiding surface wear.

With regard to Category 3, Primary Contributors, the committee recommended that the following actions be taken.

1. Improper Maintenance

Care should be taken to ensure that maintenance equipment, procedures, and personnel are effective in providing the services required to prevent latent detrimental effects on the valve. For example, equipment planned for use should be checked out thoroughly prior to use, procedures should be proven, and personnel should be trained adequately.

2. Valve Orientation

In view of the increased risk of LLRT failure for rolled valves (those valves installed with the stem not in the vertical plane through the valve centerline), care should be exercised to ensure correct poppet-to-seat alignment. If this alignment proves problematic, the compensation (i.e., modification of dimensions) should be considered.

3. Excessive Clearances/Seat-to-Guide Misalignment

In the event conditions indicate that excessive clearances or misalignments exist, accurate measurements should be taken to determine the extent of these conditions. Should it be determined from these measurements that in fact such a problem exists, action should be considered to establish optimum conditions. This should involve consultation with appropriate suppliers or manufacturers.

4. Lack of Concentricity, Incorrect Seat Contact, Excessive Coefficient of Friction/Corrosion

   Due to the critical nature of the interaction of these conditions, it is recommended that great care be taken in ensuring proper concentricity, providing correct seat contact, and minimizing friction to the extent feasible. In the event that any of these conditions prove to be problematic, efforts should be taken to mitigate their effects. For example, buildup of various guide surfaces has been employed and appears effective in some cases for correcting poor concentricity and providing correct seat contact. With proper guidance, the negative aspects of friction are minimized.

PNL Findings. It was reported in Reference 2.1.1, "of MSIVs provided by three different manufacturers, one particular type of valve dominated the extreme leakage incidents. About 60% of the MSIVs in service are provided by this manufacturer." If one valve is more susceptible to leakage than another, or if one valve has a consistently greater magnitude of leakage, then differences in valve design would clearly appear to have a safety significance.

Evaluation. The committee recommend actions to correct or mitigate the effects of each primary and secondary contributor. However, the apparent superior performance of the Crane valve design (ball and cone seat geometry) was not mentioned. No recommendations that are specific to a given valve type were made. With the data available to the committee, some valve-specific recommendations might have been expected.

Also, as regards recommendation number 3 under Category 2 (leakage sources other than seat), it is not explicit that this recommendation is directed at correcting leak paths outside the MSIV itself. Identified extraneous leak paths such as steam line drains should be corrected before testing, but the MSIVs should be tested in the as-found condition.

Conclusions. The committee recommendations are generally consistent with their findings as regards the causes of MSIV leakage. If the classification of contributors is correct, the implementation of the committee recommendations should substantially reduce the incidence and magnitude of LLRT failure. The

major unresolved issue surrounding the committee recommendations is the translation of the general recommendations into plant and valve-specific recommendations and procedures. No information on this has been provided by the committee.

2.1.4 Overall Conclusions - Data Collection and Evaluation

It is concluded that the BWROG Committee data collection effort provided an adequate basis for the solution of the MSIV leakage problem. The sample size, both in number of plants and valve history (operating years) represented gives confidence that the data are representative. The only significant issue of concern is whether there may be non-BWROG plants with a history of serious valve leakage which, if included in the data base might alter the conclusions with regard to ranking of contributors. This concern could be reduced by releasing the results of the BWROG study of all licensees and specifically asking each non-BWROG licensees to provide a subjective assessment of the BWROG ranking of contributors based on their own experience. This could highlight areas of possible uncertainty in the contributor ranking, especially if any non-BWROG licensees feel that they have "solved" their leakage problem by means which are not related to the committee's primary or secondary contributors.

2.2 RECOMMENDATIONS ON POTENTIAL OPERATOR ACTIONS

2.2.1 Summary of BWROG Work

The BWROG report "Potential Operator Actions to Control MSIV Leakage" evaluated ten (10) symptomatic conditions which would or could provide an indication of fuel failures and MSIV leakage. These conditions, summarized in Table 1, were further categorized into three major groups:

- Group 1: Those directly symptomatic of conditions for which control of MSIV leakage is appropriate.
- Group 2: Those symptomatic of conditions for which control of MSIV leakage may be appropriate, and
- Group 3: Those not appropriate for MSIV leakage control.

Only Groups 1 and 2 were addressed by the BWROG Committee as being of any significance to the MSIV leakage problem. Three of the ten symptomatic conditions were categorized in Group 3. While all were considered to be of

TABLE 1. Summary of Potential Symptomatic Conditions for Which Control of MSIV Leakage may be Appropriate

Symptomatic Conditions Considered	Group 1 Appropriate	Group 2 may be Appropriate	Group 3 not Appropriate
• High main steam line radiation	X		
• High area radiation level near the main steam lines	X		
• High control room air intake radiation		X	
• High offsite radioactivity release rate		X	
• High secondary containment HVAC exhaust radiation		X	
• High turbine building HVAC radiation		X	
• High offgas pretreatment radiation		X	
• High drywell pressure			X
• High drywell radiation			X
• Low RPV water level			X

great significance to overall plant safety and also were entry conditions into the Emergency Procedure Guidelines (EPGs), they provided no direct correlation to MSIV leakage and were not evaluated for potential operator actions in this report by the BWROG. Of the remaining seven symptomatic conditions two were categorized in Group 1, (directly related to MSIV leakage) and the other five were categorized in Group 2, (possible consequences of MSIV leakage).

Next, the most probable leakage pathways were decided upon by the BWROG. They can be summarized in the following three major types or subpaths:

1. All systems and subsystems intact,
2. Steam line breaks in containment, and
3. Steam line breaks outside containment.

For each potential operator action, consideration was given to each of the above flow paths with discussion of the methods of radioactive release treatment.

Once the BWROG defined the important indications of MSIV leakage and the most probable flow paths for radioactive leakage, they proceeded to examine potential operator actions which would minimize the dose contribution due to MSIV leakage. The BWROG defined nine potential actions, summarized in Table 2, which will reduce the dose consequences of MSIV leakage. Each potential operator action was evaluated for its effect on reduction of radioactive releases from the plant, feasibility of implementation, other benefits, drawbacks, and consistency with the Emergency Procedure Guidelines (EPGs).

Following the completion of the classification of the ten (10) symptomatic conditions and nine (9) operator actions, the BWROG provided direction for modifying the existing Generic Emergency Procedure Guidelines, (Rev. 3, BWR 1 through 6, December 8, 1982). The operator action guidelines were prioritized in three categories:

- control and treat any MSIV leakage,
- contain any MSIV leakage in the main steam system, and
- control the release of any MSIV leakage when containment is not possible.

2.2.2. Approach

The reviewers evaluated the BWROG work by examining the following: 1) the list of symptoms for which MSIV leakage control may be appropriate to determine if the list was complete and consistent, 2) the flow paths identified as being of interest to the control and management of MSIV leakage, 3) the proposed operator action strategies to determine if the actions would be effective in controlling release, whether they could be readily implemented, and if they introduced any other significant operational problems, and 4) the proposed EPG changes to implement the operator action strategies at the appropriate time.

Each area was examined individually and as part of the whole for completeness, internal consistency and effectiveness in accomplishing the stated goals.

TABLE 2. Summary of Operator Actions Considered for MSIV Leakage Control

Operator Action Considered	Recommended	Not Recommended
• Operation of the offgas system	Plant-specific	
• Operation of the mechanical vacuum pump		X
• Containment within the main steam system		
- Closure of main turbine stop, control and bypass valve, and isolate main steam lines	X	
- Isolate main condenser and establish turbine seals	Plant-specific	
• RPV depressurization to the suppression pool	X	
• Flooding of the main steam lines		
- Upstream of the MSIVs		
- By flooding the RPV		X
- With clean water source	X	
- Back-filling from main condenser	Plant-specific	
- Downstream of the MSIVs		
- With clean water source	Plant-specific	
- Back-filling from main condenser	Plant-specific	
• Pressurization between the MSIVs		
- With air		X
- With nitrogen	X	
- With clean water source	X	
• Treatment/containment within the plant buildings		
- Operate secondary containment and turbine building HVAC. On high exhaust radiation, confirm HVAC isolation and start SBGT	X	
- On high air intake radiation, start control room HVAC pressurization mode	X	
• Utilization of the MSIV-LCS	Plant-specific	
• Flooding the primary containment		X

2.2.3 Evaluation

2.2.3.1 Symptomatic Conditions

The BWROG looked at 10 symptomatic conditions for which MSIV leakage may be appropriate. Of the ten (10) conditions, eight (8) dealt with radioactive steam (i.e., fuel failures) and the other two (2) dealt with potential situations which could lead to fuel damage (i.e,. low RPV water level and high drywell pressure.

The BWROG addressed only single symptomatic conditions in their evaluation. While this is a valid approach, more than one of the symptoms could exist following an accident, so efforts should be directed towards assessing combinations of symptomatic conditions. An example of this may be high drywell radiation, (which in most plants doesn't close the MSIVs), and increasing secondary containment radiation. In this particular instance the operator may want to consider closing the MSIVs in hopes of stopping further release of radioactivity into the secondary containment.

In the BWROG report on page 27 the author states "Area radiation monitor locations near the main steam lines are plant specific and some plants may not have area monitors close enough to the main steam lines to warrant action on this condition. Additional monitors could be added should these operator actions be judged warranted." This comment was in reference to a Group 1 item, (high area radiation level near the main steam lines) which the BWROG states, on page A-1, is a condition for which MSIV isolation is appropriate. If this is the case, then backfitting the area monitors should be considered if they are not already installed.

2.2.3.2 Flow Paths

As stated above, the leakage flowpaths can be categorized into three (3) major types; all systems intact, in-containment steam line breaks, and steam line breaks outside containment. The following systems were considered as being functional during some part of the BWROG evaluations;

1. Offgas system/main condenser
2. Auxiliary steam system
3. Mechanical vacuum pumps

4. Main turbine stop, control, and bypass valves
5. Main steam drain system/MSIV-LCS
6. SRVs
7. Turbine building HVAC
8. SGTS
9. Control Room HVAC

The above systems were used during the discussion of the potential operator actions analysis in a number of different configurations to achieve the most effective mitigation of the radioactive release. The systems were selected for use depended on the size, location, and type of leakage that existed.

Systems not considered but of some value in reducing either the driving pressure or the amount of radioactive release are the emergency core cooling systems (ECCS):

1. HPCI/HPCS
2. RCIC
3. Containment atmosphere control
4. Containment/drywell/suppression pool cooling or spray
5. LPCS/LPCI

These systems are Class 1E systems and thus, electrical power for them should be available for use in mitigating the severity of the event and reducing the radioactive release. The high pressure systems could be used in reducing the steam line pressure prior to depressurization, while the low pressure systems could provide the additional function of condensing the steam in the drywell/containment following depressurization. It is not clear why some consideration was not given to the ECC systems.

2.2.3.3 Potential Operator Actions

Table 2 contains the nine (9) potential operator actions that were evaluated by the BWROG as being capable of reducing MSIV leakage. Each potential operator action was discussed by the BWROG as follows:

1. Potential Operator Action - a description of the action and how it was to be carried out.

2. Flow Path for any Potential Release - the most probable flow paths considering various leak locations and size.

3. Benefits of the Action - the potential benefits of performing this action.

4. Drawbacks of the Action - any potential drawbacks to performing this action.

5. Ability of Plant to Implement - how the action was to be implemented at various facilities.

6. Feasibility and Merit of EPG Integration - any difficulties associated with the integration of the action into the current EPGs.

Of the nine suggested potential operator actions, seven were recommended by the BWROG for integration into the EPGs, with only three being totally independent of plant-specific design features. Since the other four operator actions are dependent upon the design of systems that exist at a given site, some order of preference needs to be stated. If it is determinated that one potential operator action is significantly better than another, the desirability of making the necessary backfit at the other sites should be examined (i.e., auxiliary steam to maintain the operability of the offgas system).

The report provided a description of possible approaches available to the operator during an accident, as well as identifying secondary concerns the operator should address.

2.2.3.4 Suggested EPG Changes

In Appendix A of the BWROG report, a method was described by which the EPG could be changed to incorporate MSIV leakage effects. The currently existing EPG MSIV leakage control steps were presented along with the changes recommended in the report (Reference 1.2.3). A comparison of the BWROG suggested changes and the current EPG was made, and an evaluation follows.

There is no guidance in the BWROG EPG recommended changes as to how to incorporate the entry conditions into the existing EPGs. For example on page A-1 of the BWROG document gives two (2) entry conditions as existing in the

EPG. Using these entry conditions would put the operator into two different locations in the EPG, the Secondary Containment Control or Reactivity Release Control Guidelines. According to the potential operator actions it is the intent of the BWROG to incorporate the changes into the Radioactivity Release Control Guidelines of the EPG.

The current EPG, Rev. 3 includes as an entry condition to the Secondary Containment Control Guidelines "an area radiation level above the maximum normal operating radiation level." This entry condition was either overlooked by the analysis of symptomatic conditions or lumped into "high area radiation level near the main steam lines." If this is the case some discussion is needed as to why the current EPG entry condition was not considered in their recommended changes.

The prerequisites proposed in the EPG changes which already exist in the current EPG are located in the Secondary Containment Control Guidelines portion of the EPG. It should have been stated that these items will be duplicated in the Reactivity Release Control Guidelines section of the current EPG.

No reference was made in the proposed EPG changes to "an offgas pretreatment radiation level above the maximum normal operating radiation level" even though it was listed as an entry condition to this procedure.

The BWROG proposed the following order for the containment and reduction of MSIV leakage:

For Containment Control

1. Isolate MSIVs
2. Operate offgas system (SJAE), if possible
3. Depressurize vessel
4. Contain leakage in main steam lines
5. Initiate MSIV-LCS, if available
6. Pressurize between MSIVs with nitrogen
7. Fill between MSIVs with water

For Secondary Containment and Control Building Control

1. Isolate associated HVACs

2. Initiate SBGT

3. Initiate pressurization mode for control room HVAC.

The BWROG did not include in their proposed changes the "Flooding of the main steam lines" upstream or downstream of the MSIVs even though they considered it to be a viable and recommended operator action. In the potential operator action discussions, page 16, it states that this action could be incorporated in either the Radioactivity Release Control Guideline or in EPG Contingency 6, RPV FLOODING sections. This item shows an inconsistency in the text between the discussion and implementation.

The BWROG did not demonstrate that the proposed EPG changes did not adversely impact the other EPG guidelines.

2.2.3 Conclusions

In general, the BWROG provided the necessary support for the recommendations presented in this document. The document provided a good overview of the initiating conditions, leakage flow paths, potential operator actions, and necessary changes to the EPGs. Some additional work appears to be needed in the areas of symptomatic conditions as well as the interaction of the potential operator action with overall performance. Also useful would be a discussion from the BWROG point of view of the feasibility of enhancing the capability of the existing plants to make possible those plant-specific operator actions which are demonstrated to be superior in controlling the leakage problem. Finally, if changes to the current EPG Radioactivity Release Control Guidelines are to be made, a study of the interactions with the other EPGs and associated problems should be performed.

2.3 IMPROVED DOSE CALCULATION METHOD

2.3.1 Summary of BWROG Work

This method was developed by General Electric for the BWROG to provide a more realistic, yet conservative, evaluation of control room and offsite dose consequences compared to the methods utilized in previous FSAR analyses. It is

expected that plant-unique analyses using this model will show that MSIV leakages significantly in excess of technical specifications do not constitute a safety problem.

As directed by the BWR Owners Group, the model was based on a non-break, isolation transient with all piping downstream of the MSIVs to the turbine-condenser assumed intact. Principal fission product attenuation mechanisms considered in this model which have not been previously considered are: 1) flow discharge through the Safety Relief Valve (SRVs) , 2) plateout of particulates in the reactor vessel, steamlines, bypass lines, and condenser, and 3) decay of fission products while in transit.

The basic model employed is a three-compartment model for offsite dose calculations or a four-compartment model for a control room calculation. The model may also be divided into three areas of calculation: 1) reactor pressure vessel response, 2) ex-vessel transport, and 3) dose calculations. As derived, the model is a combination of empirical data and analytical equations. The empirical data can be changed without invalidating the model if more precise information becomes available.

2.3.2 Approach

The BWR Owner's Group Report NEDO-30259, A Technique for Evaluation of BWR MSIV Leakage Contribution to Radiological Dose Rate Calculations (Reference 2.3.1), presents the model in three parts: 1) the in-vessel model, 2) the plant transport model, and 3) the dose model. The accident scenarios are appropriately presented along with the in-vessel model. We will follow a similar breakdown in discussing the methods presented.

2.3.3 Evaluation

2.3.3.1 In-Vessel Model

The Owner's Group picks as their accident scenario a nonbreak isolation event with delayed recovery of water makeup. BWR nonbreak transients with a makeup water/heatload imbalance include, in the nomenclature of the Reactor Safety Study (Reference 2.3.2), the sequences TC, TW, TQUV, TPE, and TPI. In these sequences, the release pathway of radionuclides prior to possible vessel head failure is as shown in Figure 1, which is taken from Gieseke, et al.,

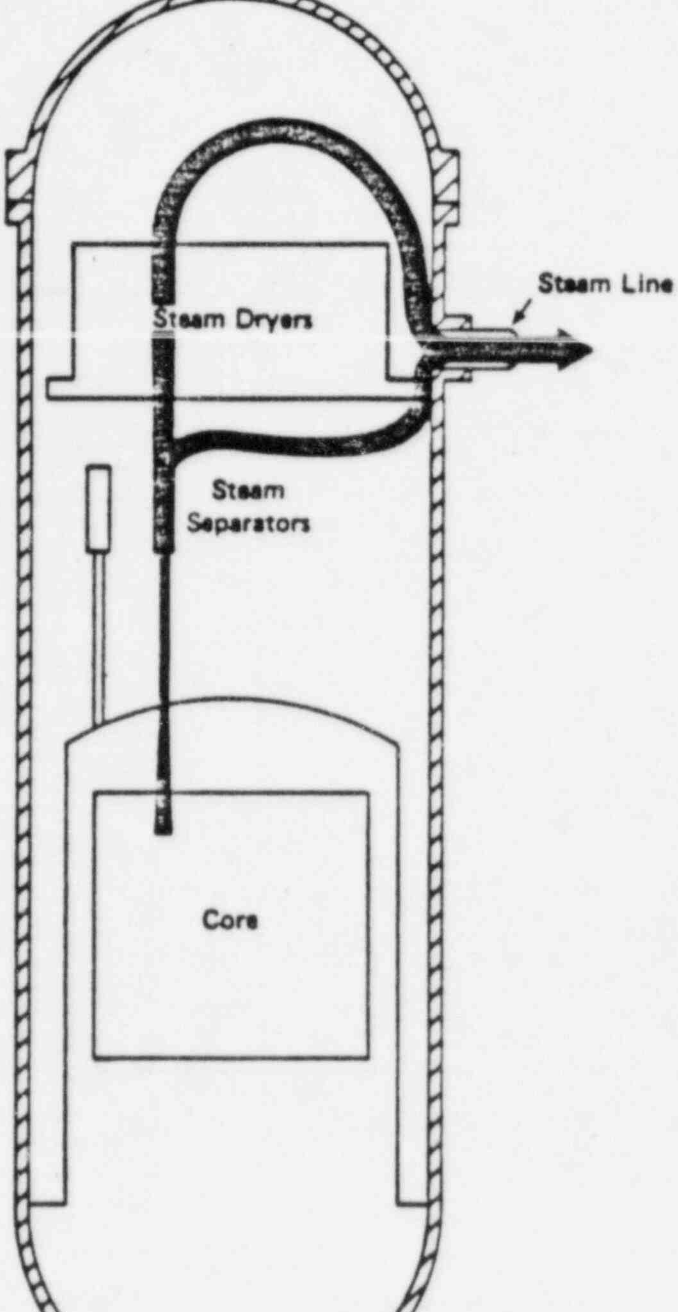

Figure 1. Flowpaths for Fission Product Transport in Non-Break Reactor Safety Study Sequences TC, TQIV, and TPI for BWRs. (Taken from Reference 2.3.2.)

Radionuclide Release Under Specific Accident Conditions, Vol. 3, BWR, Mark III Design (Reference 2.3.3). The release path continued from the figure would proceed either through the MSIVs or through the suppression pool, wetwell and, by some means, through containment. Depressurization would be achieved through the safety release valves (SRVs), as assumed in the Owner's Group report (Reference 2.3.1). If makeup water is completely recovered in time to avoid problems overshadowing MSIV leakage, e.g., vessel failure, then many changeovers of reactor pressure vessel (RPV) steam do occur in the recovery and post-recovery periods, as postulated in the document. The many changes of RPV steam give a huge decontamination effect in the model by flushing released radionuclides to the suppression pool. However, it must be asked if there are any accidents relevant to MSIV leakage for which this flushing does not occur. If the delivery of makeup water is not only delayed but also impaired for an extended period, so vessel failure is only marginally avoided, it would seem that lower levels of flushing and longer releases are possible.

Of interest to consider is the category of accidents involving a break inside containment with impaired ECC response, especially a recirculation line break. Accidents in this category in the nomenclature of the Reactor Safety Study (reference 2.3.2) are (A, S_1, S_2)E; (A, S_1, S_2)J; and (A, S_1, S_2)I. Here A indicates a large break, with S_1 and S_2 successively smaller breaks. The primary release pathway of the steam and radionuclides from the RPV is shown in Figure 2, taken from reference 2.3.3. The primary release to the environment, however, may occur through the steam line and MSIVs. Steam generated in recovery or post-recovery might exit from the break without contacting or diluting radionuclides in the steam dryers or upper dome. If we combine this less effective scrubbing geometry with a hypothesis of water added being marginally enough to forestall vessel failure, we see a possibility of a prolonged release of greater quantities of radionuclides than given by the Owner's Group model.

For the large in-containment break cases (AE, AJ, AI), the pressure driving the MSIV leakage will be lower, but the steam scrubbing would be less than for small- or no-break cases. For the small-break cases (S_2E, S_2J, S_2I), the pressure will be higher but possibly controllable by opening the SRVs,

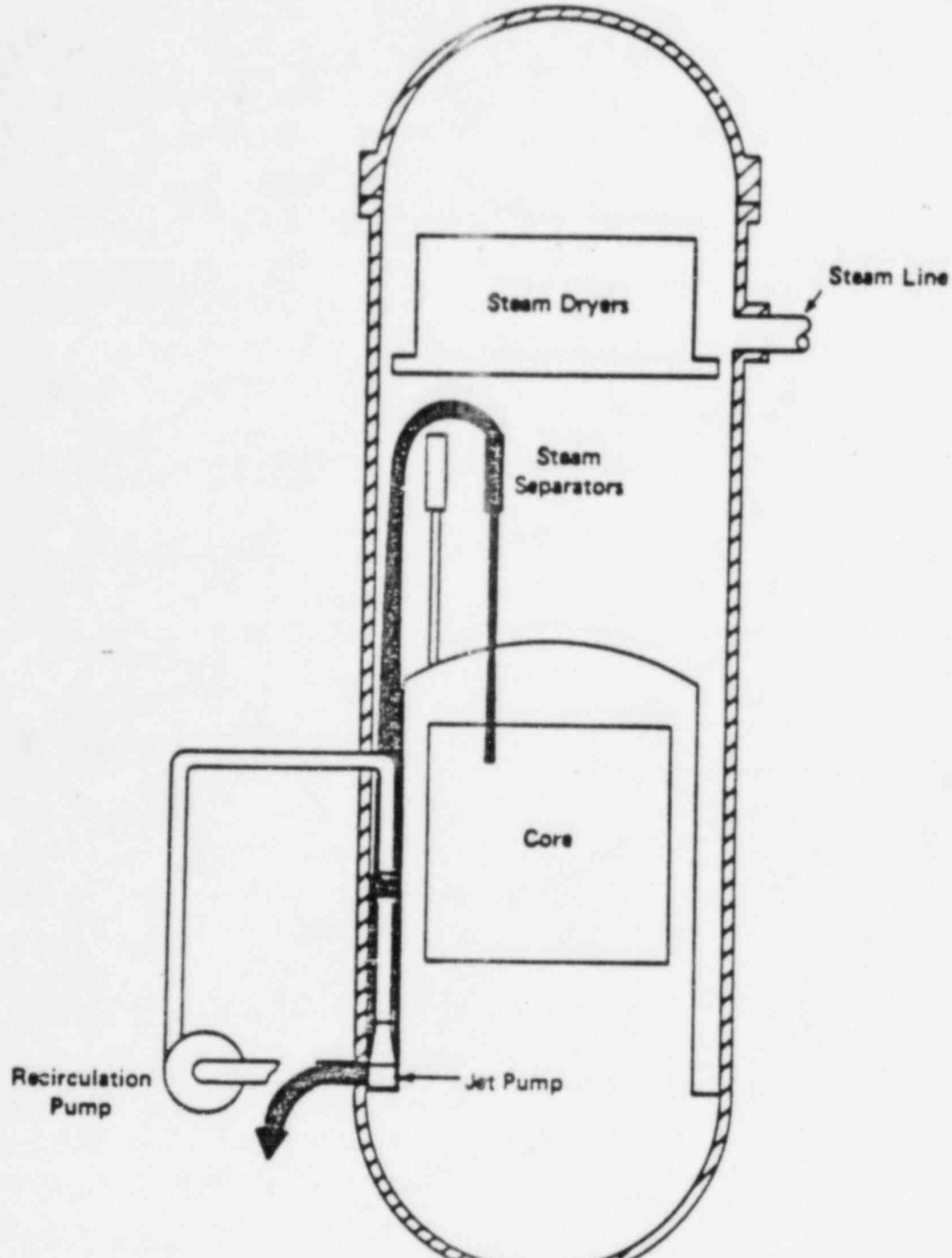

Figure 2. Flowpath for Main Fission Product Transport from Recirculation Line Break in a BWR. (Taken from Reference 2.3.2.)

thereby approximating the conditions and assumptions in the Owner's Group model. Some intermediate size recirculation line break may be a "worst case" for MSIV leakage, particularly if the SRVs do not operate, in that a significant pressure drives the leakage, but less efficient scrubbing occurs. Some compensation may be realized by reduced MSIV leakage due to the valves having closed with pressure assisting the seating of the poppets.

For the recirculation line breaks, the time to onset of release of volatile fission products could be less than the t_0 = 40 minutes value recommended, though 40 minutes is a good estimate of time to major releases. This does not affect the remainder of the analysis, but has some effect on releases of short-lived radionuclides.

Revolatilization during recovery and post-recovery of some of the radionuclides sent to the suppression pool is a possibility, depending on the source of the restored cooling water. The high pressure core spray (HPCS) system, for example, draws first from the condensate storage tank, then from the suppression pool. The low pressure core spray (LPCS) system draws directly from the suppression pool. The reactor core isolation cooling (RCIC) system draws first from the condensate tank, then from the steam condensed in the residual heat removal (RHR) heat exchangers, then from the suppression pool. While the concentration of radionuclides in the suppression pool is not likely to get very high, use of recycled suppression pool water in the RPV is likely to preclude the multiplication of RPV radionuclide inventory by 2.6×10^{-7} in 20 minutes predicted by the Owner's Group model.

We note the typographical error in Equation 1 of Reference 2.3.1. The quantity A on the right-hand side should be a simple additive term, not divided by the denominator that divides the rest of the right-hand side expression.

The procedures and equations in Step 2 and Step 3 represent a needed attempt to estimate simply the steam production during a "dramatic recovery" with complete makeup water restoration. Presumably, account is taken of sensible heats, heats of fusion, heats of vaporization, and energy released in zirconium-water reaction. We have been unable, however, to reproduce the thinking of the authors (combining energy balance, conservation, correlations,

and approximations) to arrive exactly at Equations 1 and 2. A little explanation would probably clarify the content of these two equations.

The validity of Equation 3 implemented in the example for the post-recovery steaming rate depends on that post-recovery period (for purposes of radionuclide leakage) being short, i.e. on the order of 20 minutes. The implementation in the example and the suggestions of Step 4 makes the approximation that the post-recovery steaming rate is that produced by the decay heat power 20 minutes into the recovery period. Thus the steaming and hence the flushing to the suppression pool could be overstated after 20 minutes. With the "dramatic recovery" assumption the decay heat would be removed as sensible heat without much steaming after a period on this order, and the restoration of sprays would shortly clean the RPV atmosphere. For a marginal recovery (if such is possible), this overstatement of steam flushing might be significant.

2.3.3.2 Plant Transport Model

The Owners' Group model (Reference 2.3.1) treats plant transport of radionuclides as flow between a very small number of compartments, lumping many of the removal processes both in and between compartments into "filtration factors" on the radionuclide transport between compartments. This is a reasonable approximation, but we believe a somewhat more elegant and more accurate treatment can be had with a rather modest additional effort. Describing the evolution of compartment radionuclide contents with differential equations and then solving them as done by the Owners' Group is certainly to be commended.

Equation 4 and the defining relations which follow it give the radionuclide inventory in the RPV in the model. The overwhelming size of the SRV removal term L_s $\lambda 1$, in compared with the radionuclide decay constant λ and the MSIV leakage term L_m in the calculated sample, show what a tremendous share of the decontamination is being attributed to the radionuclide transport to the suppression pool, i.e., multiplication of the RPV inventory by 2.6×10^{-7} in 20 minutes of post-recovery steaming in the example. Setting the radionuclide evolution rate S to zero in Equation 4 neglects any re-entrainment or continuing emission of radionuclides that may be occurring. While the rate of new emissions during the late recovery and post-recovery phases may be small,

these new emissions will have missed most of the changes in RPV steam which give the extremely rapid depletion in the Owners' Group model.

Equation 6 and subsequent equations and procedures in Step 6 (as implemented in the example) for the radionuclide inventory in the turbine/condenser account for the effects of plateout and time delay between reactor pressure vessel and condenser in an ad hoc way. The "filtration factor" f_{pipe} for plateout in the pipes is an adequate expression for plateout in steady-state flow. The expression given for the deposition velocity V_d on page 2-16 is an empirical one for deposition of molecular iodine I_2 and HI on stainless steel (Reference 2.3.4) rather than a settling velocity for cesium iodide particulates. The deposition velocity for particulates is likely to be higher for sizes down to the order of 0.1 micron radius. The use of

$$f_{pipe} = \exp\left(- A_d V_d / A_c V_B\right)$$

and

$$V_d = 9.0 \times 10^{-8} \exp\left(8100/RT_s\right) \text{ cm/sec}$$

makes the removal by deposition in the pipe small. If the evidence continues to favor aerosol as the iodine emission form, we suggest the use of a size-dependent gravitational settling velocity and a spectrum of particle sizes rather than the more conservative iodine vapor deposition velocity.

Implied in the discussion of Step 6 and in the example for Steps 5 and 6 is the use of a delay for transit time through the steam lines to the condenser. This delay time is calculated as the transit time through the main steam lines (both inside and outside the containment) and turbine bypass line in a plug flow model. This calculation would give an estimate of the effective transit time if the flow persisted long enough to give an effectively steady-state concentration in the steam lines, but it gives erroneous and nonconservative results when applied to the "filling transient" in the main steam lines. Because of axial convection in the main steam lines, the first arrival of radionuclides at the condenser will probably occur much faster than

estimated by this transit time. The convection which gives this enhanced propagation of a radionuclide contamination front is generated by nonuniform cooling of the steam lines in the vicinity of the pipe supports and steam taps for various steam drawoffs. High concentrations of radionuclides (depleted only by deposition and decay) do arrive at the condenser in a time on the order of the Owners' Group model delay time, but smaller concentrations will have arrived much sooner. Also, the pressure cycling for the SRVs may give surges in the part of the main steam line between RPV and MSIVs which reduce the effectiveness of this part of the line in giving a delay.

Equations 6 and 12 of Reference 2.3.1 imply that the leakage rate from the condenser is determined by the MSIV leakage rate into the condenser. (We assume that V in Equation 12 is the same as that defined just after Equation 5). For scenarios of greatest interest, the volume leakage rate from the condenser is almost independent of the leakage rate into the condenser. Most of the steam leaked into the condenser should condense there except at extremely high MSIV leakage rates. The noncondensible gas content of the in-leakage to the condenser might eventually, under some conditions, drive an outleakage. A greater contributor to outleakage from the condenser, however, should be the barometric pressure changes (or, to a lesser extent, temperature changes) which cause the condenser to "breathe" through the leaky turbine seals or any other condenser leaks.

As for the contribution of condensible gases to the condenser outleakage, we see no basis for the prescription following Equation 13, but we believe it to be a conservative treatment of that contribution. Again, however, we think that other phenomena override it as a contributor to condenser leakage.

For a "pumped" condenser, of course, a condenser outflow characteristic of the pumping should be used. The outflow would then not be to the turbine building.

We trust that no confusion will result from the use of S_2 with a different meaning on the two sides of Equation 6. Presumably something like S_2^1 was intended on the right-hand side of Equation 6 and in the definition four equations later.

The two items which might be controversial in the evaluation of the radionuclide inventory in the turbine building are: 1) the term L_2 (presumably the same as L_c) for flow into the turbine building from the condenser, and 2) the removal factor F_2 to account for particle settling in the condenser. As previously mentioned, condenser outflow may be enhanced by "breathing" of the condenser, requiring a higher L_2 or L_c. Additional information concerning the F_2 expression would be necessary before concurring with its adequacy.

We note that Equation 15 is referred to as a removal fraction for particulate forms, even though the earlier expression for deposition velocity V_d in the steam lines was appropriate to molecular I_2 and HI.

If a closed compartment contains a well-mixed suspension or contaminant vapor that is depositing on a deposition area A_d with a normal deposition velocity V_d, then the airborne concentration C has a time dependence given by

$$C = C_o \exp\left(-\frac{V_d A_d}{\tau} t\right)$$

where C_o is the concentration (contaminant per unit volume) at time zero, t is the elapsed time, and τ is the volume of the compartment. The values of $V_d A_d/\tau$ should be compared with the value 0.92/hr used in the Owners' Group model expression

$$F_2 = \exp(-0.92t)$$

For the reference plant we have

A_d = 252,000 ft^2 horizontal deposition area
τ = 120,000 ft^3 condenser volume

A collection of particle gravitational settling velocities calculated for moist air at 40°C and the corresponding values of $V_d A_d/\tau$ for the reference condenser appear in Table 1.

TABLE 1. Gravitational Settling Velocities and Gravitational Settling Decay Constant $V_d A_d/\tau$ for the Reference Condenser

Particle Radius (microns)	Settling Velocity (ft/hr)	Settling Aerosol Decay Constant $V_d A_d/\tau$ (hours^{-1})
0.184	0.209	0.44
0.331	0.577	1.21
0.594	1.686	3.54
1.07	5.164	10.8

From Table 1, we see that the gravitational settling aerosol decay constant 0.92/hr is appropriate for particles of radius on the order of 0.25 microns, with larger particles settling more rapidly and smaller particles settling less rapidly. Most aerosol particle mass will lie in the radius range covered in Table 1. One might expect the early deposition to occur more rapidly than given by the equation for F_2 with decay constant 0.92/hr, but later deposition after larger particles have settled may occur less rapidly. A more precise dependence of aerosol concentration on time can be generated using a particle size spectrum. The expression F_2 is correct for an order of magnitude estimate, however.

The treatment of settling in the condenser is ad hoc, however, since it lumps the effect into a "filtration factor" and requires the use of a somewhat arbitrarily chosen aerosol "age".

The quantity Q of radionuclides released from the turbine building (Figure 2-4 in Reference 2.3.1) assumes the same level of treatment as the preceding release and inventory expressions. The "filtration factor" F_3 is presumably taken as near unity. The control room integrated activity expression depends for its accuracy on the accuracy of χ/Q and on the accuracy of the calculated releases from the turbine and turbine building.

Alternative Plant Transport Model

An alternative to the Owners' Group model which avoids ad hoc use of delay times, filtration factors, and aerosol age is to write differential equations for the quantity of volatilized radionuclides of a given form in each of a series of connected compartments:

$$\frac{dN_j}{dt} = \dot{v}_j^{(1)} C_{j-1} - \dot{v}_j^{(2)} \frac{N_j}{V_j} - \lambda N_j - \sum_m (A_j^m V_j^m) \frac{N_j}{V_j}$$

Here $\dot{v}_j^{(1)}$ and $\dot{v}_j^{(2)}$ are volume flow rate into and out of the j-th compartment, C_{j-1} is the concentration of this form of release in the compartment ahead of the j-th, λ is the radionuclide decay constant, and V_j^m and A_j^m are the deposition velocity and deposition area, respectively, of the m-th deposition process in the j-th compartment.

If one takes a piecewise constant concentration C_0 in the zeroth or source compartment (reactor pressure vessel), one can obtain explicit solutions to this set of ordinary differential equations for a large number (say 10 to 30) of compartments, not just the four or so used in the Owners' Group model. This allows a "fill transient" in the steam lines without the use of "delay times" based on steady-state flow. Furthermore, the compartments could be chosen to correspond to convective cells treated as "well mixed". Conservatism comes from using a small number of compartments, which expedites the progression of radionuclides down the flow stream.

By a "form of release" to be treated by this set of differential equations, we mean, for example, a particular size group of aerosols or the class of ideal gases. For the decay constant λ to be unique, of course, one needs to specialize to a particular isotope within a particular release form. For many isotopes and physical release forms, however, it is possible to calculate concentrations for all isotopes simultaneously for the given physical release by settling λ to zero, then doing a retrospective correction for decay for each isotope.

2.3.3.3 Dosimetry

The Owners' Group report considers three types of exposure: 1) inhalation of radioiodine, 2) external gamma exposure, and 3) external beta exposure. The inhalation dose commitments are calculated for control-room exposure only, using thyroid dose conversion factors from Regulatory Guide 1.09. These dose factors are based on a 50-year dose commitment period. These values are appropriate for the analysis when corrected for breathing rate as is done. The external gamma dose conversion factors represent whole-body exposure at the surface of the body (i.e., skin dose). These factors should be corrected to

represent the dose at a tissue depth of 5 cm (i.e., whole-body dose). The difference would be about a 20% reduction in dose which may not be significant for the present analysis. The beta dose conversion factors are strictly applicable only to skin-dose evaluation. They should be modified for penetration to the sensitive layers of skin (7 mg/cm^2). This correction may not be significant compared to other uncertainties. The doses as presented in the report should not be added, as they represent exposure of different organs.

In summary, the doses evaluated should be carefully labeled as to what they represent. The inhalation dose is a thyroid dose commitment. The beta and gamma doses are approximate doses to the skin. For comparison to 10 CFR 500 guidelines the following doses should be calculated:

Whole Body: External Gamma (5 cm depth)
Inhalation of Particulates

Thyroid: External Gamma (5 cm depth)
Inhalation of Radioiodine

The doses evaluated by the Owners' Group method cannot be added to give any meaningful quantity.

2.3.4 <u>Conclusions</u>

The Owners' Group model for release of radionuclides through MSIV leakage contains a number of useful insights and innovations. However, the assertion that it is necessarily conservative has not been substantiated. The following are items which we regard as nonconservative:

1. The dilution of radionuclides in RPV steam by SRV release to the suppression pool may be less effective than modeled.
2. No re-entrainment is accounted for.
3. The delay time for released radionuclides to reach the condenser will probably be less than given in the model.
4. Leakage from the condenser is probably larger than given in the model because of barometric pressure changes.

5. Leakage past turbine stop valve, turbine control valve, and turbine seals provides an additional and shorter leakage path to the one through the condenser, unless the turbine bypass valve is opened to assure that most flow goes through the condenser.

However, one item of excessive conservatism is noted in the model. Deposition velocity in the main steam line is likely to be higher than the one used, at least after some cooling of the main steam line has occurred to reduce a possible thermophoretic repulsion.

The doses calculated using this method must be carefully labeled as to what they represent for comparison with 10 CFR 100 guidelines. The doses calculated by this method cannot be added to give any meaningful quantity.

3.0 CONCLUSIONS

1. It is concluded that the BWROG MSIV Leakage Committee collected data from a reasonable sampling of operating BWRs in order to characterize the MSIV leakage problem. The data collected by the committee were not reviewed by PNL. However, the data collection forms and process described in the committee report indicate that the data collection effort was adequate to support development of a correlation between MSIV leakage performance and possible causative factors. From the report, it is concluded that the data base generated by the committee was superior in size and detail to what PNL could have developed from Licensee Event Reports (LERs) and published data. Data collected independently by PNL supported the findings of the committee.

2. Because little detail was provided on the committee's data evaluation process, it is not possible to independently confirm the adequacy of the committee's data analysis. The fact that the committee's findings as regards primary contributors are supported by PNL's independent review of LERs and other published data suggests that the process yielded satisfactory results. It is therefore concluded that the data analysis was probably satisfactory, and that there is a good probability that the primary contributors to excessive MSIV leakage were identified. However, because of the nature of the data and the analysis described in the committee report, there is a significant likelihood that only a small amount of additional data might have provided the basis for elevating a noncontributor to secondary contributor status, or even a secondary contributor to primary. For this reason, the classifications should not be considered "frozen" but should be periodically re-evaluated.

3. The committee recommendations are generally consistent with their findings as regards the causes of MSIV leakage. If the classification of contributors is correct, the implementation of the committee recommendations should substantially reduce the incidence

and magnitude of LLRT failure. It is concluded that the major unresolved issue surrounding the committee recommendations is the translation of the general recommendations into plant and valve-specific recommendations and procedures. No information on this has been provided by the committee.

4. It is concluded that the BWROG provided the necessary support for the operator action recommendations presented in Reference 1.2.3. The document provided a good overview of the initiating conditions, leakage flow paths, potential operator actions, and necessary changes to the EPGs. It is concluded that the report could have strengthened and made more useful by inclusion of additional discussion of a) the interaction of the potential operator action with overall performance, b) the feasibility of backfitting existing plants with the equipment necessary to make generally possible those plant-specific operator actions which are demonstrated to be superior in controlling leakage, and c) the interactions of the Radioactivity Release Control Guidelines with the other EPGs and associated problems.

5. It is concluded that the Owners' Group dose calculation model contains a number of useful insights and innovations, however, it is not necessarily conservative. The following items are possibly nonconservative:

- The dilution of radionuclides in RPV steam by SRV release to the suppression pool may be less effective than modeled.
- No re-entrainment is accounted for.
- The delay time for released radionuclides to reach the condenser will probably be less than given in the model.
- Leakage from the condenser is probably larger than given in the model because of barometric pressure changes.

- Leakage past turbine stop valve, turbine control valve, and turbine seals provides an additional and shorter leakage path to the one through the condenser, unless the turbine bypass valve is opened to assure that most flow goes through the condenser.

It is concluded that the doses calculated using this method must be carefully reviewed and labeled as to what they represent for comparison with 10 CFR 100 guidelines.

4.0 REFERENCES

1.2.1 General Design Criteria 55, "Reactor Coolant Pressure Boundary Penetrating Containment," of Appendix A, "General Design Criteria," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities."

1.2.2 10 CFR Part 100, General Site Criteria.

1.2.3 "Potential Operator Actions to Control MSIV Leakage," NEDO-30324 Class I, September 1985, General Electric Company.

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2.3.2 Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, WASH-1400, 1975.

2.3.3 J. A. Gieseke, P. Cybulskis, R. S. Denning, M. R. Kuhlman, K. W. Lee, H. Chen, Radionuclide Release Under Specific LWR Accident Conditions, Vol. III, BWR, Mark III Design, BMI-2104, Battelle Columbus Laboratories, July 1984.

2.3.4 S. L. Nicolosi and P. Baybutt, Vapor Deposition Velocity Measurements and Correlations for I_2 and CsI, NUREG/CR-2713, USNRC, 1982.

ATTACHMENT 1

BWROG MSIV REVIEW CHECKLIST

Item No.	Checklist Item
I.3.a	Data collection
I.1	Number of plants
I.2	Number of utilities
I.3	Review of data forms
I.3.a	Generic plant information
I.3.b	Valve data form
I.3.c	Maintenance history form
I.4	Number of valve types
I.5	Operation cycle information
I.6	Leak rate test information
I.7	Valve information
I.8	Maintenance/testing records
I.9	Qualification/experience of review team
I.10	Data collection method
II.0	Data assessment
II.1	Potential contributors
II.2	Primary contributors
II.3	Secondary contributors
II.4	Noncontributors
II.5	Data reduction method
III.0	Recommendations/applications
III.1	Primary contributors
III.2	Secondary contributors
III.3	Noncontributor
III.4	Method
III.5	Implementation

CHECKLIST ITEM DESCRIPTION

I.0 Data Collection

I.1 Number of Plants

- Check that number of plants surveyed is an appropriate percentage.
- Check that plants surveyed extend over entire product line.
- Check that plants surveyed extend over all vavle vendors.

I.2 Number of Utilities

- Check that appropriate number of utilities were contacted.
- Check on validity of utilities operating experience if contacted.

I.3 Review of Data Forms

- Determine usage of form (when did plant submit?).
- Does form include appropriate information?

I.3.b Valve Data Form

- Does form include appropriate information?
- Determine how vendor uses form.

I.3.c Maintenance History Form

- Does form include appropriate information?
- Determine how/when vendor uses form.
- Cross-check form against contributors.

I.4 Number of Valve Types

- Check for proper sample of all Main Steam Isolation Valves.
- Check for proper sample of valve vendor types.

I.5 Operating Cycle Information

- Was operating cycle information factored into methodology?
- Check for types of cycle information.

I.6 Leak Rate Test Information

- Was all LRT information reported (even nonleaking valves)?
- How did BWROG define hi, low, medium leak rates?

I.7 Valve Information

- Compare collected information against application.

I.8 Maintenance/Testing Information

- Was maintenance/testing information used in analysis?

I.9 Qualification/Experience of Review Team

- Check to see that plants provide experienced personnel versus trainee.
- Check to see that BWROG Review Team have adequate credentials.

I.10 Data Collation Methodology

- Check to see if methodology was consistent with scope.
- Check to see that methodology was properly applied.

II.0 Data Assessment/Reduction

II.1 Potential Contributors

- Additional contributors.
- Check each contributors against data collection and reasonableness.

II.2 Primary Contributors

- Were primary contributors defined?
- Did all primary contributors come from potential contributors?

II.3 Secondary Contributors

- Were secondary contributors properly defined?
- Did all secondary contributors come from potential contributors?

II.4 Noncontributors

- Were noncontributors properly defined?
- Did all noncontributors come from potential contributors?

II.5 Data Reduction Method

- Was method consistent with scope?
- Was method properly applied?

III.0 Recommendations/Applications

III.1 Primary Contributors

- Was proper or logical conclusion reached about primary contributors?
- Was proper or logical recommendation proposed?

III.2 Secondary Contributors

- Was proper or logical conclusions reached about secondary contributor?
- Was proper or logical recommendations proposed?

III.3 Noncontributors

- Was proper or logical conclusions reached about noncontributors?
- Was proper or logical recommendations proposed?

III.4 Method

- Does method correspond to scope?
- Was method applied properly?

III.5 Implementation

- Does implementation plan follow recommendations?
- Do they provide a feedback loop?

APPENDIX B

Main Steam Isolation Valve Historical Data Evaluation and Assessment

MAIN STEAM ISOLATION VALVE
HISTORICAL DATA EVALUATION AND ASSESSMENT

Prepared for BWROG by the MSIV Leakage
Control Committee

APPROVED BY: M. E. Hollins
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MSIV Leakage Committee Chairman

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EXECUTIVE SUMMARY

This report applies to balance-disc wye pattern valve designs commonly used in main steam isolation valve (MSIV) service in domestic boiling water reactors (BWRs) and examines the probable causes and proposes certain corrective actions to minimize the MSIV seat leakage experienced during typical local leak rate testing (LLRT) at BWRs. These probable causes and corrective actions are based on an extensive historical data base developed from utilities' LLRT, maintenance, and operating histories. Also included in this examination are the results from utilities, vendors, and industrial research programs, in conjunction with interviews with knowledgeable personnel from various organizations.

To examine the reasons for MSIVs failing the LLRT, potential contributors to MSIV failures were listed and analyzed. Based on an analysis of each potential contributor, these contributors were grouped into three categories: non-contributors, secondary contributors, and primary contributors.

From the categorization, it was determined that the most probable cause for the typical MSIV failure was produced from combinations of the primary contributors. These contributors are improper maintenance, valve orientation, excessive clearance, seat-to-guide misalignment, lack of concentricity, incorrect seat contact, and excessive coefficient of friction/corrosion.

Based on the categorizations, the recommended corrective actions are again divided into three categories that may mitigate the effects of slight deviations from the acceptance criteria and those necessary to alleviate the more chronic valve failure.

No corrective action beyond present practice is recommended for noncontributors.

The recommended corrective action for secondary contributors involves establishing standardized and technically correct procedures for maintenance and testing of MSIVs. This includes consideration of testing in the direction of flow and assurance that the valves are maintained in their as-manufactured configuration. These corrective actions also include the possibility of closing the valves with steam pressure and increasing the actuator operator pressure.

The corrective actions for primary contributors are based on the more common valve failures that produce moderate to high leak rates. These corrective actions focus on maintaining or establishing adequate internal valve geometry to produce acceptable valve leak rates. These actions include a program to examine the valve internals, maintenance equipment to establish adequate poppet-to-valve body seat alignment, and modifications to produce an alignment that will minimize unfavorable conditions and allow proper seat contact.

TABLE OF CONTENTS

I. DEFINITIONS

Noncontributors

Potential leakage contributors that through testing or analysis have been determined to have little or no effect on MSIV leakage rates, and/or leakage contributors that have occurred during other phases of plant operation or construction that should not occur during normal plant operation.

Secondary Contributors

Potential leakage contributors that may affect MSIV leakage in some instances and normally only have a minor effect on MSIV leakage rates. These contributors usually produce a low to moderate leak rate but may produce a high leak rate infrequently; however, these contributors usually can be readily addressed and corrected and therefore eliminated as a consistent source of leakage failure.

Primary Contributors

Potential leakage contributors that routinely produce MSIV leak rate failures and normally cause moderate to high MSIV leakage rates; however, the measured leakage rate could vary from low to high depending on the overall effect of the contributor. These contributors usually cannot be eliminated or minimized without extensive controls and/or modifications.

Leak Rate Criteria

The amount of acceptable leakage that can pass through an MSIV. For most plants, the allowable leakage is 11.5 standard cubic feet per hour (SCFH) at 25 pounds per square inch differential (PSID) test pressure. This criteria may vary for some plants but is usually specified in the plant technical specifications.

Low Leakage

MSIV leakage measured during local leak rate testing (LLRT) that exceeds the allowable leak rate criteria but is less than approximately 100 SCFH.

Moderate Leakage

MSIV leakage measured during local leak rate testing that is greater than 100 SCFH but less than 500 SCFH.

High Leakage

MSIV leakage measured during local leak rate testing that is greater than 500 SCFH.

Note: These defined terms are provided to quantify their use within this report but should be considered very general descriptions.

II. DESCRIPTION

A. Problem Statement

During numerous outages, the main steam isolation valves at various plants have failed to meet the local leak rate test criterion. These failures (judged to be related to the main seat) can cause troublesome and time-consuming disassembly and maintenance activities. To improve this situation, a sub-group of the BWR Owners Group was formed with the objectives of investigating the problem and determining promising corrective actions.

This report describes the investigative approach, the potential contributing factors, the most probable causes, and proposed actions to correct or improve the situation.

B. Investigative Approach

The investigative approach determined by the technical group to be most productive involved generating an extensive data base from experience at plant sites. This data were tabulated and sorted by plant, valve type, size, leakage performance, and corrective action taken in the past by plant personnel. This data base was reviewed extensively and expanded through further requests and contacts with plant personnel.

Where necessary and feasible, plant personnel were interviewed to clarify any questionable data and to add any further information. These discussions provided a more thorough understanding of actual experience.

With the data collection and review completed, the technical group made a Kepner-Tregoe analysis of the information. This technique focused the thinking process on problem analysis and provided an organized structure to solve the problems that were defined earlier.

This approach explored what the problem was, when it occurred, and how various aspects could be related. Potential causes were listed and analyzed, and consequently, a most likely cause (or causes) was determined. Corrective actions resulting from this analysis were then recommended.

C. Listing of Potential Contributors

The following is a list of potential contributors to MSIV leakage that was reviewed by the technical group. These contributors are discussed in detail in the following section (II.D).

1. seat geometry
2. pipe loading
3. thermal distortion
4. inadequate actuator loading
5. MSIV aging
6. leakage sources other than seat
7. actuator/stem binding
8. valve damage
9. valve design differences
10. LLRT pressurization method
11. closing procedure
12. foreign deposits
13. poppet rotation
14. improper maintenance
15. valve orientation
16. excessive clearances/seat to guide misalignment
17. lack of concentricity
18. incorrect seat contact
19. excessive coefficient of friction/corrosion

D. Analysis of Potential Contributors

This section describes the analyses of the potential contributors.

1. Seat Geometry

   Three geometries that are presently in service were considered. They are as follows: Crane--ball and cone; Atwood & Morrill--cone and cone with semi-line contact; and Rockwell--cone and cone with full-seat contact.

   The Crane design was judged to be the most forgiving concept since it would allow proper seat contact with some misalignment of the poppet to seat. The Rockwell and Atwood & Morrill designs were judged to be less forgiving in that the potential for leakage could exist when misalignment is present. However, the potential for leakage in any of these designs is a function of the magnitude of misalignment. Other contributing factors may worsen the situation. These are discussed further in other areas of the description.

   Additionally, all three of these concepts have been used at Browns Ferry Nuclear Plant (BFNP) without any significant change in leakage results following an operating cycle.

   Measurements performed at BFNP, Peach Bottom (PB), and on the General Electric (GE) test valves (References 1 and 2) also have indicated that seat geometry in the "as found" condition is not a major contributor to high seat leakage.

   For example, valves that leaked at high leak rates (3,000 SCFH) and low leak rates (100 SCFH) were measured, and it was determined through testing at BFNP

and GE (References 1, 2, and 3) that the seat geometry was satisfactory and should have produced a relatively low leaking or acceptable valve test for each seat configuration.

Therefore, it was judged that seat geometries and the typical deviations measured in themselves were not primary contributors to high leakage.

2., 3. Pipe Loading and Thermal Distortion

Pipe loading and thermal distortion were considered potential contributors to the MSIV leakage problem but were discounted in light of References 1 and 2. These reports showed no effects from thermal-induced loads, and the only instance in which pipe loading became a consideration was when the bending moments far exceeded those loads anticipated through normal installation.

4. Inadequate Actuator Loading

Inadequate actuator loading was considered a potential contributor to the MSIV leakage problem since it was shown in References 1, 2, and 3 that increased actuator loading can reduce seat leakage. It should be noted that net seat loading is reduced on the inboard valve when the LLRT test pressure is applied between the valves. However, it has been determined that increasing the actuator loading can compensate for this reduced net seat load.

It also has been shown that increased actuator loading (above the normal 90 psi) can provide an acceptable leakage rate for those valves that have a leakage rate less than 500 SCFH (Reference 3). Additionally, although valve sizes vary, actuator

sizes generally do not; therefore, seat loading per unit area is larger in small valves than in larger ones.

Actuator loading should not be considered a primary contributor to high leakage, but it should be considered because it has been demonstrated in References 1, 2, and 3 that increased actuator loading will improve some low to moderate leakage to the point of meeting acceptance criteria. For example, increases in actuator loading may help overcome small increases in friction from sources such as corrosion (see II.D.19).

5. MSIV Aging
The age of MSIVs used in BWR plants varies widely in terms of actual life and service time. This was considered a potential contributing factor to LLRT failures since it can be postulated that the effects of wear on valve and actuator internals as a function of time can have an adverse impact on LLRT performance. This theory was subsequently dismissed, however, on the basis that the LLRT failure data clearly show that MSIVs of virtually all ages have had failures without significant differences in the ratio of tests passed to tests failed.

6. Leakage Sources Other Than Seat
Leakage sources (i.e., packing, gasket, drain valves, and test connections) other than through the seats were considered potential contributors to the MSIV leakage problem but were discounted as primary causes since they are generally identifiable, and the leakage can be determined, corrected, or isolated. Additionally, to date there has been no indication of the gasket or packing contributing to high leakage.

7. Actuator/Stem Binding
Stem binding was judged initially to be a potential contributing factor, but historical data has shown that this condition has occurred only a limited number of times.

Even though binding of the actuator parts has occurred, such as binding of the spring plate on the yoke rods or jamming of the poppet (as opposed to cocking, as discussed later) in the valve body during stroke travel, this has occurred infrequently and therefore was considered a noncontributor.

8. Valve Damage
Valve damage has resulted from steam flow and improper maintenance; however, steam cutting or erosion of the main seats has not been observed during valve inspections. Flow-induced damage may include valve stem bending, valve stem disc separation, and damage to the guide ribs. Improper maintenance has resulted in the galling of the yoke rods, valve stem, and pitting of the valve stem, as well as damage to the valve seat. Damage to the stem affects stem leak tightness, which is not related to main seat leakage. However, it could affect the valve cycle time, and it could reduce the effectiveness of the actuator force. Damage to the guide ribs has occurred in the area where the poppet and body make contact when the valve is open. This occurrence has been infrequent and was judged a secondary cause of LLRT failure.

9. Valve Design Differences
There are three major suppliers of MSIVs. In spite of the similarity of external appearances, major differences exist in the valve internal designs. The

differences can be summarized as follows (refer to Figures 3, 4, and 5):

Valve Manufacturer	Crane	Rockwell	A&M
Size	20"	16" - 28"	18" - 28"
Seat hardface material	stellite 6/ haynes 25	stellite 21/ stellite 6	stellite 21/ stellite 6
Seat configuration	ball/cone	cone/cone	cone/cone
Contact	line	surface	line
Guide system	1. top liner and lower cage 2. tighter clearance between the cage and the poppet 3. circumferential guidance near the seat	guide ribs 3 to 4	guide ribs 3
Unsupported length of valve stem	short	long	long
Pilot to stem interface	threaded joint	threaded joint	one piece
Poppet design	one piece	threaded joint	one piece
Stem-to-poppet connection	spring loaded	not spring loaded	spring loaded

Note: For further detail, see Figures 3, 4, and 5.

A detailed review of performance data from plants with various valve designs showed that these design differences may affect the number of failures but are not primary causes of LLRT failure. However, it was noted that the designs as applied to various valve sizes may affect the magnitude of leakage (see paragraph II.D.4).

10. LLRT Pressurization Method

Currently, the most common method for applying LLRT pressure is to pressurize between the inboard and outboard MSIVs. This was considered a potential LLRT failure source since it can be postulated that this method is unnecessarily conservative. It was determined subsequently that this factor can certainly apply to inboard MSIV test failures that modestly exceed the acceptance criteria since the inboard valves are being pressurized in the direction opposite to flow that will oppose the actuator force and decrease the net seat loading.

This factor definitely does not apply to outboard MSIV test failures since pressure is applied in the correct flow direction. Similarly, it does not apply to inboard MSIV test failures that grossly exceed the acceptance criteria since it cannot reasonably be expected that pressurization in the correct flow direction would completely mitigate leakage rates of such relatively large proportions.

Consequently, this factor can be regarded as a legitimate potential contributor only for low leakage failures on inboard valves. Thus, it is considered to be a secondary contributor.

11. Closing Procedures

The present practice varies from closing the MSIVs while the system is pressurized and flow exists to closing the MSIVs after the system has been depressurized fully and virtually no flow exists. Not optimizing this procedure was determined to be applicable to LLRT failures that modestly exceed the acceptance criteria. However, it cannot be ascertained that the assistance provided by pressure and

flow will effectively help to mitigate more substantial leakage rates. The increased seating force from closure under flow could help overcome abnormal resistance from friction in other sources (see II.D.4 and 19).

Although using the optimum procedure may assist moderately leaking valves in passing the LLRT, it was not judged to be significant in reducing high leakage rates and therefore was judged to be a secondary contributor.

12. Foreign Deposits

Heavy corrosion deposits or construction debris have been found in some valves after disassembly, following failure of preoperational leak rate tests. Such material interfered with closure of the valve and produced excessive leakage, and closure on such material sometimes produced damage requiring seat maintenance. However, after plants have been in operation, subsequent accumulations have been insignificant.

Because this foreign material should exist only during preoperational conditions, this situation is judged to be a noncontributing factor in LLRT failure during outages at operating plants.

13. Poppet Rotation

Valve poppet rotation was considered a potential contributor to the MSIV leakage problem since this phenomenon has been observed at several sites and during EPRI testing (References 1 and 2). Although this has not been directly linked with through-seat leakage, it could become a contributing factor for the following reasons:

a. With rotation, seating surfaces are not constant in relation to one another, which would be detrimental with an out-of-round condition existing in either poppet or body seat. This could produce erratic LLRT results since consistent seat contact may not be achieved.

b. Continual rotation of a poppet could cause wear between the poppet and body guiding surfaces, which could affect valve clearances and operation.

Therefore, this problem was judged potentially to affect MSIV leakage rates in some cases, but it was not considered to have a major impact with respect to high leak rates unless wear becomes excessive and leads to clearance problems (II.D.16 and 17).

14. Improper Maintenance
Some high seat leakage cases are believed traceable to improper maintenance and/or use of improper valve repair tools. In particular, refinishing of seats with improper tools and procedures has caused poor alignment or concentricity between body seats and guide ribs. In such cases, damage may have been caused during repairs following preoperational testing in early plants (built before current valve maintenance tools were available). Such improper maintenance probably was a contributing factor to high leak rates in some operating plants.

15. Valve Orientation
The MSIV stem travels in a 45-degree angle relative to the pipe centerline. This makes valve maintenance much more difficult and increases the chance of damage to the valve internals. The Nine Mile

Point (NMP) outboard valves internals have the configuration of the typical wye pattern valve, except the body configuration is that of a 90-degree angle valve, and the internals travel on a vertical centerline. The leakage performance is significantly better than a typical wye pattern MSIV.

For some inboard MSIVs, the stem is further rolled (rotated) to the side by as much as 35 degrees. In this arrangement, the poppet is not supported by a rib guide at the base of the poppet; instead, it is cradled between two rib guides. This potentially increases the misalignment (for further discussion refer to Item 16) between the centerline of the poppet and the centerline of the seat. This increases the required movement (sliding against friction) for the poppet to seat properly. Review of the MSIV leakage data base shows that this orientation can be a primary factor in LLRT failure.

16. Excessive Clearances/Seat to Guide Misalignment
In the manner that this wye-type valve was manufactured, a diametrical clearance exists between the poppet and guides that varies from approximately .015 to .025 inches with the three MSIV manufacturers. When the valve is installed in the plant on a horizontal pipe run, the poppet slides on the guides by gravity. This effectively misaligns the poppet to main seat by half the original diametrical clearance. In addition, on the 35-degree rolled valves, the poppet is cradled between two guide ribs (as noted in Item II.D.15). Due to the differences in the diameters of the poppet and guide ribs and due to the spacing of the guide ribs, the poppet is allowed to drop further below the centerline of the

main seat (approximately 0.040 inches further in the 26-inch BFNP valves).

This effectively forces the main body seat to perform the final guiding of the poppet into the seat so the poppet hits the bottom part of the body seat first as it enters the seating area and then must slide along the seating surface toward the main seat centerline to make full contact with the body seat (see Figure 1).

In addition, previous main seat maintenance, guide rib wear, or damage may increase the distance the poppet will have to travel when it enters the seat.

Since the direction of poppet movement during seat engagement is significantly different from the direction of force being applied by the actuator during seat engagement, the net force moving the poppet in this direction is reduced. Therefore, any opposing forces (i.e., friction) potentially could prevent the sliding movement from taking place. This net sliding force is reduced even further on the 35-degree rolled valve since the movement is slightly upward with respect to a horizontal plane, whereas in the non-rolled valve, the movement is parallel to a horizontal plane (due to the 45-degree wye angle in conjunction with the 90-degree included seat cone angle).

This type of valve movement contrasts with an angle valve that drops the poppet vertically, directly into the seat. As expected and shown in the data base, the angle valve had no significant leakage history (see II.D.15). In addition, measurements at

BFNP and PB have indicated that seat-to-poppet centerline misalignment can be related to leakage in the "as found" condition (following plant cycle operation).

Therefore, it was judged that excessive clearances are a primary contributor to valve leakage.

17. Lack of Concentricity

Lack of adequate roundness of the mating seats and improper concentricity of the seats with the guide surfaces were considered possible contributors to the seat leakage. Experience has shown that although the seating surface on the poppet can be eccentric relative to the poppet outside diameter, the roundness may be quite acceptable. This eccentricity, when combined with improper rib guidance and/or poppet rotation, could be a potentially significant contributor to leakage. With proper maintenance of the seats (roundness and concentricity), this is judged not to be a cause of serious leakage. Further, previous tests during the GE-EPRI program (References 1 and 2) demonstrated that even with seats out of round (tir .004"), the valve would pass the LLRT criterion with application of normal actuator load.

It should be noted further that a series of precise roundness and concentricity measurements at BFNP and PB have shown clearly that even valves that have failed the LLRT excessively have been shown to have good roundness and flatness (very minor deviation from true conical geometry) and acceptable concentricity. This indicates that this potential cause, although it is a concern, is not sufficient to produce the relatively high leakage rates occasionally

observed during the LLRT but could contribute to moderate leakage unless concentricity deviation is extreme.

18. Incorrect Seat Contact
It is clear that for the MSIV to pass the LLRT, the mating seats must be in close contact. Any mechanism that might be identified as a possible means for preventing this contact could be a probable cause for a LLRT failure. As expected, experience has shown that an eccentric, positive stop (to simulate excessive seating friction) installed in the valve to prevent full closure would cause a cocking, as shown in Figure 2, and excessive leakage similar to that observed at plant sites. Tests by GE have shown that a gap on the order of 0.0006 inch would not cause excessive leakage, whereas a gap of 0.020 inches would cause excessive leakage (see References 1 and 2). One means for creating such a gap would involve misalignment between the centerline of the supporting guide ribs and seats, as well as possible cocking of the poppet due to improper guidance related to clearances and excessive drag or friction forces. This is discussed further in Items II.D.16 and II.D.19. It also should be noted that mating seat geometry could influence this behavior, as discussed in Item II.D.1.

Incorrect clearance or other aberrations sufficient to cause improper main seat contact could lead to poor seating of the pilot seat, as well. Such a situation has been observed at various sites where clearances between the poppet and guide ribs were sufficiently large to allow not only eccentric mating of the main seats but also misalignment of the pilot seat. This misalignment was great enough to

damage the end of the stem and stem bending (due to eccentric column loading) resulted. Therefore, it has been determined that incorrect seat contact can be a primary contributor to seat leakage.

19. Excessive Coefficient of Friction/Corrosion
Excessive coefficient of friction due to oxidation or corrosion buildup on the guides and seating surfaces was considered a potential contributor to the MSIV leakage problem, since it has been demonstrated that some valves that fail LLRT can be brought within acceptable limits merely by cleaning these mating surfaces. This phenomenon has been demonstrated to exist only after installation at the plant; that is, clean valves have been shown to be leak tight. It appears that there is no effective way to prevent corrosion, and therefore, it must be compensated for. Additionally, it has been shown that excessive friction may not be a problem in itself but may act in combination with several other factors, as explained in Items II.D.4, II.D.11, II.D.15, and II.D.16. As the friction forces increase, the sliding of the poppet to the main seat is impaired to the point that the proper mating of the seats is prevented. A review of Figure 2 illustrates that when the sliding motion ceases, the poppet tilts, allowing the top of the poppet to engage the upper valve bore before seating can be achieved. This locks the poppet and restricts further movement.

Due to the abc e factors, it has been determined that this is a primary factor in LLRT leakage.

III. CONCLUSIONS

Based on the analysis of the potential contributors listed in Item II.C, the following categories have been developed:

A. Category 1 - Noncontributors

It is concluded that the following items are not contributors to failure of the LLRT.

1. pipe loading (Item II.C.2)
2. thermal distortion (Item II.C.3)
3. MSIV aging (Item II.C.5)
4. actuator/stem binding (Item II.C.7)
5. valve design differences (Item II.C.9)
6. foreign deposits (Item II.C.12)

B. Category 2 - Secondary Contributors

It is concluded that although the following items may have a minor effect on seat leakage, they are not considered primary contributors to LLRT failure.

1. seat geometry (Item II.C.1)
2. inadequate actuator loading (Item II.C.4)
3. leakage sources other than seat (Item II.C.6)
4. valve damage (Item II.C.8)
5. LLRT pressurization method (Item II.C.10)
6. closing procedure (Item II.C.11)
7. poppet rotation (Item II.C.13)

C. Category 3 - Primary Contributors

It is concluded that the following items are the primary contributors to LLRT failure.

1. improper maintenance (Item II.C.14)
2. valve orientation (Item II.C.15)
3. excessive clearance/seat to guide misalignment (Item II.C.16)
4. lack of concentricity (Item II.C.17)

5. incorrect seat contact (Item II.C.18)
6. excessive coefficient of friction/corrosion (Item II.C.19)

D. Summary

It is concluded from a review of the collected data base, discussions with cognizant plant personnel, review of tests and operating experience, and analysis of possible contributing factors that the most probable cause for the most common LLRT failures is some combination of those items listed in Category III, Primary Contributors. The following scenario describes one such combination.

With the wye pattern valve design, the poppet is built to a smaller diameter (approximately .020 inches) than the valve internal bore and guide structure. When the valve is installed in a horizontal pipe run, the poppet rests on the lower guide ribs, due to the valve design and gravitational forces. This aligns the poppet centerline .010 inch below the centerline of the seat. Therefore, for the poppet to seat properly and make complete (concentric) contact with the main seat, it must slide along the main seat to eliminate the lateral misalignment.

If additional eccentricity is present from such things as guide rib wear, improper maintenance (original seat centerline moved due to lapping tool design or misuse), poppet wear, or concentricity changes due to poppet out-of-roundness, the sliding distance of the poppet on the main seat must increase. Additionally, on the rolled valves, the poppet is cradled between two guide ribs, which increases the sliding distance significantly.

Consequently, the main seat must provide a significant amount of guiding to achieve proper seat contact. Since the component of force from the actuator causing the poppet to slide is less than the total actuator output force, any significant increase in opposing forces may prevent this sliding operation. In fact, if the sliding motion is impaired, the poppet may tilt, allowing the top of the poppet to engage the valve body before proper seat contact is made (as shown on Figure 2).

It is postulated that over some period of time during the plant operating cycle, the oxidation buildup on the seating surfaces creates enough friction, in combination with the previously described conditions, to lock up the poppet before proper seat contact occurs. This creates a sufficient gap between the seating surfaces to cause significant leakage even though the seats appear to be in good condition.

IV. RECOMMENDATIONS

Note: These recommendations may affect the previous qualifications and/or design specifications for this equipment. Therefore, these design qualifications and design specifications should be evaluated by each utility prior to implementing any recommended actions.

A. Category 1 - Noncontributors

Relative to Category 1 (Section III.A), it is recommended that no action be taken beyond current practice.

B. Category 2 - Secondary Contributors

Relative to Category 2 (Section III.B), it is recommended that the following actions be considered.

1. (II.C.1) Seat Geometry

   Care should be taken to maintain the as-manufactured seat geometry. Any contemplated changes should be carefully assessed and analyzed to ensure that the changes will not be detrimental to valve performance.

2. (II.C.4) Inadequate Actuator Loading

   Care should be taken to ensure that the design operating pressure for the actuator is maintained properly. Further, consideration should be given to increasing actuator operating pressure for valves exhibiting marginal LLRT failures.

3. (II.C.6) Leakage Sources Other Than Seat

   Care should be taken to correct or isolate any identifiable leak paths before LLRTs are performed.

4. (II.C.8) Valve Damage

   It is observed that many of these failures are related to maintenance. For those related to maintenance, attention should be devoted to careful

maintenance supervision and inspection to reveal any incipient failures.

5. (II.C.10) LLRT Pressurization Method
Wherever feasible, consideration should be given to applying the LLRT test pressure in the direction of steam flow for all valves being tested or compensating for decreased seat loading on the inboard valves when pressurizing between valves.

6. (II.C.11) Closing Procedure
Inasmuch as it may be beneficial to close the MSIVs with some steam flow and reactor pressure prior to cold shutdown, the individual plants should review the feasibility of this operation and justify that this condition bounds those postulated to occur during operation.

7. (II.C.13) Poppet Rotation
Consideration should be given to preventing possible poppet rotation by installing an appropriate anti-rotation device to preclude possible guiding surface wear.

C. Category 3 - Primary Contributors

Relative to Category 3, it is recommended that the following actions be taken.

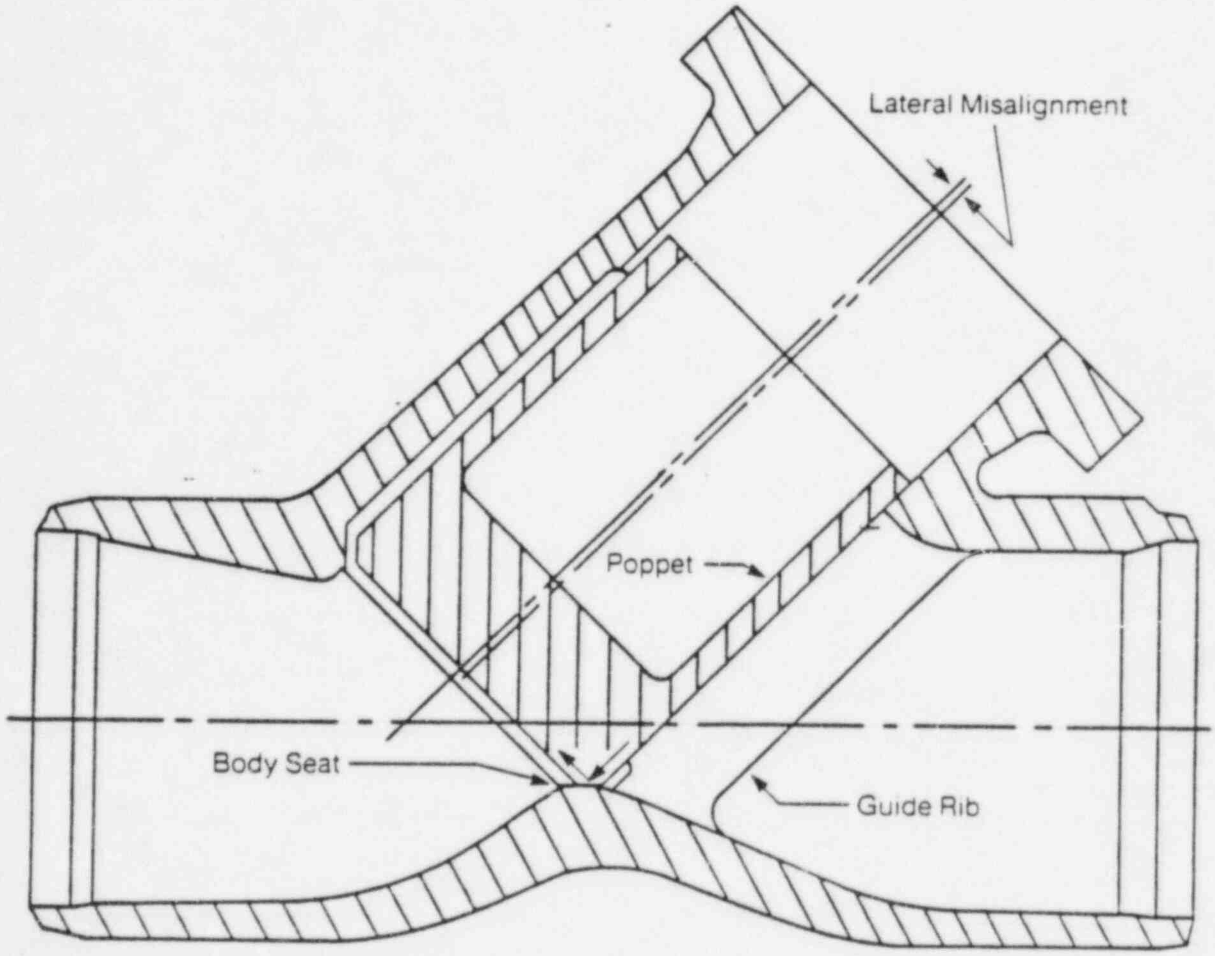
1. (II.C.14) Improper Maintenance
Care should be taken to ensure that maintenance equipment, procedures, and personnel are effective in providing the services required to prevent latent detrimental effects on the valve. For example, equipment planned for use should be checked out thoroughly prior to use, procedures should be proven, and personnel should be trained adequately.

2. (II.C.15) Valve Orientation
   In view of the increased risk of LLRT failure for rolled valves, care should be exercised to ensure correct poppet-to-seat alignment. If this alignment proves problematic, then compensation (i.e., modification of dimensions) should be considered.

3. (II.C.16) Excessive Clearances/Seat-to-Guide Misalignment
   In the event conditions indicate that excessive clearances or misalignments exist, accurate measurements should be taken to determine the extent of these conditions. Should it be determined from these measurements that in fact such a problem exists, action should be considered to establish optimum conditions. This should involve consultation with appropriate suppliers or manufacturers.

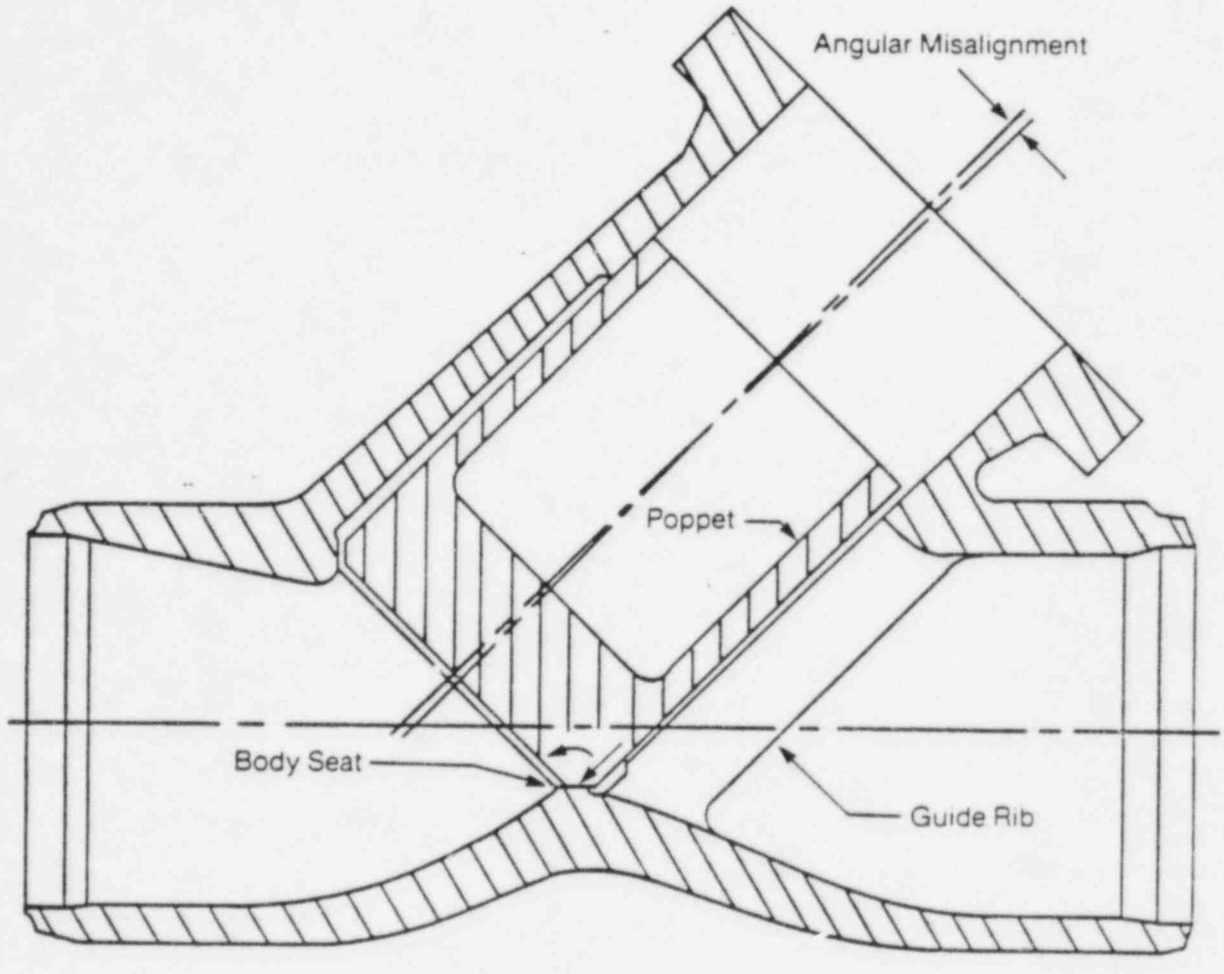
4. (Items II.C.17, 18, 19) Lack of Concentricity, Incorrect Seat Contact, Excessive Coefficient of Friction/Corrosion
   Due to the close interaction of these three items, they are being combined in this discussion.

   Due to the critical, indeed primary, nature of the interaction of these conditions, it is recommended that great care be taken in ensuring proper concentricity, providing correct seat contact, and minimizing friction to the extent feasible. In the event that any of these conditions prove to be problematic, efforts should be taken to mitigate their effects. For example, buildup of various guide surfaces has been employed and appears effective in some cases for correcting poor concentricity and providing correct seat contact. With proper guidance, the negative aspects of friction are minimized.



MSIV with lateral misalignment.

Figure 1



MSIV with poppet tilt.

Figure 2

FIGURE 3

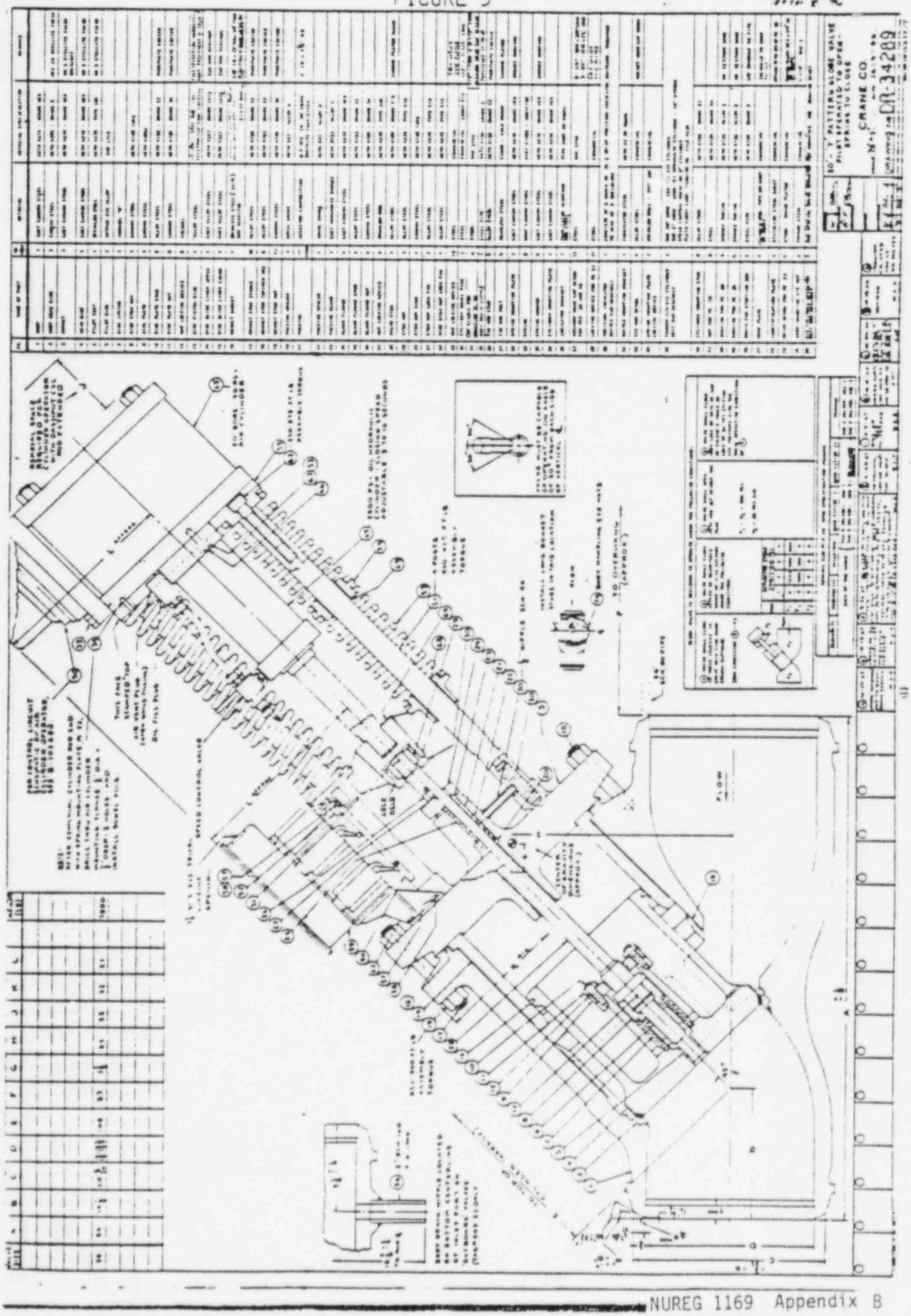


FIGURE 4

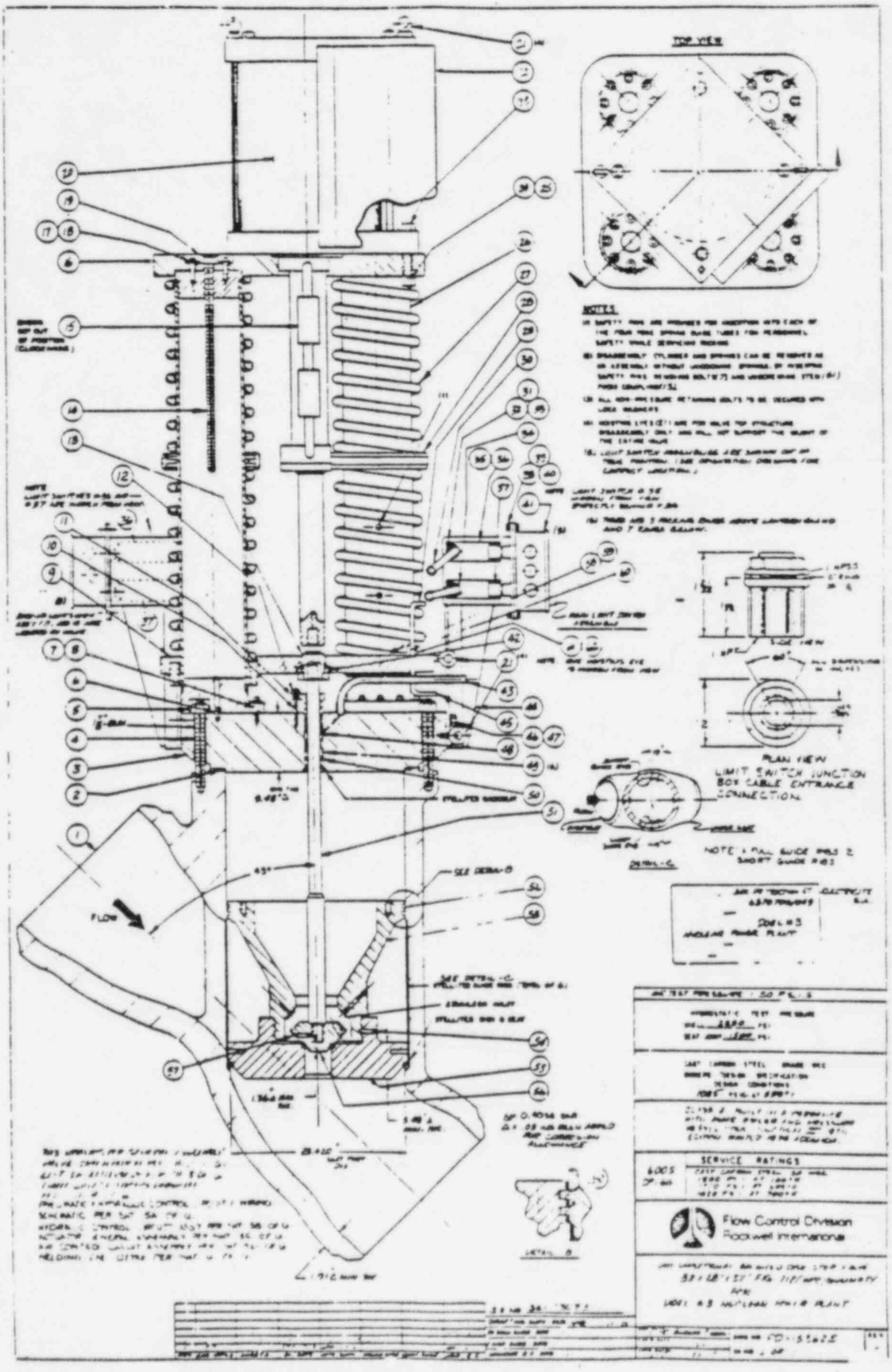
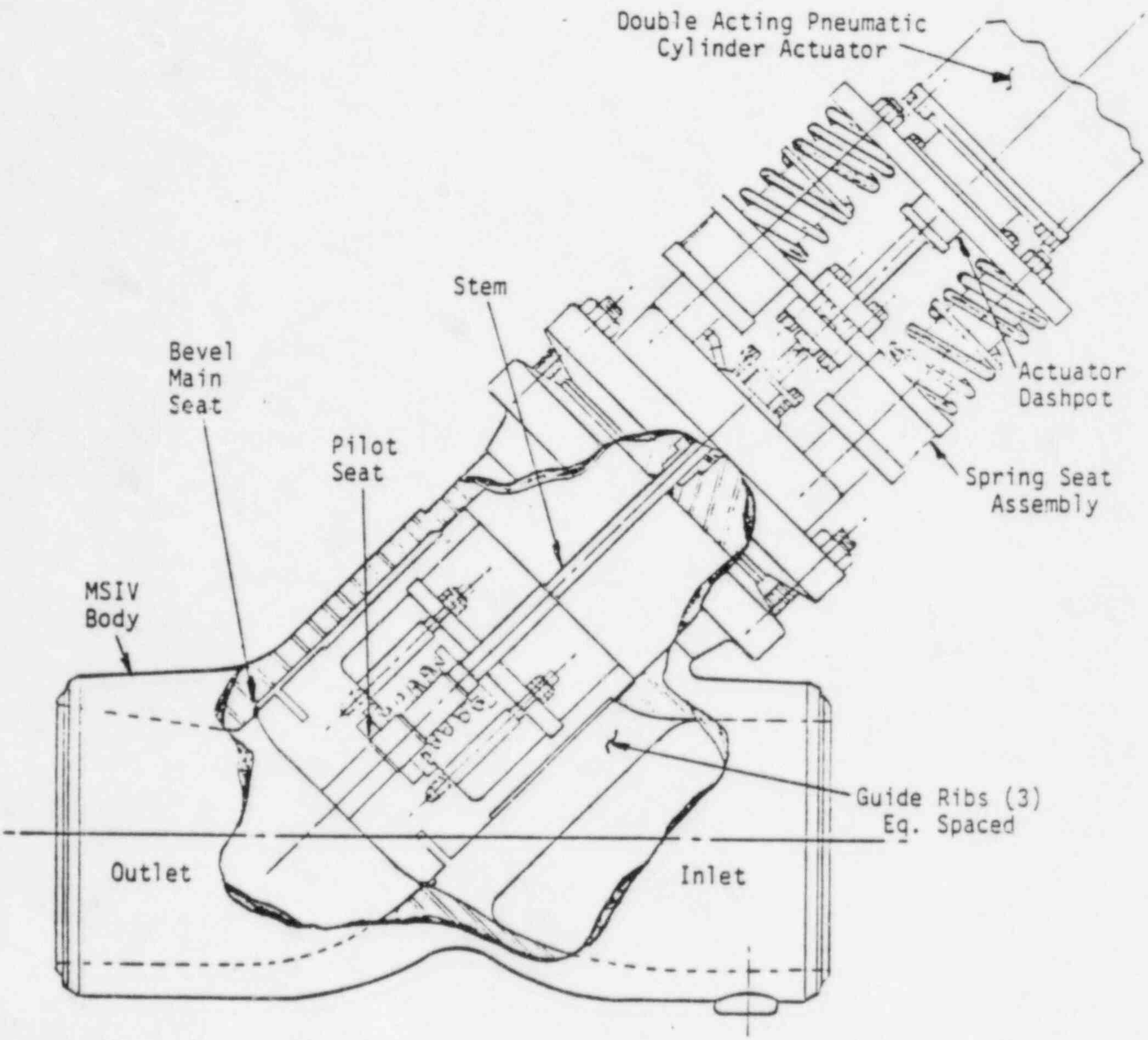

TOP VIEW
NOTES
PLAN VIEW
LIMIT SWITCH JUNCTION
BOX CABLE ENTRANCE
CONNECTION
FLOW
SERVICE RATINGS
Flow Control Division
Rockwell International
DETAIL B

FIGURE 5

MSIV CROSS SECTIONAL VIEW



(Source: Atwood & Morrill Co., Inc.)

V. REFERENCES

1. Electric Power Research Institute (EPRI). Comparison of Generic BWR-MSIV Configurations. EPRI NP-2454, Palo Alto, Calif. June 1982.

2. Electric Power Research Institute (EPRI). Measurements and Comparisons of Generic BWR Main Steam Isolation Valves. EPRI NP-2381, Vols. 1 and 2, Palo Alto, Calif. July 1982.

3. Tennessee Valley Authority (TVA). Technical Evaluation of Browns Ferry Nuclear Plant Main Steam Isolation Valve Containment Integrity Leak Rates. TVA, Chattanooga, Tenn. Presented to NRC on February 1, 1982.

APPENDIX 1

DESCRIPTION OF THE DATA BASE

DESCRIPTION OF THE DATA BASE

Data sheets were sent to the BWR Owners Group for input to the data base. A total of four forms were requested. Copies of the failure request forms are included in this appendix. These forms called for plant contact information, valve description, and maintenance history.

The data base now consists of 18 plant contact records, 136 valve description records, and 586 maintenance history records.

The 586 maintenance history records documented repairs, in some cases from the early 1970s. The following is a list of plants and their owners that participated in the report development:

Utility	Plant(s)
Boston Edison Company	Pilgrim 1
Detroit Edison Company	Fermi 2
Georgia Power Company	Hatch 1, 2
GPU Nuclear Corporation	Oyster Creek 1
Iowa Electric Light and Power Company	Duane Arnold
Long Island Lighting Company	Shoreham
Mississippi Power & Light Company	Grand Gulf 1
Niagara Mohawk Power Corporation	Nine Mile Point 1, 2
Northeast Utilities	Millstone 1
Northern States Power Company	Monticello
Pennsylvania Power & Light Company	Susquehanna 1, 2
Philadelphia Electric Company	Peach Bottom 2, 3 Limerick 1, 2
Public Service Electric and Gas Company	Hope Creek 1
Tennessee Valley Authority	Browns Ferry 1, 2, 3
Washington Public Power Supply System	WNP-2

The data base is stored in the Institute of Nuclear Power Operations' computer under limited access and could be expanded in the future.

GENERIC PLANT INFORMATION FORM

PLANT DOCKET NUMBER: ☐☐☐

POINT OF CONTACT: ______________________________

PHONE NUMBER: ______________________________

PLANT CYCLE LENGTH: ______ months

AVE. NUMBER SCRAMS/CYCLE: ________

AVE. NUMBER OF MSIV CYCLES/PLANT CYCLE: ________

AVE. NUMBER OF MSIV HEATUPS/COOLDOWNS/PLANT CYCLE: ________

AT WHAT POINT ARE MSIV'S OPENED/CLOSED DURING:

STARTUP: ______________________________

SHUTDOWN: ______________________________

VALVE DATA FORM

CONTROL NUMBER [ ][ ][ ][/][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][-][ ]

DOCKET VALVE NUMBER USE ONLY FOR REPLACEMENT VALVE

MANUFACTURER: [ ]

SIZE: [ ]

LOCATION: [ ]

ACTUATOR MFG.: [ ]

ACTUATOR MODEL: [ ]

VENDOR DWG NUMBER: [ ]

IN SERVICE DATE: [ ][ ][ ][ ][ ][ ]
YR MO DA

MAX. ALLOWABLE D/P TO OPEN [ ] PSIG

CHEMISTRY NORM: O_2 [ ] PPM COND. [ ] UMHO

STEAM LEAKOFF MONITORED? [ ] YES [ ] NO HOW? ____________

MAINTENANCE HISTORY FORM

MSIV LEAKAGE SURVEY

CONTROL NUMBER				/											/				

DOCKET VALVE NUMBER MAINTENANCE DATE

LEAKAGE SOURCE [ ]

1A - MAIN SEAT/POPPET
1B - PILOT SEAT/POPPET
1C - STEM PACKING
X - OTHER

SOURCE DESCRIPTION IF SOURCE IS 'OTHER' ____________________

____

____

SOURCE IDENTIFICATION (HOW WAS LEAKAGE SOURCE FOUND OR DISCRIMINATED FROM OTHER SOURCES?) ____________________

____

____

LEAK RATE DATA

MAX. LEAK RATE DURING TEST: ________ ~~SCFM~~ H
VALVE D/P AT MAX. LEAK RATE: ________ PSIG
LEAK RATE AFTR REPAIR: ________ SCFM
VALVE D/P AFTER REPAIR: ________ PSIG
NUMBER OF REPAIRS: ________

LEAK RATE TEST PROCEDURE:

PROCEDURE NUMBER: ____________________

REVISION: ____________________

VALVE INSPECTION DATA

VISUAL:
______ 2A CORROSION
______ 2B WEAR
______ 2C CRACKS
______ 2D OXIDATION
______ 2E PITS
______ 2X OTHER
(DESCRIBE): ____________________

____

____

MEASUREMENTS: SEAT RUNOUT: ____________

DISC RUNOUT: ____________

SEAT ROUNDNESS: ____________

GUIDE RIB ORIENTATION: ____________

OTHER (DESCRIBE): ____________

GUIDE RIB DAMAGE OR WEAR (DESCRIBE): ____________

REPAIR DATA

ACTION:
- ____ - 3A - LAP OR GRIND MAIN SEAT OR PILOT
- ____ - 3B - REPACK
- ____ - 3C - TIGHTEN PACKING
- ____ - 3D - REMOVE LANTERN RING PERMANENTLY
- ____ - 3E - STRAIGHTEN STEM
- ____ - 3F - POLISH STEM
- ____ - 3X - OTHER

(DESCRIBE): ____________

REPLACEMENT DATA

ACTION:
- ____ 4A - ENTIRE VALVE ASSY
- ____ 4B - STEM
- ____ 4C - PILOT DISC
- ____ 4D - PILOT SEAT
- ____ 4E - MAIN DISC
- ____ 4F - MAIN SEAT
- ____ 4G - GUIDE RIB
- ____ 4H - LANTERN RING
- ____ 4I - OPERATOR
- ____ 4J - OTHER

(DESCRIBE): ____________

MATERIAL CHANGE DATA

DESCRIBE ANY MODIFICATION PERFORMED SUCH AS ANTI-ROTATION DEVICE, OR FLOATING ____________

APPENDIX C

Philadelphia Electric Company
Submittal Concerning MSIV Leak Test Performance

PBAPS MSIV LEAKAGE

The BWR Owners Group formed a committee to investigate the subject of MSIV leakage in 1982. The major parts of the BWROG program encompased:

- Collection of data and identification of the cause of excessive MSIV leakage,
- assessment of potential methods of reducing MSIV leakage,
- identification of a range of potential operator actions for the control of MSIV leakage, and
- development of a "realistic" model for the assessment of the dose contribution of MSIV leakage.

The BWROG Committee has recently concluded these studies and a meeting has been scheduled for February 23, 1984 to describe the results of these efforts to the NRC staff. PECo. has been one of the most active utility supporters and participants in the MSIV Leakage Committee work. A total of 17 BWR utilities participated in this effort.

The model which has been developed by the BWROG provides a more realistic, yet conservative, evaluation of MSIV leakage contribution to control room and offsite doses compared to the methods utilized in FSAR analyses. The model is based on a non-break, isolation transient with all piping downstream of the MSIV's to the turbine-condenser intact. A TID source term is assumed and atmospheric dispersion coefficients assumed are "accident χ/Q's" developed in accordance with Regulatory Guide 1.145. Principal fission product attenuation mechanisms considered in this model not previously considered are:

1. Flow through the SRV's into the suppression pool.

2. Plateout in the RPV, steamlines, bypass lines and main condenser.

3. Decay of fission products while in transit.

The results of the plant-unique application of this model to PBAPS indicate that MSIV leakages significantly in excess of technical specification limits do not constitute a safety problem. This finding is consistent with the conclusions of the NRC Accident Evaluation Branch relative to generic issue C-8 (see NUREG-0933).

The plant configuration modeled for Peach Bottom is consistent with the BWROG committee identification of appropriate operator actions and in accordance with plant operating procedures. In this configuration, MSIV leakage is transported to the main condenser which is maintained at a vacuum by the mechanical vacuum pump. The mechanical vacuum pump discharges to the plant main stack. Steam seals on the turbine and turbine valves are maintained operable by the use of plant auxiliary steam and the continued operation of the steam packing exhauster.

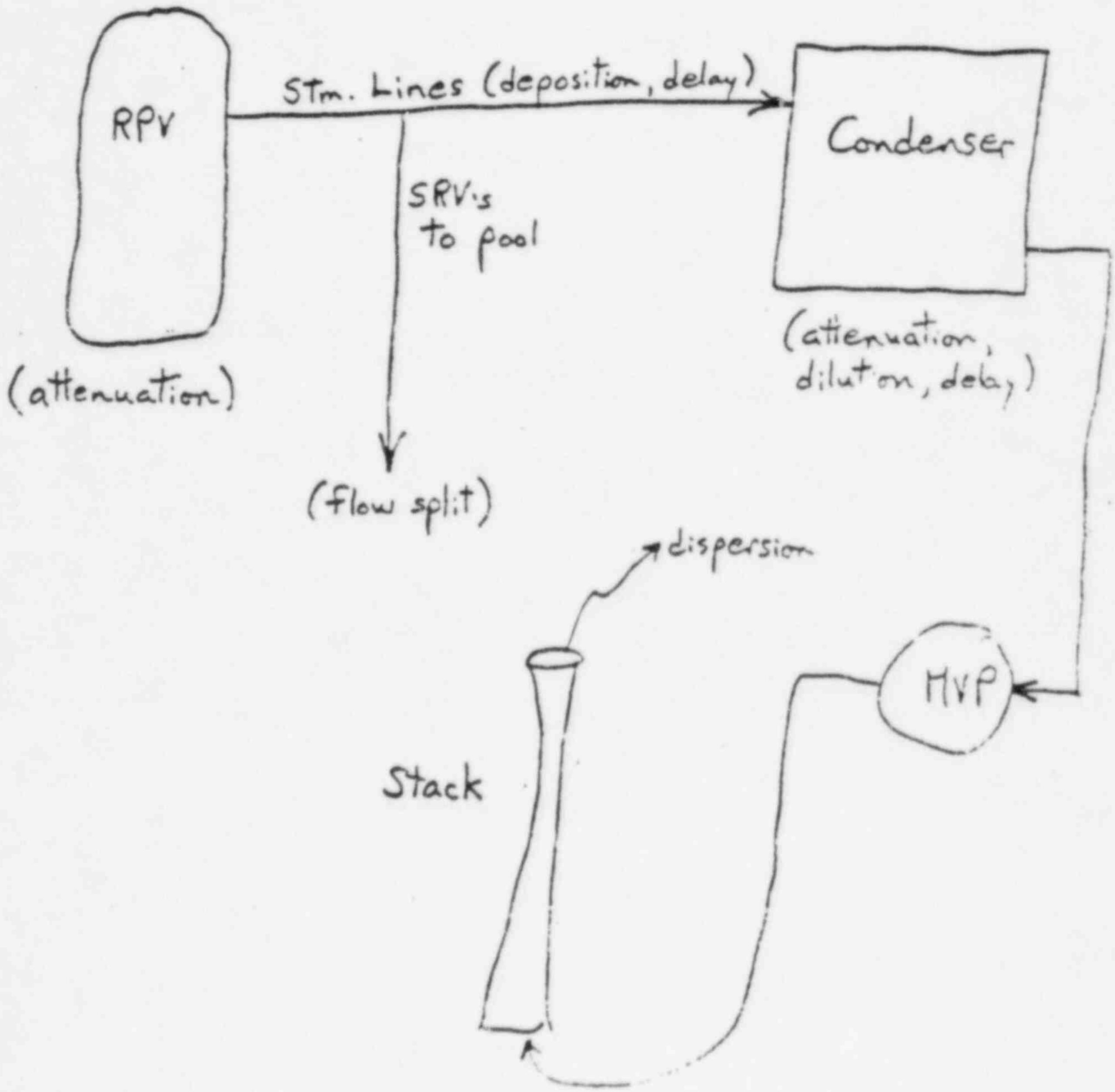
The Owners Group data collection and assessment effort has revealed that guide rib wear and poppet misalignment are the primary causes of excessive leakage. This conclusion has been based on detailed dimensional measurements of MSIV's at both Peach Bottom and Browns Ferry. Improved tooling and maintenance practices which directly address these problem

areas have been developed and partially implemented over the past few years. Although the data base is currently somewhat limited, significant improvements in "as-found" leakage have already been observed. Further improvements are expected as additional experience with the improved maintenance practices is obtained.

Prepared by: D. R. Helwig
January 4, 1984

DRH/cmv/E3

PBAPS MSIV Dose Model



PHILADELPHIA ELECTRIC
MSIV MAINTENANCE PROGRAM

BACKGROUND

Peach Bottom Station has (8) Atwood & Morril 26" MSIV valves per Unit. Two valves are located in each of the four (4) main steam leads. All valve stems are mounted 45 degrees off the vertical centerline and the outer inboard valves (2) are centered 30 degrees.

I. Atwood & Morril Tool/Primitive Design

A. Non-Repeatative

B. Operator Sensitive

II. PECo Original Tool

A. Features

1. Fixed mounting off of three (3) arms, 120 degrees apart.

2. Tool centered in valves off of guide ribs.

3. Very rigid and easy to use after original set-up.

4. Three polishing heads, 120 degrees apart.

B. Disadvantages

1. Set-up was difficult and time consuming.

2. Only 6 minutes per hour operation, remainder required to replace polishing cloth.

III. PECo Modified Tool

A. Features

1. Mounting used machined gasket surfaces and radial spigot fits, utilizing same concept as actual bonnet in stem. Support arms verified to be parallel to valve face to minimize installation errors.

NOTE: This design was verified with a mock-up prior to use at Peach Bottom #2 - 4th Refuel Outage.

2. Tool had sufficient supply of polishing cloth to lap most valves, without removal of heads.

3. Tool set-up is simplified, reducing set-up time and providing better assurance for repeatability.

B. Results

1. Failure rate was reduced significantly on Unit #2, 5th Refueling Outage. Four of eight valves passed the initial leak rate.

2. Imprint left by poppet during this outage (February-June 1982) showed 360 degrees circumferential contact on the valves disassembled at varying widths.

3. Amount of polishing required to obtain 360 degrees seat contact of the desired width was significantly reduced in time.

4. General Electric seat contour measuring tool was utilized to determine the seat angle on the No. 2 Unit No. 86 "B" outboard MSIV. General Electric verified the seat angle contour was consistant across the machined surface.

5. Failure rate on Unit 3, 5th Refueling Outage (February 1983), five of eight valves passed. Only one valve had off scale leakage.

6. General Electric measured three (3) MSIV valves, the 80 "A", 90 "C", 80 "D" valves during the February 1983 Unit 3 Refuel Outage. The results showed minimal guide wear and a consistant inbody seat angle on two of the three valves. Only one valve the 80 "D" appeared to have some guide wear.

IV. Related Improvements

A. Pilot Seat Verification

1. Developed test rig capable of testing for pilot seat leakage (1981 Unit #3 Refuel Outage).

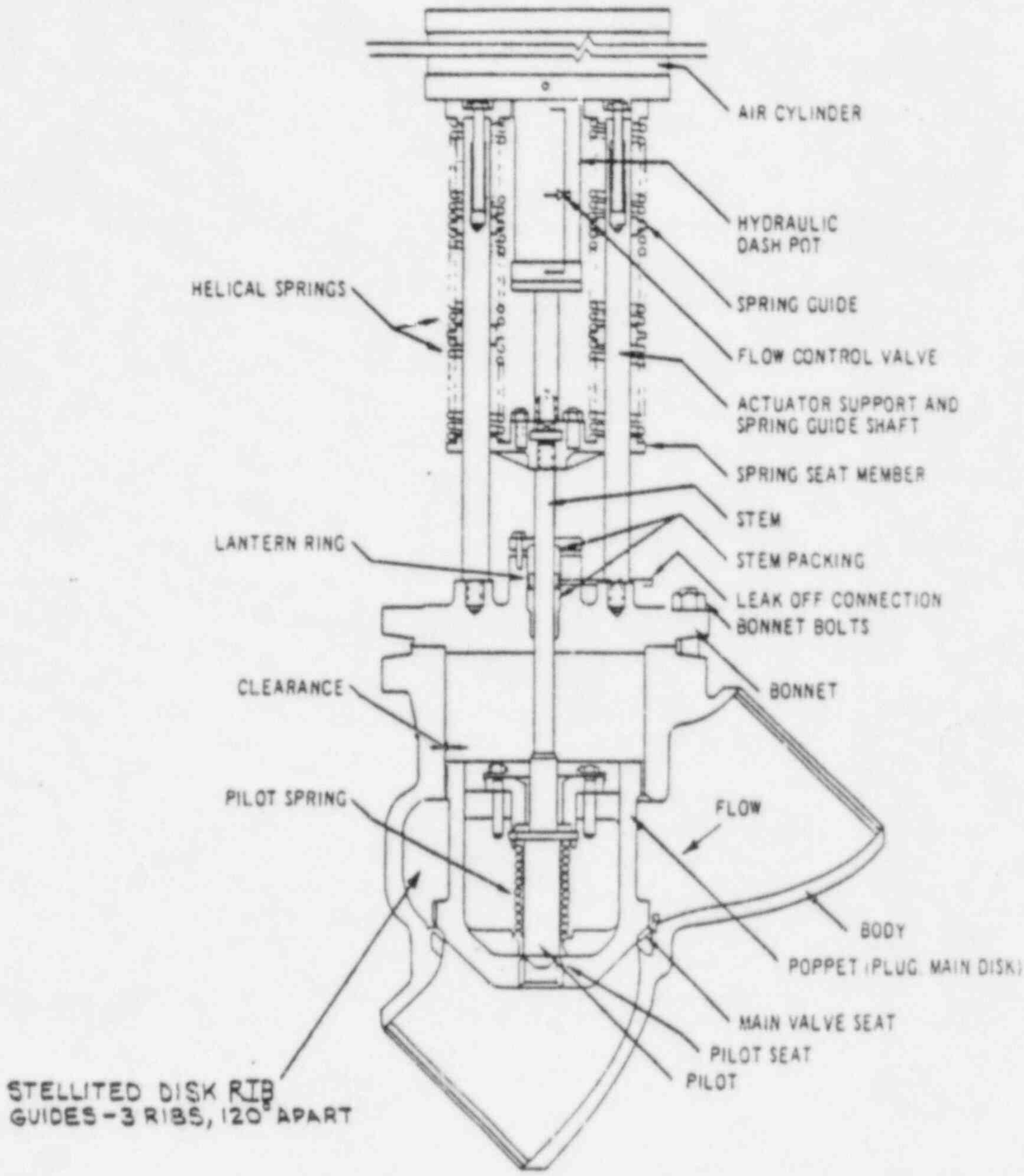
2. Modified Dexter supplied tool to replace hand operated lapping plates to polish poppet seat.

B. Valve Leak Rate Testing

1. Test Plug - Fabricated and utilized plug to measure actual valve leakage of outboard valve when installed in inboard valve. (1981 - Unit 3 Refuel Outage)

2. Maintenance program, procedures, reviewed periodically with valve manufacturer to refine where possible.

William A Taylor
1/5/84



PHILADELPHIA ELECTRIC COMPANY
PEACH BOTTOM ATOMIC POWER STATION
UNITS 2 AND 3
UPDATED FINAL SAFETY ANALYSIS REPORT

MAIN STEAM ISOLATION VALVE

FIGURE 4.6.1

Guidance for Reducing Release of Primary Coolant Inventory (Fission Products) Through Closed MSIVs

Scope

The following guidance is provided to form the basis of a Peach Bottom procedure which is intended to retain fission products which may leak through MSIVs. This guidance is applicable if the MSIVs have correctly isolated in response to safety system initiation, but for some reason, leakage through the MSIVs is greater than the 11 SCFH specified, or one or more MSIVs have failed to isolate.

Identification of Conditions Which Would Require Utilization of this Guidance

The conditions which would indicate that excessive leakage through the MSIVs is occurring and action must be taken to limit the release of fission products through the MSIVs would be evidence of gross fuel failure in conjunction with one or more of the following:

a) Failure of the main steam line radiation monitors to indicate reduced radiation levels following isolation. A review of past data should indicate the normal reduction in radiation levels following isolation. From this data, an appropriate entry level position can be identified.

b) Area radiation monitors in the turbine building which are affected by main steam line or high pressure turbine steam flow should be monitored following isolation to determine if adequate reduction in radiation levels has occurred. Again, past data should be used to establish a criteria for procedure implementation.

c) Portable radiation instrumentation may be used to survey areas of the turbine building near the main steam stop valves to determine if radiation levels in this area have reduced as expected following isolation.

d) Increase in vent stack releases could also be an indication of excessive MSIV leakage and loss of integrity of the main steam lines in the turbine building.

Procedural Steps To Be Implemented

a) Verify that turbine main steam stop valves, control valves, and bypass valves are closed.

b) If sufficient steam flow and pressure are availabe, maintain condenser vacuum with the SJAE and recombiner systems. Otherwise, isolate all main steam line drains, and users (turbine stop valve above seat drains, and steam supplies to the steam jet air ejectors, recombiner, reactor feedpump turbine high pressure steam lines, and the steam seals) to establish the integrity of the main steam line.

c) Maintain condenser circulating water system in service.

d) Maintain or re-establish turbine seals using auxiliary steam from boilers.

e) Close the condenser air offtake valves.

f) When condenser vacuum reaches approximately 7" Hg., start mechanical vacuum pump and throttle air off-take valve to mechanical vacuum pump to maintain off gas stack release rate below the tech. spec. limit.

g) If unable to maintain off gas stack release rate below the tech. spec limit, then throttle the condenser air off take valve and condenser vacuum breaker valve(s) to maintain off gas stack release rate below the alert level.

h) Monitor main steam line pressure. If pressure is above 20 psig (minimum detectable pressure), there is an indication of MSIV leakage and integrity of the main steam line.

i) If the above measures do not result in acceptable release rates, depressurize the primary coolant system to the suppression pool.

Under these conditions, the above guidance will provide the maximum retention time of fission products reaching the condenser through leaking turbine stop valves and control valves. If steam is available for the SJAE and recombiner systems, several days of holdup time could be expected for noble gases in the off gas holdup pipe. Otherwise, noble gases would eventually be released by way of the mechanical vacuum pump to the main stack. Much of the iodine would be plated out in the condenser.

If the main steam line shows no significant pressure above ambient, assumptions can be made that a leak exists in this piping or a valve between the main steam line and the condenser is leaking. If a leak exists in the piping, high airborne activity levels will occur in the turbine building or reactor building which should be identified by portable continuous air monitors. Leakage to the reactor building would be processed through the standby gas treatment system prior to release through the off gas stack. If leakage is into the turbine building, a decision should be made based on the airborne levels and vent stack radiation readings regarding the use of the turbine bypass valves to depressurize the main steam line to the condenser, thereby venting this piping through the condenser to the main stack via the mechanical vacuum pump. Depending on the size of the leak, this operation will reduce building airborne levels and transfer the release from the vent stack (with a short time delay) to the main stack (with a longer time delay) with additional reduction due to plate out in the condenser.

I. MSIV Test Results

A. Relief Request: Testing schedule relief requested for 4 of the 8 MSIV (80A, 86A, 80C, 80D)

1. Failure of 80C and 80D will not result in a penetration failure (redundant valve in series for which relief is not requested).

2. Only 80A and 86A on same penetration.

B. Last Test Results - Unit 2 (1982)

1. Only "D" steam line penetration failed.

2. 1982 test results does not reflect all of the improvements in the maintenance techniques.

3. It is highly probable that all four penetrations currently have leakage rates of less than the Tech Spec limits based on:

a. Improved maintenance techniques implemented during 1982 outage.

b. Limited exposure to operating conditions during current cycle (12 months).

C. Last Test Results - Unit 3 (1983)

1. Low leakage results on Unit 3 MSIV demonstrate adequacy of improved maintenance techniques implemented during 1981 Unit 3 outage.

2. All penetrations met Tech Spec limit of 11.5 CFH.

3. Only two valves exhibited leakage rates in excess of 100 CFH.

II. Feedwater Valve Test Results - Unit 2

Results of last four outages (1977, 1978, 1980, 1982).

1. No failures.

2. Highest valve leakage for all feedwater valves was 10.6 CFH.

3. Average leakage for all feedwater valves was 2.5 CFH.

4. Highest valve leakage on the feedwater valves for which relief is requested was 4.0 CFH.

5. Average leakage on the feedwater valves, for which relief is requested, was 1.4 CFH.

III. Probability that approval of exemption request will result in a breach of containment is negligible for the following reasons.

1. Relief requested for only seven isolation valves.

2. Redundant isolation valves provided on each penetration.

3. Recent test results show few large as found leak rates.

4. Improved maintenance techniques implemented during last outage.

5. Limited exposure to operating conditions during current cycle.

6. Forty of the sixty-six isolation valve penetrations have been tested within the last four months or will be tested prior to the outage. This enhances the confidence that containment integrity is intact.

IV. In the unlikely event that the MSIV penetrations exhibit leak rates in excess of Tech Spec limits, the off-site radiological impact is minimal for the following reasons.

1. Additional operator actions are available to minimize MSIV leakage.

2. BWR Owners' Group study confirms that even at MSIV leak rates significantly in excess of Tech Spec limits, off-site doses are a small fraction of Part 100 limits.

Unit 2 - Last MSIV Test Results (1982)

MSIV	As Found Leakage (CFH)	1980	1978
~~80A~~	33.3	>1800	
~~86A~~	~~4.0~~		
Steam Line "A"	~~4.0~~		
80B	> 1800		
86B	> 1800		
Steam Line "B"	> 1800		
~~80C~~	~~> 1800~~		
86C	4.9		
Steam Line "C"	4.9		
~~80D~~	~~> 1800~~		
86D	1.0		
Steam Line "D"	1.0		

Acceptance criteria: 11.5 SCFH @ 25 psig

VERSION 1
TOOL

TOO

(TOOL NOT
SEATED PROPERLY
NUTS INSTALLED
DIAL INDICATOR

Unit 3 - Last MSIV Test Results (1983)

MSIV	As Found Leakage (CFH)
80A	1106
86A	2.5
Steam Line "A"	2.5
80B	3.9
86B	7.6
Steam Line "B"	3.9
80C	48.0
86C	1.5
Steam Line "C"	1.5
80D	> 1800
86D	2.4
Steam Line "D"	2.4

Acceptance criteria: 11.5 SCFH @ 25 psig

Economic Penalty - Power Replacement Costs

A. Testing Outage (3 days)

Period: Dec. 3 through Dec. 6 - $1,356,000

Period: Feb. 20 through Feb. 23 - $1,081,000

B. Testing & Repair Outage (3 days + 6 weeks)

Period: Dec. 3 through Jan. 17 - $19,897,000

Period: Feb. 20 through April 5 - $15,435,000

Exemption Request

1. Delay LLRT of some MSIV and FW valves by two months beyond the two-year interval (8% extension).

2. Applies to 4 of the 8 MSIV and 3 of the 4 FW check isolation valves.

3. Involves 5 of the 66 containment pipe penetrations.

Penetration	Valve	Due Dates
"A" Main Steam	80A, 86A	2-20-84
"C" Main Steam	80C	4-2-84
"D" Main Steam	80D	4-14-84
"A" FW	28A, 96A	3-12-84, 3-13-84
"B" FW	28B	3-15-84

4. Reason for exemption request:

   - Need for additional planning will preclude start of pipe replacement prior to April 1984. The need to replace the piping was not identified until October 1983.

   - Will not attain the necessary core exposure by February 20, 1984, to permit the planned reload.

Pipe Integrity Issue

1. Inspected 126 of 136 non-conforming welds.

2. Found 26 welds with indications.

   - repaired 21 welds
   - Other 5 welds meet code

3. Implemented tighter technical specifications on primary coolant leakage limit and collection and leakage flow monitoring system.

4. Installed moisture monitoring system on 5 unrepaired welds.

5. PECo's and NRC's Safety Evaluation (Nov. 30, 1983) conclude the following:

   A. Continuous power operation of the plant-up to 4100 hours with 5 defective welds is justified by their conformance with the code required safety margin and by calculation of crack growth rates.

   B. Ten uninspected welds in the Recirculation, RHR and RWCU systems will not create any major concern to the continuous power operation of the plant for 4100 hours.

   C. The enhanced surveillance measures will provide adequate assurance that possible cracks in pipes will be detected before growing to a size that will compromise the safety of the plant.

APPENDIX D

Modifications to CRAC2

APPENDIX D

Modifications to CRAC2

Modifications to the CRAC2 computer program were necessary to provide the acute organ doses needed for the MSIV leakage analysis. The changes were made to cause a report of acute organ doses to be printed as a function of distance from the release. The doses printed are the average and maximum individual doses from external and inhalation exposure for selected time periods following the beginning of the accident.

In addition to causing this report to be printed, the program was also modified to give the inhalation dose for a 50 year dose commitment period. The original acute organ dose calculations for the CRAC2 program were for short commitment time periods to properly represent the likelihood of various acute health effects. The program was modified to uniformly calculate a 50-year dose commitment for all organs considered.

The changes made to the CRAC2 program are described in this section. The initial version of the program was that distributed by Sandia National Laboratories (Ritchie et al. 1984) with updates through February 7, 1983. Details of the code modifications are described here to allow interested persons to make similar modifications. A summary of the subroutines changed is presented below. Listings of portions of the program that have been changed follow the table. Lines of coding changed are enclosed in brackets.

Subroutine	Summary of Changes for the Special Dose Report
MAIN Program	Add COMMON Block SPECOP Call DISORG to print final report
CHRON	Add COMMON Block SPECOP Set acute dose factor to 50-year commitment value.
DAMAGE	Add COMMON Blocks SPECOP and SPECDS Call DISORG to initialize dose arrays Set current dose values into arrays for further processing Call DISORG to process data for current case

Subroutine	Summary of Changes for the Special Dose Report
DISORG	New subroutine to process dose data and call DOSRPT to print the special dose vs. distance report
DOSRPT	New subroutine to print the special report of dose vs. distance
OPT	Add COMMON Block SPECOP Modify READ and WRITE statements for extra option flag NDS

Modifications to MAIN Program

```
      COMMON /PLACE/ ZMAX(2), POP(16,34), TOA,                       MAIN
     1               IHP, IPOP, ISECNO(16), ISITE, ISTART,           MAIN
     2               MO                                              MAIN
      INTEGER   METBIN,DIRBIN,IRAND,IWGHT                            MAIN
C     LEVEL2,METBIN                                                  MAIN
      COMMON /METBIN/ METBIN(24,365)                                 MAIN
C     LEVEL2,RSMRYL                                                  MAIN
      COMMON /RSMRY/ RSMRYL(11424)                                   MAIN
      COMMON /METB/ DIRBIN(30,17), IRAND(30),                        MAIN
     1              IWGHT(30),SPACE(30),NTOT,NBIN                    MAIN
      COMMON /RANDAY/ NDAY(12,2), NTIME(12,2)                        MAIN
      COMMON /RES1/ DSCALE(10),ORGNAM,RESNAM(2,90),RESFAC(90),       MAIN
     1  RSCALE(90),IORGTM,NRES,NROPT,NSCALE                          MAIN
      COMMON/METEO/ METEOR(24,5)                                     MAIN
      COMMON /NRMLZ/ NORM,NLC                                        MAIN
      COMMON /ORDER/ ISPAT,ISIT,IPCFU,ITOP,IISO,ILEAK,ICHRN,IACUT,ILAT MAIN
      COMMON /SPATLR/ IORSRN(34)                                     MAIN
      REAL*8 ORGNAM, RESNAM
C
C*** AUGUST 1983 MODIFICATION BY DL STRENGE.
C
      COMMON /SPECOP/NDS,NHE,NOC,NIG
C
C     COMMON SPECOP HAS SPECIAL OPTION FLAGS IN ADDITION TO STANDARDS.
C
C     NDS .GT. 0 TO CALCULATE AND PRINT ALL ACUTE ORGAN DOSES VS. DISTANCE
C     NDS .EQ. 2 TO SUM ALL TIME PERIODS (EXCEPT FIRST) FOR DOSE COMMITMENT
C
C   NHE .T. 0 TO CALCULATE AND PRING A SPECIAL ACUTE EFFECTS REPORT.
C
C     NOC .GT. 0 TO PRINT A SPECIAL FILE OF GROUND CONCENTRATIONS FOR USE
C     BY THE COMPUTER PROGRAM DECON.
C***
C
C DAY(12)            NUMBER OF DAYS IN EACH MONTH                    MAIN
      DIMENSION DAY(12)                                              MAIN
      INTEGER   IBIN(30),IBIT(30)                                    MAIN
      DATA DAY/31.,28.,31. , 30.,31.,30. , 31.,31.,30. , 31.,30.,31./ MAIN
      DATA IBIN/30*0/, IBIT/30*0/                                    MAIN
C                                                                    MAIN
      IREST=-1                                                       MAIN
C                                                                    MAIN
C   CALL INPUT TO READ IN AND PRINT REQUIRED DATA                    MAIN
  100 CALL INPUT                                                     MAIN
      IF(ISI.NE.5) GO TO 105                                         MAIN
C     CLEAR WEATHER BIN COUNTERS                                     MAIN
      DO 102 NB=1,30                                                 MAIN
      IBIN(NB)=0                                                     MAIN
  102 IBIT(NB)=0                                                     MAIN
  105 CONTINUE                                                       MAIN
C                                                                    MAIN
C     CLEAR LEAKAGE SUMMARY TABLE                                    MAIN
      DO 22 IN = 1,11424                                             MAIN
   22 RSMRYL(IN)=0.0                                                 MAIN
C                                                                    MAIN
C   DO FOR EACH SITE PROCESSED                                       MAIN
      NPB3 = NPB(3)                                                  MAIN
      IS=1                                                           MAIN
      NP(3)=IS                                                       MAIN
                                                                     MAIN
```

```
C*** AUGUST 1983 MODIFICATION BY DL STRENGE
C
C     PRINT SPECIAL HEALTH EFFECTS REPORT IF NHE .GT. ZERO.
C
        IF(NHE.GT.0) CALL HERPT(NOT,NPB)
C
C                                                                              MAIN
C    PRINT SPECIAL ACUTE DOSE VS. DISTANCE REPORT IF NDS .GE. 1
C
       ANP = NP(5)
       L = NPB(2)
       NEARLY = 8
       ICALL = ISI+2
        IF(NDS.GT.0) CALL DISORG(ICALL,NST,NEARLY,L,ANP)
C
C***
C
C  CALL FSUM TO COMPUTE FINAL SUMMARIES                                        MAIN
       MDUM=0
       IF(NROPT .EQ. 0) CALL FSUM(L,PROB,MDUM,MONTH,IDAY,IHOUR)                MAIN
C      IF(NROPT .EQ. 0) CALL FSUM
       IF(NROPT .GT. 0) CALL FSUMOP(L,PROP,MDUM,MONTH,IDAY,IHOUR)              MAIN
C      IF(NROPT .GT. 0) CALL FSUMOP
C                                                                              MAIN
       GO TO 100                                                               MAIN
       END                                                                     MAIN
```

Modifications to Subroutine CHRON

```
C
      COMMON /ISO/ NAME(54), HALF(54), RLAM(54), TYPE(54),
     1          VD(54), IGRP(54), ITYPE(54), NGRP, NGPOLD, NIS, NISOLD
      REAL*8 NAME
      COMMON /INPT/ AMAG(50), BRATE(4), EVACON(10), P(20,4), PERM,
     1           PARMOD, SHFAC(4,2), SUBGRP, ID(18), IREST,
     2           NPB(4), NP(5), NAT, NIT, NOT, NCT,
     3           NPL, NPO, NPH, NPP, NPA, NRE,
     4           NTAPE, NT30, NUM, NEVAC, EVCONI(7,6), EVCOST(4)
      REAL*8 NUCLID(6,10)
      COMMON /EXPO/ CF(5,10,2), DAYS1(6), DAYS2(6), DCINH(10,8,6),
     1          CSING(10,8,6), SRING(10,8,6), RIING(10,8,6),
     2          RTING(10,8,6), DSCOM(6,8,6), NUCLID, DEC,
     3          PROFAC(6), RDLIM(6,2), TAGE(6), TEFF(6,10),
     4          TIMEK, SDEE(6,10,2), NIE(6), NEXP, INDEX(6,10), ICOST
     5          , TOTIME, NCRIT(6), INHAL(6)
      COMMON /HLTH/ AORG(13), EPLORG(8), LAORG(8), LAEFF(8),
     1          DL(4,8), FATFAC(8), PL(2,8), MRCON(8,10),
     2          INCON(8,7,54), GRCON(8,3,54), CLCON(8,54),
     3          TOTLAT(8,10), TOTORG(8), TOTLE, FATAL(6), EPLINJ(6),
     4          INDERL(8), INDLA(8), JORG(8), KORG(13), DOSMAR,
     5          NLA, NEARLY, NORGUS, NHLTH, NDL, INTIME, ORGDOS,
     6          FACT(2), FACTOR(8), ORGFAC(8), THRESH(2), IREST
      COMMON /ORDER/ ISPAT,ISIT,IPOPU,ITOP,IISO,ILEAK,ICHRM,IACUT,ILAT
      REAL*8 AORG, EPLORG, LAORG, LAEFF
      REAL*8 INHAL, INCON, MRCON, FATFAC
C
      COMMON/SPECOP/NDS,NHE,NDC,NIG
C
C*********************************************************************
C
C  THIS SUBROUTINE READS IN THE REQUIRED GROUND, CLOUD, AND INHALATION
C     DOSE CONVERSION FACTORS FROM THE HEALTH FILE DEPENDING ON THE
C     ORGANS SPECIFIED BY SUBGROUPS ACUTE AND LATENT.  IT THEN READS IN
C     ADDITIONAL DATA USED IN COMPUTING THE LATENT EFFECTS FROM CHRONIC
C     EXPOSURE AND PERFORMS PRELIMINARY PROCESSING OF THIS DATA.
C
C*********************************************************************
C
C  GORG(13)          VALID ORGAN NAMES IN THE ORDER THAT THEY ARE STORED
C                    ON THE HEALTH FILE
      REAL*8 AISO(54), GORG(13), ANAME
      DIMENSION TEMCLD(54), TEMGRD(3,54), TEMINH(7,54), INDISO(54)
      DIMENSION JKG(10),JKI(10)
C
      DATA BLANK /4H    /
      DATA GORG /4HLUNG,8HT MARROW,8HSKELETON,7HT E C L,7HST WALL,
     X 7HSI+CONT,8HULI WALL,8HLLI WALL,7HTHYROID,5HOTHER,6HW BODY,
     X 6HTESTES,7HOVARIES/
      DATA NITSV /10/
```

```
      GO TO 2895
 2903 WRITE(NOT,2807) L,JORG(L),(SRING(J,L,M),M=1,6)
      GO TO 2895
 2904 WRITE(NOT,2807) L,JORG(L), (RTING(J,L,M),M=1,6)
      GO TO 2895
 2905 WRITE(NOT,2807) L, JORG(L), (RTING(J,L,M),M=1,6)
 2807 FORMAT (1X,2I5,1P7E10.3)
 2895 CONTINUE
C
 2900 CONTINUE
C     TYPE 8888,SDEE(1,1,1),RDLIM(1,1),PROFAC(1),GRCON(NCRIT(I),3,
C    .   INDEX(I,J)),K,INDEX(I,J)
C8888 FORMAT(' CHRON: ',4E10.3,2I5)
C
C*****************************************************************
C   MODIFICATION BY DL STRENGE, SEPTEMBER 1983, TO PRINT GROUND
C   CONCENTRATION FILE.
C***************************************************************
      IF(NDC.GT.0) WRITE(15) NIE(6),NTE(1),(JKG(I),I=1,10),
     . (JKI(J),J=1,10)
C*****************************************************************
C   MODIFICATION BY RT HADLEY, NOVEMBER 1984, TO ALLOW SUMMING OF
C   ALL TIME PERIODS (EXCEPT FIRST) FOR DOSE COMMITMENT.
C*****************************************************************
      IF(NDS.NE.2) GOTO 2950
      DO 2940 IORG = 1,8
      DO 2940 I = 1, NIS
      INCON(IORG,1,I)=INCON(IORG,2,I)
      DO 2940 J=3,7
      INCON(IORG,1,I)=INCON(IORG,1,I)+INCON(IORG,J,I)
2940  CONTINUE
      RETURN
C  MODIFY INCON DEPENDING ON THE NUMBER OF TIME PERIODS TO BE
C    PROCESSED FOR LATENT EFFECTS FROM EARLY EXPOSURE
2950  IF (INTIME .EQ. 10) RETURN
      IT1 = INTIME + 1
      IT2 = INTIME + 2
      DO 80 IORG = 1,8
      DO 80 I = 1, NIS
      DO 80 J = IT2, 11
      INDX = J
      IF (J .GT. 7) INDX = 7
      INCON(IORG,IT1,I)=INCON(IORG,IT1,I)+INCON(IORG,INDX,I)
   80 CONTINUE
      RETURN
      END
```

Modifications to Subroutine DAMAGE

```
C
C TEMC(3,10)        CHRONIC INHALATION, INGESTION, & GROUND DOSE FOR 10    DAMAGE
C                   TIME PERIODS                                           DAMAGE
C TOTCHR(8,10)      EXPECTED CASES FROM CHRONIC DOSE FOR 8 ORGANS IN 10    DAMAGE
C                   TIME PERIODS                                           DAMAGE
C TOTCHR(8,10)      EXPECTED CASES FROM CHRONIC DOSE FOR 8 ORGANS IN 10    DAMAGE
C                   TIME PERIODS                                           DAMAGE
C TCORG(8)          EXPECTED CASES FOR EACH ORGAN OVER ALL TIME PERIODS    DAMAGE
C                   FROM CHRONIC EXPOSURE                                  DAMAGE
C ALABEL(4)         TITLES FOR CHRONIC OUTPUT                              DAMAGE
      COMMON/TOTDO1/ TOTDOS(8,6)                                           DAMAGE
      COMMON /INTCST/ CSTDEC,CSTINT                                        DAMAGE
      COMMON /DRLS/ DR(20)                                                 DAMAGE
      COMMON/EXPD/IEXPD                                                    DAMAGE
      COMMON/EXPOD/EXPD(6)                                                 DAMAGE
      COMMON/EXPTIM/EXPTM                                                  DAMAGE
      COMMON /POPOPT/ IPOPT
      COMMON /COSTS/ COST(6,16,2),CMILK(16,2),CCROP(16,2)
      COMMON /POPEXP/ POPEX(5,16,2)
      DIMENSION TEMC(3,10),TOTCHR(8,10),TCORG(8)                           DAMAGE
C*** AUGUST 1983 MODIFICATION BY DL STRENGE.
      COMMON /HEFAIN/ PIL(8,15),PFA(8,15),ANP
     {COMMON /SPECOP/ NDS,NHE,NDC,NIG
     {COMMON /SPECDS/DD(8,34)
C***
      DIMENSION INTRVL(4,5),NDID(5),ICRVD(6)                               DAMAGE
      DIMENSION FAT(6),EINJ(6)                                             DAMAGE
      DIMENSION IDRF(4),IDRI(5),IDMD(6),IDTD(7)                            DAMAGE
C
C*** AUGUST 1983 MODIFICATION BY DL STRENGE.
      DIMENSION PIN(8),PB(8,6),PFAT(8)
C***
      REAL*8 ALABEL(4)
C     REAL   ALABEL(4)                                                     DAMAGE
C      TGSTAT(34) IS TOTAL EXPOSURE TIME BY INTERVAL                       DAMAGE
      DIMENSION IWGHI(6)                                                   DAMAGE
```

```
C
C*** AUGUST 1983 MODIFICATION BY DL STRENGE
C    IF NDS .GT. 0 THEN INITIALIZE SPECIAL DOSE VS. DISTANCE ARRAYS.
C    BY CALLING SUBROUTINE DISORG WITH ICALL = 0.
C
      IF(NDS.GT.0.AND.NP(5).EQ.1) CALL DISORG(0,NSI,NEARLY,NPB2,ANP)
C***
C    START LOOP ON LEAKAGE MODES                                        DAMAGE
C
      DO 2500 L = 1,NPB2                                                DAMAGE
C
C*** AUGUST 1983 MODIFICATION BY DL STRENGE.
      DO 3009 IEARLY = 1,NEARLY
C
      PIN(IEARLY) =0.
      PFAT(IEARLY) = 0.
      DO 3008 K = 1,NSI
      DD(IEARLY,K) = 0.
 3008 CONTINUE
 3009 CONTINUE
C***
      NP(2) = L                                                         DAMAGE
      IF(NPB2 .EQ. 1 .AND. NPB1 .EQ. 1) GO TO 2                         DAMAGE
      READ(12) AC,GC,EFHGHT,HITE                                        DAMAGE
    2 EFLEAK = EF(L)                                                    DAMAGE
C  FINITE CLOUD CORRECTION                                              DAMAGE
      DO 3004  K = 1,NSI                                                DAMAGE
      SZ=SIGMAZ(K)                                                      DAMAGE
      HGT=HITE(K)                                                       DAMAGE
      SF(K)=SHINCF(SZ,HGT) * EFHGHT(K) * RT2OPI / SZ                    DAMAGE
 3004 CONTINUE                                                          DAMAGE
C                                                                       DAMAGE
C    CLEAR TOTALS ARRAYS                                                DAMAGE
      DO 25 ISEC = 1,NSEC                                               DAMAGE
      CSTMLK(ISEC,35)=0.                                                DAMAGE
      CSTCRP(ISEC,35)=0.                                                DAMAGE
      TPEOPL(ISEC,1)=0.0                                                DAMAGE
      TPEOPL(ISEC,2)=0.0                                                DAMAGE
      TPEOPL(ISEC,3)=0.0                                                DAMAGE
      WBODY(ISEC)=0.0                                                   DAMAGE
      DO 21 IEVAC=1,6                                                   DAMAGE
      FKILL(ISEC,IEVAC)=0.                                              DAMAGE
      FINJ(ISEC,IEVAC)=0.                                               DAMAGE
      PMO200(ISEC,IEVAC)=0.                                             DAMAGE
   21 CONTINUE                                                          DAMAGE
      TOTLA(ISEC) = 0.                                                  DAMAGE
      TOTCH(ISEC) = 0.                                                  DAMAGE
      DO 24 IH =1,10                                                    DAMAGE
      CST(ISEC,IH) = .0                                                 DAMAGE
24    CONTINUE                                                          DAMAGE
      DO 27 ILA = 1,8                                                   DAMAGE
      FLORG(ISEC,ILA) = 0.                                              DAMAGE
      FCORG(ISEC,ILA) = 0.                                              DAMAGE
   27 CONTINUE
```

```
      IF(NROPT .EQ. 5) FRES(ISEC,K)=ORGDOS                             DAMAGE
 2100 CONTINUE                                                         DAMAGE
C  END OF OUTER LOOP ON SECTORS  (ISEC=1,NSEC)                         DAMAGE
C                                                                      DAMAGE
C*** AUGUST 1983 MODIFICATION BY DL STRENGE.
C    IF NOS.GE.0 SET ORGAN DATA IN ARRAYS FOR FURTHER PROCESSING.
C    CALCUALTE NET DOSE FOR EVACUATION.
C
      IF(NOS.LE.0) GO TO 2110
      DO 2108 IE = 1, NEVAC
      IF(EVCONI(1,IE).LE.0.) GO TO 2108
      DO 2106 IRLY = 1,NEARLY
      DO(IRLY,K)=DO(IRLY,K) + TOTDOS(IRLY,IE)*EVCONI(1,IE)
 2106 CONTINUE
 2108 CONTINUE
 2110 CONTINUE
C
C***
      IF(NROPT .NE. 0) GO TO 2300                                      DAMAGE
C                                                                      DAMAGE
C     TOTAR IS THE TOTAL INTERDICTION AREA FOR 1=MILK,2=CROPS          DAMAGE
C     3=MILK+CROPS,4=PEOPLE @10YR,5=PEOPLE>10YR                        DAMAGE
      IF(ICOST .NE. 0) TOTAR(ICOST)=TOTAR(ICOST) + AREA(K) * EF(L) /   DAMAGE
     1 . 2589988.                                                      DAMAGE
C  DSTMAX IS THE MAXIMUM DISTANCE CORRESPONDING TO INTERD/DECONTAM AREAS DAMAGE
      IF(ICOST .NE. 0) DSTMAX(ICOST)=R(K) / 1609.34                    DAMAGE
      DO 2900 IEVAC=1,NEVAC                                            DAMAGE
C     MAXIMUM RADIUS OF FATALITY - DISFAT                              DAMAGE
      IF(FATAL(IEVAC) .GT. 0.) DISFAT(IEVAC)=R(K) / 1609.34            DAMAGE
C     MAXIMUM RADIUS OF INJURY - DISINJ                                DAMAGE
      IF(ERLINJ(IEVAC) .GT. 0.) DISINJ(IEVAC)=R(K) / 1609.34           DAMAGE
 2900 CONTINUE                                                         DAMAGE
      IF(K .NE. IDMD(ICMD)) GO TO 2140                                 DAMAGE
      DO 2130 IEVAC=1,NEVAC                                            DAMAGE
      AMD(ICMD,IEVAC)=TOTDOS(IBMP,IEVAC)                               DAMAGE
 2130 CONTINUE                                                         DAMAGE
      ICMD=ICMD + 1                                                    DAMAGE
 2140 CONTINUE                                                         DAMAGE
      IF(K .NE. IDTD(ICTD)) GO TO 2180                                 DAMAGE
      DO 2170 IEVAC=1,NEVAC                                            DAMAGE
      ATD(ICTD,IEVAC)=TOTDOS(ITHYP,IEVAC)                              DAMAGE
 2170 CONTINUE                                                         DAMAGE
      ICTD=ICTD + 1                                                    DAMAGE
 2180 CONTINUE                                                         DAMAGE
      GO TO 2300                                                       DAMAGE
C  NROPT=4, SAVE SIZE OF AREAS WITH DIFFERENT DECONTAMINATION FACTORS  DAMAGE
 2350 CONTINUE                                                         DAMAGE
      DO 2351 ISEC=1,NSEC                                              DAMAGE
      IF(ICOST .GT. 0) FRES(ISEC,NSI+ICOST)=FRES(ISEC,NSI+ICOST) +     DAMAGE
     1  AREA(K) * EF(L) / 2589988.                                     DAMAGE
      IF(DEC .LE. 1.0) GO TO 2351                                      DAMAGE
      FRES(ISEC,NSI+6)=FRES(ISEC,NSI+6) + AREA(K) * EF(L) / 2589988.   DAMAGE
      IF(DEC .LE. 2.0) GO TO 2351                                      DAMAGE
      FRES(ISEC,NSI+7)=FRES(ISEC,NSI+7) + AREA(K) * EF(L) / 2589988.   DAMAGE
      IF(DEC .LE. 20.0) GO TO 2351                                     DAMAGE
      FRES(ISEC,NSI+8)=FRES(ISEC,NSI+8) + AREA(K) * EF(L) / 2589988.   DAMAGE
```

```
 2400 CONTINUE                                                          DAMAGE
C   END OF LOOP ON SPATIAL INTERVALS  (K=1,NSI)                         DAMAGE
C
C*** AUGUST 1983 MODIFICATION BY DL STRENGE.
C    IF NDS.GT.0 THEN CALL DISORG TO PROCESS DOSE DATA FOR CURRENT
C    START TIME.
C
      IF(NDS.GT.0) CALL DISORG(1,NSI,NEARLY,L,PROB)
      IF(NHE.LE.0) GO TO 2413
C   STORE FATALITIES AND INJURIES FOR CURRENT LEAKAGE MODE L.
C
      DO 2410 IRLY = 1,NEARLY
      PIL(IRLY,L) = PIL(IRLY,L) + PIN(IRLY)
      PFA(IRLY,L) = PFAT(IRLY) + PFA(IRLY,L)
 2410 CONTINUE
C                                                                       DAMAGE
 2413 IF(NPOPT .NE. 0) GO TO 2560                                       DAMAGE
C***
C                                                                       DAMAGE
C        SUM OF THE COST                                                DAMAGE
C                                                                       DAMAGE
      DO 4000 ISEC=1,NSEC                                               DAMAGE
      CST(ISEC,8) = CST(ISEC,1) + CST(ISEC,2)                           DAMAGE
      CST(ISEC,9) = CST(ISEC,1) + CST(ISEC,2)                           DAMAGE
     1+CST(ISEC,3) + CST(ISEC,4) + CST(ISEC,5)                          DAMAGE
      CST(ISEC,10)= CST(ISEC,1) + CST(ISEC,2)                           DAMAGE
     1+CST(ISEC,6) + CST(ISEC,7)                                        DAMAGE
 4000 CONTINUE                                                          DAMAGE
C                                                                       DAMAGE
C   COMPUTE INTERD/DECONTAM RISK VS DISTANCE FOR THE 5 ICOST LEVELS     DAMAGE
C                                                                       DAMAGE
      DO 2800 ICST=1,5                                                  DAMAGE
      NOST=NDID(ICST)                                                   DAMAGE
      DO 2700 IDST=1,NOST                                               DAMAGE
      RSKINT(IDST,ICST)=0.0                                             DAMAGE
      INT=INTRVL(IDST,ICST)
      IF(INT.GT.NSI) GO TO 2700                                         DAMAGE
      IF(R(INT)/1609.344 .GT. DSTMAX(ICST)) GO TO 2700
      RSKINT(IDST,ICST)=(PROB/P(L,2))*AREA(INT)*EF(L)/(16.*AR(INT))     DAMAGE
 2700 CONTINUE                                                          DAMAGE
 2800 CONTINUE                                                          DAMAGE
 2550 CALL STORE(L,PROB,IB,MONTH,IDAY,IHOUR)                            DAMAGE
      GO TO 2500                                                        DAMAGE
C   STORE RESULTS FOR SPECIAL OPTIONS                                   DAMAGE
 2560 CALL STOROP(L,PROB,IB,MONTH,IDAY,IHOUR)                           DAMAGE
 2500 CONTINUE                                                          DAMAGE
      RETURN                                                            DAMAGE
      E N D
```

New Subroutine DISORG

```
      SUBROUTINE DISORG(ICALL,NSI,NEARLY,L,ANP)
C
C*** NEW SUBROUTINE ADDED AUGUST 1983 BY DL STRENGE.
C
C   THIS SOUBROUTINE INITIALIZES, STORES AND CONTROLS REPORT WRITING
C    FOR SPECIAL DOSE VS. DISTANCE REPORTS.  OPTION NDS.
C
      COMMON /SPECDS/DD(8,34)
      COMMON /NRMLZ/NORM,NLC
      COMMON /INPT/ AMAG(50), BRATE(4),EVACON(10),P(20,4),PERM,
     1              PARMOD,SHFAC(4,2),SUBGRP, ID(18), IREST,
     2              NPB(4),NP(5),NAT,NIT,NOT,NCT,
     3              NPL,NPD,NPH,NPP,NPA,NRE,
     4              NTAPE,NT30,NUM,NEVAC,EVCONI(7,6),EVCOST(4)
      DIMENSION TDAV(8,34,15),TDMX(8,34,15)
C
C     IF ICALL .EQ. 0 THEN INITIALIZE ARRAYS.
C
      IF(ICALL.GT.0) GO TO 20
      DO 15 LL=1,L
      DO 10 IK=1,NSI
      DO 5 IE=1,NEARLY
      TDAV(IE,IK,LL) = 0.
      TDMX(IE,IK,LL) = 0.
    5 CONTINUE
   10 CONTINUE
   15 CONTINUE
      GO TO 100
   20 IF(ICALL.GT.1) GO TO 45
      PROB = ANP
      IF(NORM.EQ.0.AND.P(L,2).GT.0.) PROB=PROB/P(L,2)
C
C   FOR INTERMEDIATE CALLS SET DATA INTO ARRAYS FOR CURRENT
C   LEAKAGE CATEGORY.
C
      DO 40 IK=1,NSI
      DO 30 IE = 1,NEARLY
      DS = DD(IE,IK)
      IF(DS.GT.TDMX(IE,IK,L)) TDMX(IE,IK,L)=DS
      TDAV(IE,IK,L) = TDAV(IE,IK,L) + DS*PROB
   30 CONTINUE
   40 CONTINUE
      GO TO 100
C
C   FOR LAST CALL FOR CURENT CASE, CALCULATE FINAL VALUES AND CALL
C   DOSRPT TO PRINT SUMMARY REPORT OF DOSE VS. DISTANCE.
C
   45 ISI = ICALL - 2
      PRBMET = 1.0
      IF(ISI.EQ.1.OR.ISI.EQ.2.OR.ISI.EQ.3.OR.ISI.EQ.6.OR.ISI.EQ.8)
     . PRBMET = 1./ANP
      DIV = PRBMET
      DO 70 LL = 1,L
      DO 60 IK = 1,NSI
      DO 50 IE = 1,NEARLY
      TDAV(IE,IK,LL)=TDAV(IE,IK,LL)*DIV
   50 CONTINUE
   60 CONTINUE
   70 CONTINUE
C
C   CALL DOSRPT TO PRINT REPORTS.
C
      CALL DOSRPT(TDAV,TDMX,L,NOT)
C
C   END OF SUBROUTINE, RETURN.
C
  100 RETURN
      END
```

New Subroutine DOSRPT

```
      SUBROUTINE DOSRPT(TDAV,TDMX,L,NOT)
C
C*** NEW SUBROUTINE ADDED AUGUST 1983 BY DL STRENGE.
C
C   THIS SUBROUTINE WRITES A SPECIAL OUTPUT REPORT FOR EACH LEAKAGE
C     CATEGORY FOR DOSE V.. DISTANCE CALCULATIONS, OPTION NDS.
C
      COMMON / SPATL/ AR(34),AREA(34), AVGVEL(34),CHIOO(34),
     1                EFHGHT(34),HITE(34),R(34),RB(34),RHRS(34),
     2                TI(34),TIME(34),SIGMAZ(34),VEL(34),IRAIN(34),
     3                ISTA(34),NSI,NSIOLD
      COMMON /HLTH/  AORG(13),ERLORG(8),LAORG(8),LAEFF(8),
     1              DL(4,8),FATFAC(8),PL(2,8),MRCON(8,10),
     2              INCON(8,7,54),GRCON(8,3,54),CLCON(8,54),
     3              TOTLAT(8,10),TOTORG(8),TOTLE,FATAL(6),ERLINJ(6),
     4              INDERL(8),INDLA(8),JORG(8),KORG(13),DOSMAR,
     5              NLA,NEARLY,NORGUS,NHLTH,NDL,INTIME,ORGDOS,
     6              FACT(2),FACTOR(8),ORGFAC(8),THRESH(2),IREST
      REAL*8 AORG,ERLORG,LAORG,LAEFF
      REAL*8 INCON,MRCON,FATFAC
      DIMENSION TDAV(8,34,15),TDMX(8,34,15)
C
C   WRITE ONE PAGE FOR EACH LEAKAGE CATEGORY.
C
      DO 20 LL=1,L
C
C   WRITE HEADING AND ORGAN NAMES FOR STANDARD
C   ACUTE HEALTH EFFECTS
C
      WRITE(NOT,1000) LL,(ERLORG(I),I=1,4),ERLORG(7)
C
C   WRITE LINE FOR EACH DISTANCE
C
      DO 10 ID = 1,NSI
      WRITE(NOT,2000) RB(ID),((TDAV(I,ID,LL),TDMX(I,ID,LL)),
     . I=1,4),TDAV(7,ID,LL),TDMX(7,ID,LL)
   10 CONTINUE
   20 CONTINUE
      RETURN
C
C   FORMAT STATEMENTS
C
 1000 FORMAT(1H1/26X,'SPECIAL DOSE VS. DISTANCE REPORT',
     1        ' FOR EARLY ORGAN EXPOSURES'//45X,
     2        'LEAKAGE CATEGORY',I3//50X,'DOSE IN REM'/
     3        1X,'DISTANCE',6X,A8,4(14X,A8)/
     4        2X,'METERS   ',5(2X,'AVERAGE    MAXIMUM   ')/)
 2000 FORMAT(1X ,F8.0,2X,1PE10.2,9(1X,E10.2))
      END
```

Modifications to Subroutine OPT

```
      SUBROUTINE OPT                                                       OPT
C                                                                          OPT
      COMMON /INPT/ AMAG(50), BRATE(4), EVACON(10), P(20,4), PERM,         OPT
     1              PARMOD, SHFAC(4,2), SUBGRP, ID(18), IREST,             OPT
     2              NPB(4), NP(5), NAT, NIT, NOT, NCT,                     OPT
     3              NPL, NPD, NPH, NPP, NPA, NRE,                          OPT
     4              NTAPE, NT30, NUM, NEVAC, EVCONI(7,6), EVCOST(4)        OPT
      COMMON /NRMLZ/ NORM,NLC                                              OPT
C*** AUGUST 1983 MODIFICATION BY DL STRENGE.
      COMMON /SPECOP/ NDS,NHE,NDC,NIG
C***
      REAL*8 SBGRP
C************************************************************************** OPT
C                                                                          OPT
C  THIS SUBROUTINE READS IN THE PRINT OPTIONS FOR DETAILED OUTPUT          OPT
C                                                                          OPT
C************************************************************************** OPT
C                                                                          OPT
   90 FORMAT(A2,18X,I5,4X,A3,7X,A3)                                        OPT
C
C*** AUGUST 1983 MODIFICATION BY DL STRENGE TO ADD NDS,NHE AND NDC TO
C    ALL READ AND WRITE STATEMENTS.
C   SEPT 1983 MODIFICATION BY DL STRENGE TO ADD NIG TO ALL READS.
C
C***                                                                       OPT
C                                                                          OPT
C  IF MAKING MODIFICATIONS, STORE REFERENCE CASE SUBGROUP ON FILE NAT      OPT
      IF(IREST.NE.0) GO TO 2009                                            OPT
      WRITE(NAT,90) SUBGRP,NCT,PARMCD                                      OPT
      WRITE(NAT,2010) NPL,NPD,NPH,NPP,NPA,NRE,NORM,NLC,NDS,NHE,NDC         OPT
     . ,NIG
C                                                                          OPT
C  READ OPTIONS SWITCHES                                                   OPT
 2009 READ(NIT,2010) NPL,NPD,NPH,NPP,NPA,NRE,NORM,NLC,NDS,NHE,NDC          OPT
     . ,NIG
 2010 FORMAT(16I5)                                                         OPT
      IF(IREST.EQ.1) RETURN                                                OPT
      WRITE(NOT,2020) NPL,NPD,NPH,NPP,NPA,NRE,NORM,NLC,NDS,NHE,NDC         OPT
     . ,NIG
 2020 FORMAT(//,20X,'* * * INPUT PRINT OPTIONS * * *',/,                    OPT
     6/' NPL=0 OR 1          PRINT OPTION FOR INTERDICT. & DECON. ',9X,I6, OPT
     7/' NPD=0 OR 1          PRINT OPTION FOR DISPERSION          ',9X,I6, OPT
     8/' NPH=0,1,2,OR 3      PRINT OPTION FOR HEALTH EFFECTS      ',9X,I6, OPT
     9/' NPP=0 OR 1          PRINT OPTION FOR TRIAL RESULTS       ',9X,I6, OPT
     1/' NPA=0,1, OR 2       PRINT OPTION FOR ACTIVITY & AIR CONC.',9X,I6, OPT
     2/' NRE=0,1, OR 2       PRINT OPTION FOR ECONOMIC COSTS      ',9X,I6, OPT
     3/' NORM=0,1            INPUT PROB. NORMAL. OPTION IN EFFECT ',9X,I6, OPT
     4/' NLC=0,1, OR 2       OPTION TO SKIP LAT/CHRON CALCULATIONS',9X,I6, OPT
C*** AUGUST 1983 MODIFICATION BY DL STRENGE, NOV 1985 BY RT HADLEY.
     5/' NDS=0,1 OR 2        OPTION FOR ACUTE ORG. DOSE VS. DIST. ',9X,I6, OPT
     6/' NHE=0 OR 1          OPTION FOR ACUTE HE FOR ALL ORGANS   ',9X,I6, OPT
     7/' NDC=0 OR 1          OPTION TO WRITE GROUND CONC. FILE    ',9X,I6, OPT
C*** SEPT 1983 MODIFICATION BY DL STRENGE.
     8/' NIG=0 OR 1          OPTION TO DELETE INGESTION PATHWAYS  ',9X,I6) OPT
C***                                                                       OPT
 2040 CONTINUE                                                             OPT
      RETURN                                                               OPT
      END                                                                  OPT
```

APPENDIX E

Model for Filling, Deposition, and Release Processes In BWR Steam Lines Under Leaking MSIV Conditions

1. QUANTITATIVE TEMPERATURE TRANSIENT ESTIMATES

1.1 Pipe Cooling Through Insulation

For calculation of cooling of the main steam lines by conduction through the insulation after MSIV closure, two simplifications can be made:

1) The sensible heat excess above that present at ambient temperature is mainly stored in the pipe rather than the insulation.

2) The thermal conductivity of the pipe is sufficiently high that the pipe metal temperature does not vary much radially.

This allows writing the intuitive equation for the pipe cooling.

$$m_1 C \frac{d(T-T_A)}{dt} = -hA_1(T-T_A) \qquad (1.1)$$

where

m_1 = pipe mass per unit of pipe length

C = pipe heat capacity

T, T_A = pipe temperature and ambient temperature, respectively

A_1 = heat transfer area per unit of pipe length for cooling to atmosphere

h = heat transfer coefficient for cooling

If the outer surface of a 4-inch thick layer of felted rockwool were kept at ambient temperature on a 30-inch diameter pipe, we could take:

$$h = \frac{k}{r_2 \ln \frac{r_2}{r_1}}$$

$$= \frac{2.25 \times 10^{-2}\ \text{Btu/(hr ft } {}^0\text{F)}}{1.58333\ \text{ft} * \ln(19''/15'')} \qquad (1.2)$$

$$= 0.06\ \text{Btu/hr ft}^2\ {}^0\text{F}$$

Actually, the necessary heat transfer by convection from the insulation to ambient air offers some additional resistance to heat flow. An improved estimate gives:

$$h = 0.055 \text{ Btu/hr ft}^2 \text{ °F} \tag{1.3}$$

Equation 1.1 has the solution

$$T-T_A = (T-T_A)_o \exp\left(-\frac{hA_1}{m_1C}t\right) \tag{1.4}$$

where $(T-T_A)_o$ is the initial excess of pipe temperature above ambient.

For a 30-inch outside diameter pipe with 1 3/8-inch thick carbon steel walls and 4-inches of insulation, Equations 1.3 and 1.4 give:

$$T-T_A = (T-T_A)_o \exp(-1.2 \times 10^{-2} t) \tag{1.5}$$

where t is in hours. This gives a drop in the temperature difference from ambient to 1/e or 37% of the initial value in 83 hours, and to ~30% of the initial value in 4 days.

If the steam line insulation is only 2 inches thick, the overall heat transfer coefficient (conduction through insulation, then natural convection from the exterior) h is 0.107 Btu/(hr ft^2 day f), and the time for the temperature difference to drop to 1/e of its initial value is 47 hours.

1.2 Pipe Cooling by Conduction Through Pipe Hangers

Pipe hangers and pipe stops provide a conduction path through metal from BWR steam line pipes to the surroundings. For pipe hangers, the pipe is usually gripped by a split-ring saddle bolted on both sides. The saddle typically makes excellent thermal contact with the pipe, the insulation (lagging) being applied after installation. The saddle is supported by a bar (or sometimes two bars) of typically 1 ½-inch diameter which provides the support from beams or walls, frequently through shock suppressors or variable springs. We can consider the bar as the heat-flow limiting part of a path from the split saddle to the surroundings.

This picture allows us to estimate the transient cooling effect on the steam lines. Carlslaw and Jaeger (Ref. E.1) present a solution to the time dependent cooling of a region of uniform cross section located in the region $X>0$, with no heat transfer in other than the $-X$ direction for $X>0$. At the plane at $X=0$, heat can flow in the $-X$ direction with a finite heat transfer coefficient to a heat sink at ambient temperature. The temperature is uniform in the region $X>0$ at time $t=0$. It is evident that this Carlslaw and Jaeger model and solution provides a fair one-dimensional representation of the cooling of a section of BWR pipe in the vicinity of a pipe hanger after MSIV closure.

In the region $X>0$, the temperature obeys

$$\frac{\partial}{\partial t}(T-T_A) = \frac{k}{\rho C}\frac{\partial^2}{\partial x^2}(T-T_A) \tag{1.6}$$

where k, ρ, and C are thermal conductivity, density, and heat capacity of the pipe walls. The boundary condition at the $X=0$ plane we take as

$$k\,A_p\,\frac{\partial}{\partial x}(T-T_A)\bigg|_{x=o} = h_H A_H\,(T-T_A) \tag{1.7}$$

where A_p is cross sectional area of the steam line pipe wall metal, and h_H and A_H are the heat transfer coefficient and effective heat flow area, respectively, of the heat path through the pipe hanger to the surroundings.

Equation 1.7 equates the heat flow to the plane $X=0$ (saddle location) to that out to the heat sink (surroundings). The Carlslaw and Jaeger solution to Equations 1.6 and 1.7 is:

$$T-T_A = (T-T_A)_o \quad \text{erf}\,\frac{x}{2\sqrt{\kappa t}} + \exp\,(wx + w^2\kappa t)\,\text{erfc}\,\left(\frac{x}{2\sqrt{\kappa t}} + w\sqrt{\kappa t}\right) \tag{1.8}$$

where

$$\kappa = \frac{k}{\rho C} \tag{1.9}$$

$$w = \frac{h_H\ A_H}{k\ A_p}$$

x = distance from the split-ring saddle, and erf and erfc are functions defined by

$$\mathrm{erf}(z) = \frac{2}{\sqrt{\pi}} \int_0^\infty e^{-u^2} du \tag{1.10}$$

$$\mathrm{erfc}(z) = 1 - \mathrm{erf}(z) \tag{1.11}$$

For a BWR main steam line and pipe hanger with single bar support we take the following values:

$$A_p = \pi\,[(15")^2 - (15\text{-}1\ 3/8")^2] = 123.65\ \mathrm{in}^2 = 0.8587\ \mathrm{ft}^2$$

$$A_H = \frac{1}{4}\pi\,(1.5")^2 = 1.767\ \mathrm{in}^2 = 1.227 \times 10^{-2}\ \mathrm{ft}^2$$

$$k = 30\ \frac{\mathrm{Btu}}{\mathrm{hr\ ft\ ^\circ F}}$$

$$\rho = 490\ \mathrm{lbm/ft^3} \tag{1.12}$$

$$C = 0.108\ \mathrm{Btu/lbm^\circ F}$$

$$h_H = \frac{k}{L_{path}} = \frac{30\ \mathrm{Btu/hr\ ft\ ^\circ F}}{3\ \mathrm{ft}}$$

$(T-T_A)_o$ = 450°F (initial temperature difference between pipe and heat sink)

The area A_H for heat flow to the surroundings we have taken as the area of a single supporting 1 ½" diameter bar. The length L_{path} of this heat path we have taken as 3 ft, which is representative of short insulated hanger rods to beams or walls, or longer bar supports that themselves dissipate heat by convection and radiation. We will show in a subsequent section that radiation from an uninsulated bar may give a larger h_H and hence more rapid cooling than this model of conduction to a heat sink and the values in Equation 1.12.

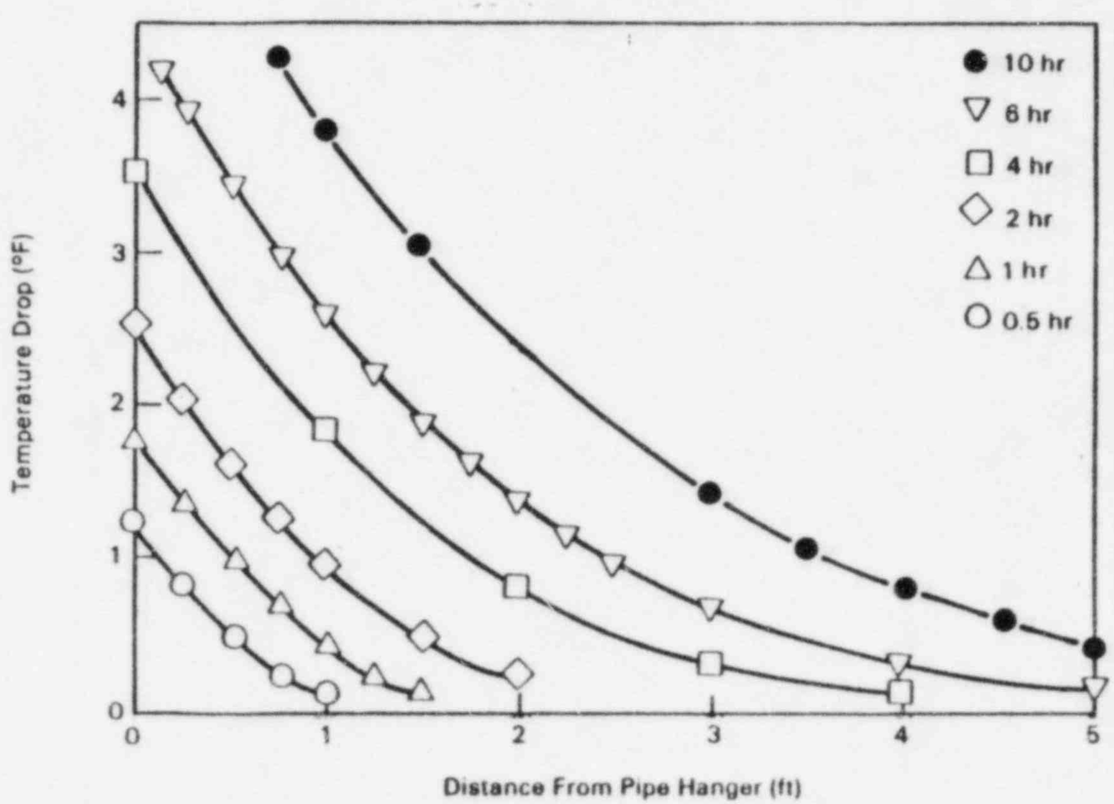


Figure 1.1 Temperature transient in main steam line near a pipe hanger with 1.5" diameter bar with insulated sides conducting to a heat sink 3 feet distance

With the assumptions of Equation 1.12, Equation 1.8 can be used to calculate the results shown in Figure 1.1. The vertical axis in the graph is $(T-T_A)_0 - (T-T_A)$, so it is essentially the amount the temperature near the pipe hanger has dropped below the temperature in the pipe farther away. This temperature difference can be expected to drive a convective flow in the steam within the pipe. See Section 2.0 of this appendix for estimates of the convective flow velocity driven by temperature differences of this magnitude.

The results in Figure 1.1 assumed a single solid hanger rod of 1 1/2" diameter as the heat leakage path to a heat sink 3 feet from the main steam line. No radiation from the hanger rod surface was taken into account. Before presenting an approximate model for radiative heat losses from protrusions, we should note that the heat leak used to calculate Figure 1.1 is representative of some pipe supports and small compared with others. The parameter $h_H A_H$ or $(k/L)A_H$ is close to that for the WNP-2 pipe support depicted in the Burns & Roe Drawing MS-95 for WNP-2. Here L is length of the heat path to a heat sink. This drawing shows the main steam line supported 2'10" from heavy overhead structure by a 2" O.D. Schedule 80 pipe for 1'6" of this distance and heavier fittings for most of the remainder. By contrast, the WNP-2 pipe support shown in Burns & Roe Drawing MS-94 should provide a heat leak several times as large.

Long protrusions through the main steam line insulation, like the longer pipe hanger shown in Burns & Roe Drawing MS-44 for WNP-2, provide a significant heat leak by radiation, even though an effective heat sink for conduction is many feet away. We have developed an approximate model for such long radiating protrusions. Our model gives as heat transfer coefficient h for such a protrusion:

$$h = k\lambda \tag{1.13}$$

where

$$\lambda = \left\{\frac{P\varepsilon\sigma}{Ak} \left[(T+T_A)(T^2+T_A{}^2\right]_{Av}\right\}^{1/2} \tag{1.14}$$

P = radiating area per unit of protrusion length, or radiating perimeter

ϵ = emissivity

σ = Stefan-Boltzmann radiation constant

A = area of good conductor in the protrusion

k = thermal conductivity

T = absolute temperature in the protrusion

T_A = absolute temperature in the surroundings

$[\ ]_{Av}$ = indicate somes appropriate averaging to linearize the thermal equations.

Using appropriate values for a 1½" diameter hanger rod, we calculate the heat transfer coefficient h used as h_H in Equations 1.6-1.11 to calculate the results in Figure 1.2. Note that this gave a stronger heat leak than conduction to a heat sink 3 feet distant.

2. AXIAL CONVECTIVE FLOW ESTIMATES

2.1 THEORY, VERIFICATION, AND IMPLIED RESULTS FOR BWR STEAM LINES

In any compartment filled with a liquid or gas whose density varies with temperature, non-uniform temperature will lead to a convective flow pattern. This is as true for horizontal cylindrical pipes as for any other shape, though the magnitude of the velocities depends on geometry as well as fluid properties and strength of the heat source or sink. Bejan and Tien (Ref. E.2) state:

> "The temperature difference applied across the ends of a horizontal pipe filled with stagnant fluid gives rise to a counterflow natural convection pattern of the kind sketched in Figure 1. The fluid motion is caused by the axial temperature gradient. The resulting changes in the hydrostatic pressure gradient forces the cold fluid to flow along the bottom towards the warm end while the warmer stream returns along the top half of the pipe.
>
> In spite of its common existence and relatively simple configuration, this type of flow has received relatively little attention."

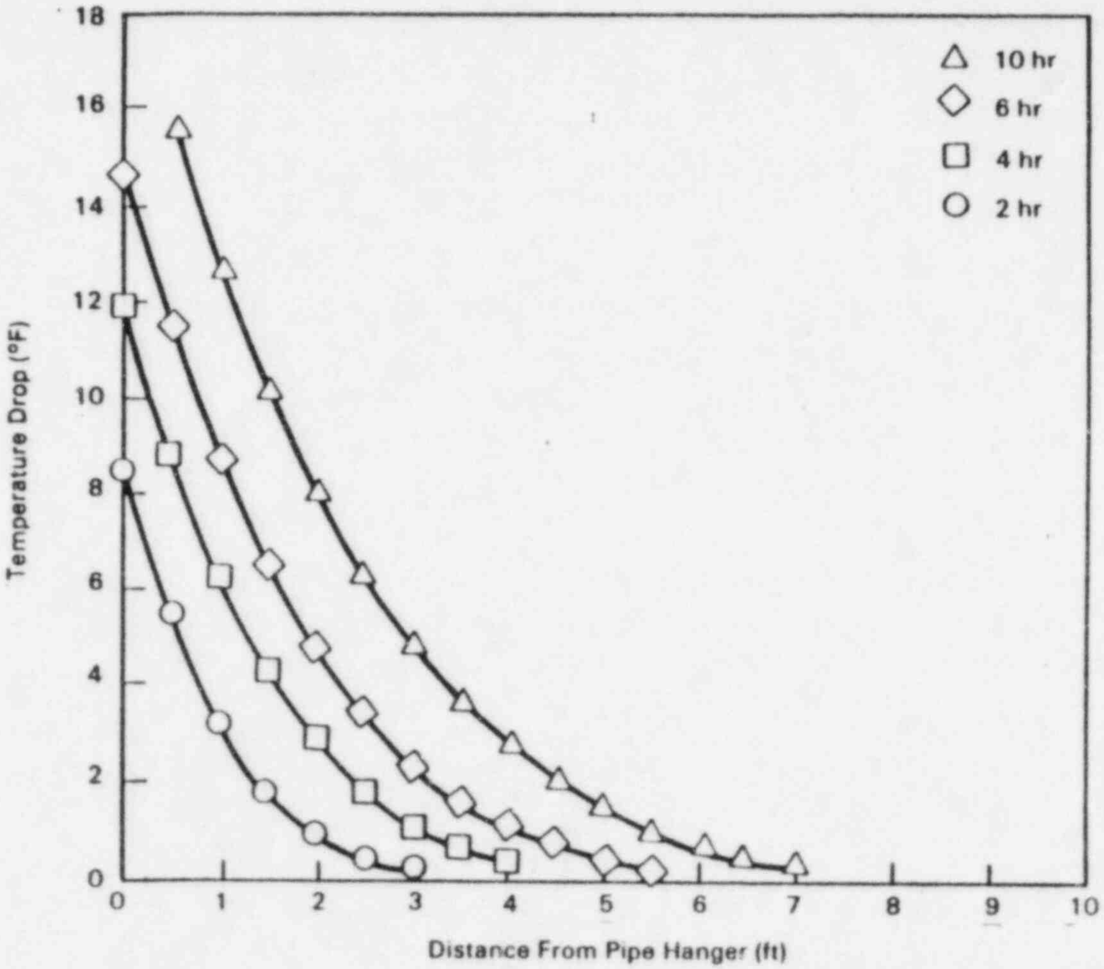


Figure 1.2 Temperature transient in main steam line near pipe hanger suspended by long uninsulated 1.5" diameter bar radiating to surroundings

Bejan and Tien (Ref. E.2) have performed an analytical perturbation analysis of the natural convective flow inside pipes driven by axial temperature difference. A sequence of papers (Refs. E.3, E.4, and E.5) presents a similar analytical perturbation analysis for rectangular ducts (rather than cylindrical pipes), a verification and extension of this analysis with a numerical computer model, and an experimental verification using an instrumented rectangular parallelepiped flow tank.

A number of observations are common to the horizontal duct and the horizontal pipe, as pointed out by these authors (Refs. D.2, E.3, E.4, and E.5). In a horizontal flow channel whose height is small compared with its length and for which the axial temperature gradient is not excessively large, the flow in a region far from the hot and cold ends (referred to as the "core region") will have a fairly simple pattern, toward the hot end below the horizontal midplane. Vertical upward or downward flow and a more complicated pattern occurs near the hot and cold ends, respectively. At small temperature differences (more generally, at small Rayleigh numbers), the flow velocities in the core region will vary linearly with the temperature difference (or more generally, the Rayleigh number). At higher Rayleigh numbers, the flow velocities increase less rapidly than linearly with Rayleigh number.

It should be noted that those theoretical treatments are presented and the experimental results interpreted in terms of dimensionless velocities, dimensionless groups of fluid properties (Grashof number, Prandtl number, Rayleigh number), and dimensionless geometry parameters (aspect ratio h/l or height/length for ducts, r_o/l or radius/length for pipes). This allows the interpretation of the results for one fluid and range of duct or pipe sizes to predict results for another fluid and another duct or pipe size.

The results of Ref. E.2 for pipes implies an axial velocity in the core region given by

$$V_z = -\frac{\text{[illegible]}_{o}\,(T_h-T_c)}{\mu l}\, C_c\ \frac{1}{8}\left(\frac{r}{r_o}\right)\left[\left(\frac{r}{r_o}\right)^2\right]^{-1}\ \sin\theta \qquad (2.1)$$

while Refs. E.3, E.4, and E.5 find a longitudinal flow velocity in the core region of rectangular ducts given by

$$V_z = \frac{\rho g \beta h^3 (T_h - T_c)}{\mu l} C_R \left[\frac{1}{6} \left(\frac{y}{h}\right)^3 - \frac{1}{4} \left(\frac{y}{h}\right)^2 + \frac{1}{12} \left(\frac{y}{h}\right) \right] \tag{2.2}$$

Here the common symbols are:

ρ = fluid density

g = acceleration of gravity

β = coefficient of thermal expansion ($1/T_{ABS}$ for gases)

μ = fluid viscosity

l = pipe or duct length

$T_h - T_c$ = temperature difference, hot end minus cold end.

The symbols y and h are distance above duct bottom and duct height, respectively. The symbols r, r_o, and θ are distance from pipe axis, pipe inside radius, and angular position measured using pipe axis as vertex and one horizontal half plane as reference.

C_c and C_R are parameters for the (circular) pipe and (rectangular) duct, respectively, and have the value unity for sufficiently low Rayleigh numbers and height to length ratios, but C_c and C_R are less than unity at higher Rayleigh numbers and greater height to length ratios. Reference E.3 gives an approximate expression for C_R based on theory,

$$C_R = 1 - 3.48 \times 10^{-6} (Ra)^2 (h/l)^3 \quad (\text{for } Ra^2 (h/l)^3 \ll 2.87 \times 10^5) \tag{2.3}$$

where the Rayleigh number Ra is for ducts

$$Ra = Gr * Pr, \tag{2.4}$$

with Grashof number Gr and Prandtl number Pr given by

$$Gr = \frac{\rho^2 g \beta h^3 (T_h - T_c)}{\mu^2} \tag{2.5}$$

$$Pr = \frac{C_p \mu}{k} \quad (2.6)$$

Here C_p is heat capacity, k is thermal conductivity, and the other properties of the fluid were previously defined. Imberger (Ref. E.5) actually determined values for C_R in verifying Equation 2.2, and values taken from a graph in Ref. E.5 are shown in Table 2.1.

It can be presumed that the factor C_c for the horizontal cylinder compartment (pipe) behaves similarly to the factor C_R for rectangular ducts, namely that C_c has the value one up to some value of $(Ra)^2 \ (r_o/l)^N$ for some positive value N, possibly N=3. For higher values of $(Ra)^2 \ (r_o/l)^N$, a smaller value of C_c should apply. This is consistent with the discussion in Ref. E.2, in which a procedure to use for determining C_c for higher values of Ra and r_o/l is given. It should be noted that for the cylindrical compartment, the Grashof number is taken as

$$Gr = \frac{\rho^2 g \beta r_o^{\ 3}(T_h - T_c)}{\mu^2} \quad (2.7)$$

with the Rayleigh number still given as the product of the Grashof and Prandtl numbers.

Table 2.1. Values of Rectangular Duct Velocity Correction C_R for Equation 2.2, Deduced From the Graph of Experimental Results in Reference 5

$(Ra)^2(h/l)^3$ →	$<5 \times 10^3$	10^4	10^5	10^6	10^7	10^8	10^9	10^{10}	10^{11}
Cr	1.	.96	.88	.74	.51	.30	.17	.09	.05

The maximum axial velocity magnitudes in the cylindrical pipe according to Equation 2.1 occur at

$$\frac{r}{r_o} = \frac{1}{\sqrt{3}} \text{ and } \sin\theta = \pm 1, \tag{2.8}$$

while the maximum longitudinal velocity magnitudes for the rectangular duct occur at

$$\frac{y}{h} = \frac{1}{2}\left(1 \pm \frac{1}{\sqrt{3}}\right) \tag{2.9}$$

The corresponding maximum velocity magnitudes are:

$$|V_z|_{max} = \frac{\rho g \beta r_o^3 (T_h - T_c)}{\mu l} C_c \times 4.81125 \times 10^{-2} \text{ (pipes)} \tag{2.10}$$

$$|V_z|_{max} = \frac{\rho g \beta h^3 (T_h - T_c)}{\mu l} C_c \times 8.01875 \times 10^{-3} \text{ (rectangular ducts)} \tag{2.11}$$

Note that from Equations 2.10 and 2.11, the ratio of the maximum velocity in a cylindrical pipe to that in a rectangular duct whose height h equals the pipe diameter is 0.75 C_c/C_R, which is a plausible result. Since we expect the velocities in the cylindrical pipe to be on the order of 75% of those in a rectangular duct of similar height, we will use for values of C_c the values of C_R interpolated from Table 2-1, where the value of h is set to $2r_o$.

Figure 2.1 shows the predicted maximum axial convective velocities for a range of temperature differences between two locations 15 feet apart axially in a BWR steam line. The mean linear velocity at the nominal MSIV leak rate is shown on the graph for comparison. Values assumed in calculating the results in Figure 2.1 using Equation 2.10 and Table 2.1 are:

$\rho = 3.91 \times 10^{-4}$ g/mcm^3 (superheated steam at 550°F and 1 atmosphere pressure)

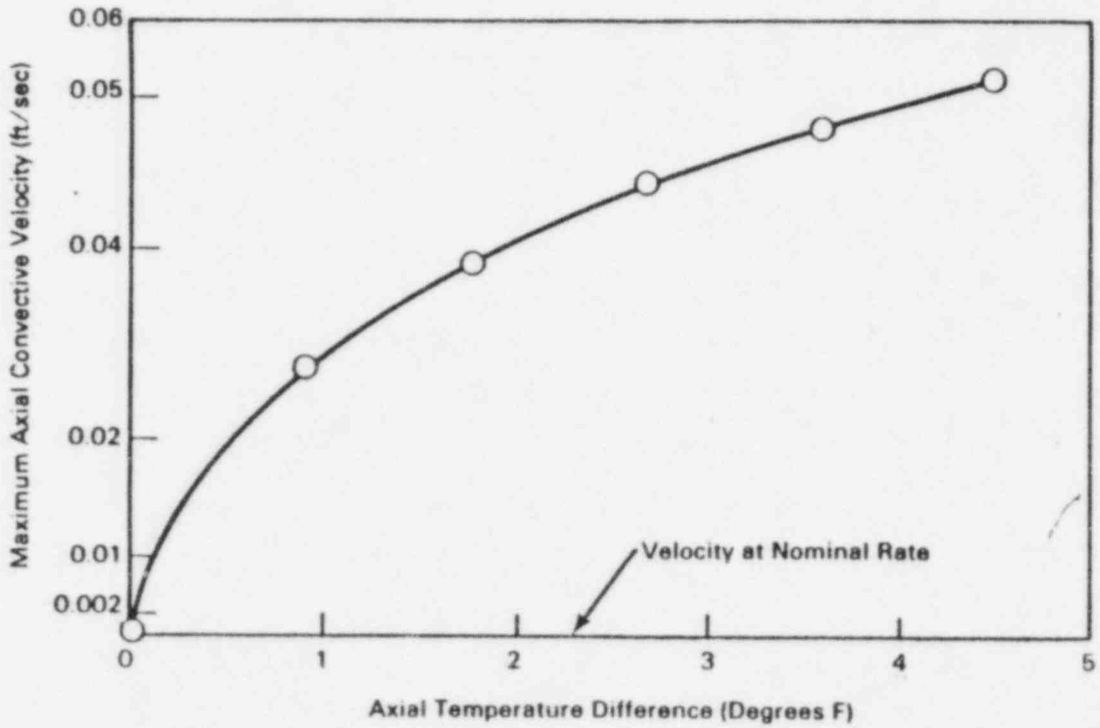


Figure 2.1 Axial convective velocities in a main steam line for varying temperature differences along a 15-foot section of pipe. The mean flow velocity at the nominal MSIV leak rate is shown for reference.

$$g = 980.665 \text{ cm/sec}^2$$

$$\beta = \frac{1}{T} = \frac{1}{560.9^0K} \text{ (coefficient of thermal expansion)} \qquad (2.12)$$

$$r_0 = 34.6075 \text{ cm} = 13.625 \text{ inches} \quad \text{(pipe radius)}$$

$$\mu = 198.146 \times 10^{-6} \quad \text{poise}$$

$$l = 457.2 \text{ cm} = 15 \text{ ft}$$

$$\frac{C_p \mu}{k} = \text{Prandtl no. of steam} = 1.06$$

Lower temperatures would give higher convective velocity, due to higher coefficient of thermal expansion β, lower viscosity μ, and high density ρ at a given pressure.

Note that the temperature gradients produced by the local cooling by pipe hangers will produce convective velocities large compared with the mean flow velocity in the pipe at the nominal MSIV leakage rate.

2.2 Other Experimental Verification

The verification of the nature of the longitudinal flow in rectangular ducts (whose width is large compared with their height h) was used in the preceding discussion as confirmation of a similar theory for cylindrical ducts. A direct measurement of the axial convective velocities ducts is reported in the abstract literature (Ref. E.8), but we have not been able to obtain a translation of the paper (which appeared originally in Japanese).

A confirmation of the order of magnitude of the convective velocities driven by a temperature difference can be obtained from boundary layer theory (Ref. E.9).

3. IMPLICATIONS OF COMPARTMENT SIZE ASSUMPTIONS

We have shown that the axial temperature differences that would occur in BWR steam line cooling will give rise to convective velocities large compared with the mean flow velocity at the nominal MSIV leakage rate. We would expect, then, that each convective cell would be well mixed and hence would have a near-uniform concentration of contaminants. Since very detailed modeling of the thermal transient in the BWR main steam line would be necessary to predict

the convective cells precisely, it is appropriate to assess the sensitivity of the advance of radionuclide concentrations to the assumptions about compartment size. We assumed (non-conservatively) in our model that the flow from one compartment (convective cell) to the next occurs at the net volume flow rate (with expansions or shrinkage according to temperature changes). That is, we have neglected interchange between convective cells by thermal and turbulent diffusion. Within this assumption, what are the trends with convective cell size?

Figure 3.1 compares the qualitative features of the propagation of a radionuclide concentration down a steam line using three different models. In a plug flow model, the concentration of radionuclides is zero ahead of an advancing front, while behind the front the concentration is C_0, the value at entry to the steam line (neglecting deposition). The front for the transition from concentration zero to concentration C_0 advances with a linear velocity τ/A, where τ is the volume flow rate and A is the flow area.

In a model with well-mixed compartments of finite size, the spatial transition from negligible concentration to concentration C_0 occurs over a set of compartments along the flow path at any one time. The breadth of this transition region is greater with increasing compartment size. If large convective cells are present, the progression of a radionuclide concentration (at reduced intensity) occurs at a faster rate than the "front velocity" in a plug flow model. A model with excessively large compartments will be conservative in that it will predict a larger early release than is realistic. A plug flow model or a model with excessively small compartments will underpredict the early release.

The qualitative features of Figure 3.1 are illustrated in the quantitative example of Figure 3.2, which presents the concentration as a function of distance along a line of 4 ft^2 cross section with a flow of 20 ft^3/hour at a time 20 hours after the start of flow. This is the amount of time to fill the first 100 ft of the line according to the plug flow model. If the convective flows result in 10 or 100 well-mixed compartments, the concentrations are as

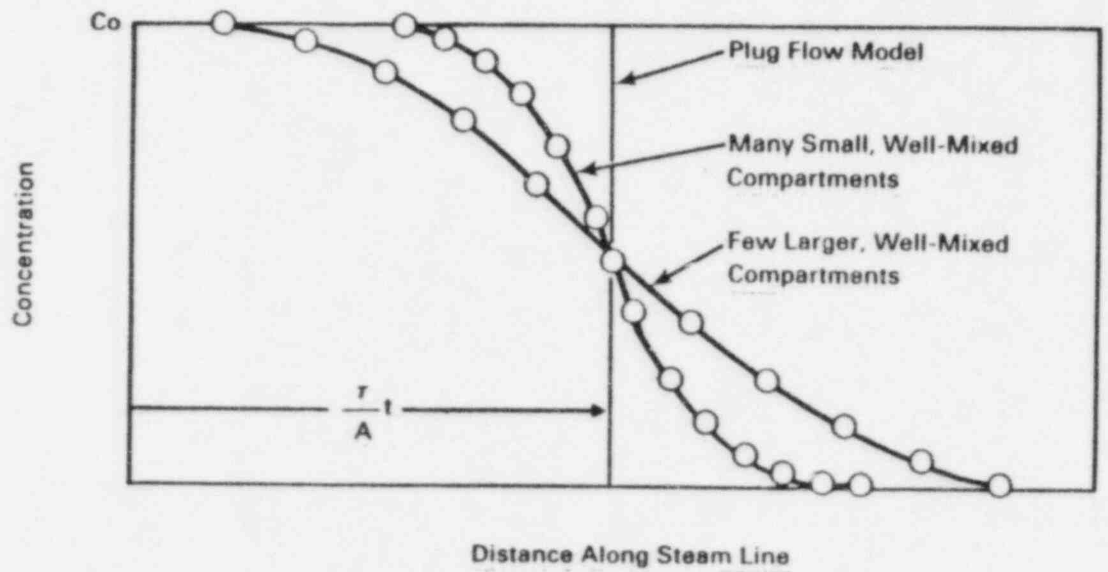


Figure 3.1 Qualitative features of flow models

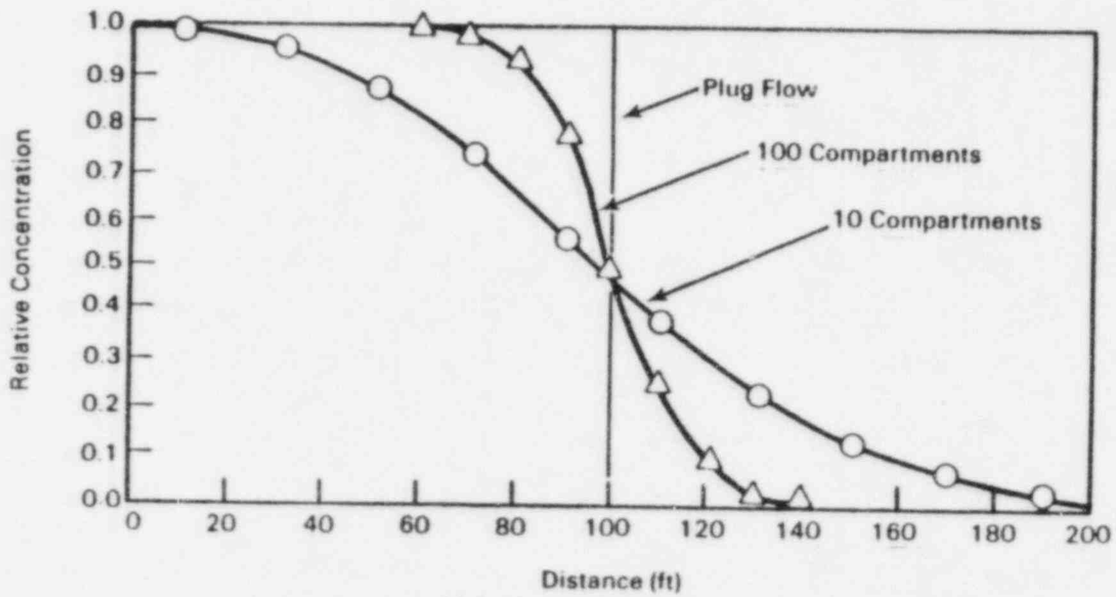


Figure 3.2 Concentration along 200-ft steam line with 4-ft^2 cross section and 20-ft^3/hr flow rate at 20 hours after start, according to three models of the flow

shown. The calculations for this figure assumed no deposition. The qualitative features of Figure 3.1 have been verified by computations with number of compartments varied from 2 to 300.

The preferred number of compartments in modeling the main steam lines and bypass lines is one in which the number of compartments is somewhere between the number of serious "heat leaks" in the cooling and twice that number, with the smaller numbers of compartments being conservative from the standpoint of early releases.

An inspection of drawings for WNP-2 main steam lines shows approximately 29 major supports of varying types (pipe stops, shock suppressors, variable springs) per steam line, with separations usually in the range 8 to 35 ft. This is an indication of the number of compartments appropriate for modeling.

4. DIVISION OF LEAKAGE FLOW BETWEEN CONDENSER AND HIGH PRESSURE TURBINE

Under conditions of MSIV leakage with the leakage flow directed down the main steam line, two paths are available for ultimate escape to the atmosphere. Path A comprises the main steam lines merged at the steam chest, with subsequent flow through the turbine stop valve and turbine control valve, into the high pressure turbine shell, and out through the labyrinth seals of the high pressure turbine. We assume that steam is not available for turbine seal operation in the scenario of interest. Path B comprises the turbine bypass draw-off lines, their merger hardware, the turbine bypass valves (in parallel), the condenser, the low pressure turbine boot, the low pressure turbine shell, and the low pressure turbine seals. These two paths are shown schematically in Figure 4.1.

The turbine seals represent negligible resistance to flow under shutdown conditions. The labyrinth seal is shown somewhat schematically in Figure 4.2 as seen by leaking air or steam in the absence of seal steam. The clearance of 20 to 30 mils between the labyrinth seal teeth and the 26" diameter shaft allows a flow area of roughly two square inches for air inleakage from each end of each turbine. Hence we expect air inleakage to bring the pressure inside the shell of the high pressure (and up to the turbine control valve) to near atmospheric pressure in a fairly short time. Similarly, the low pressure

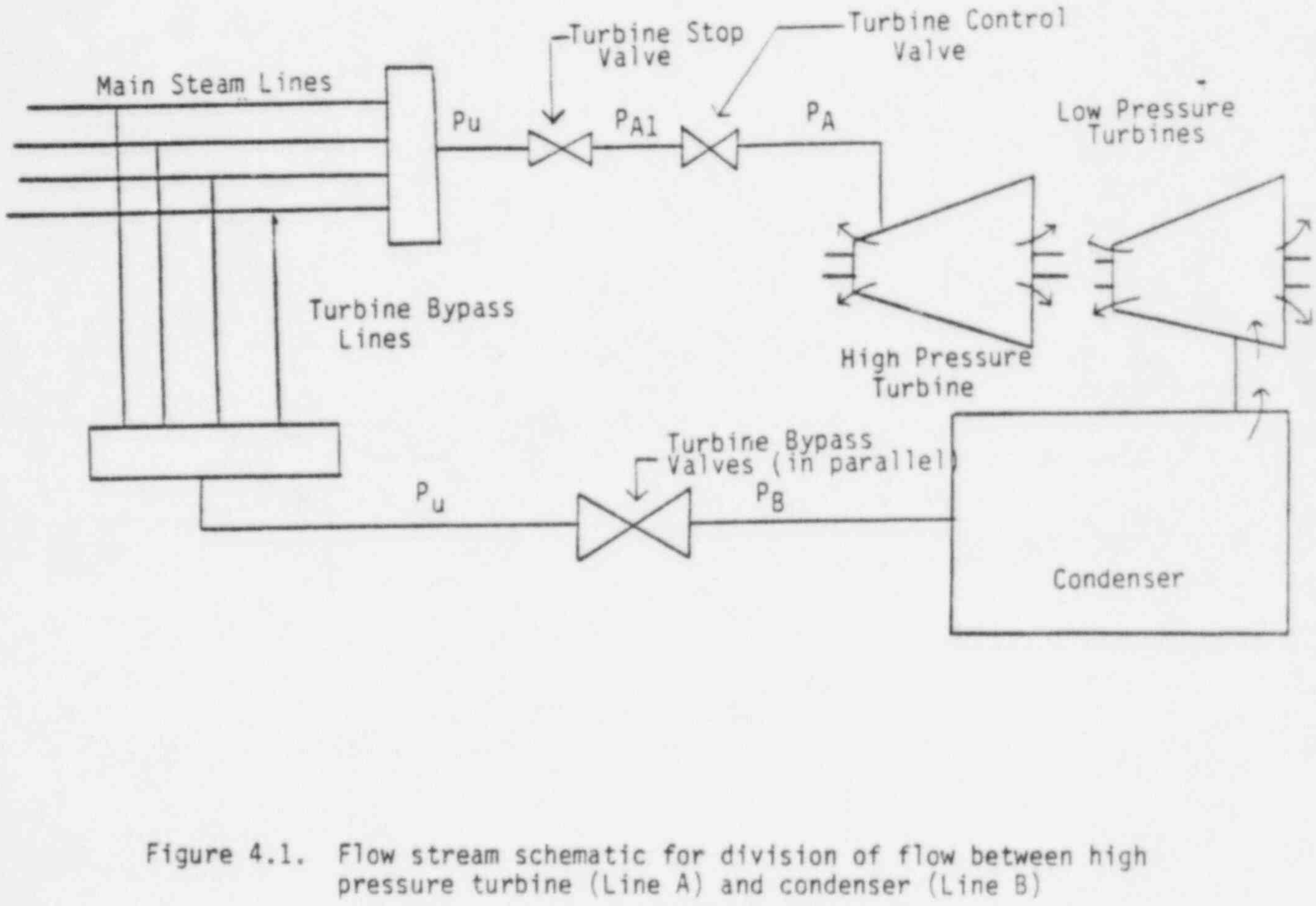


Figure 4.1. Flow stream schematic for division of flow between high pressure turbine (Line A) and condenser (Line B)

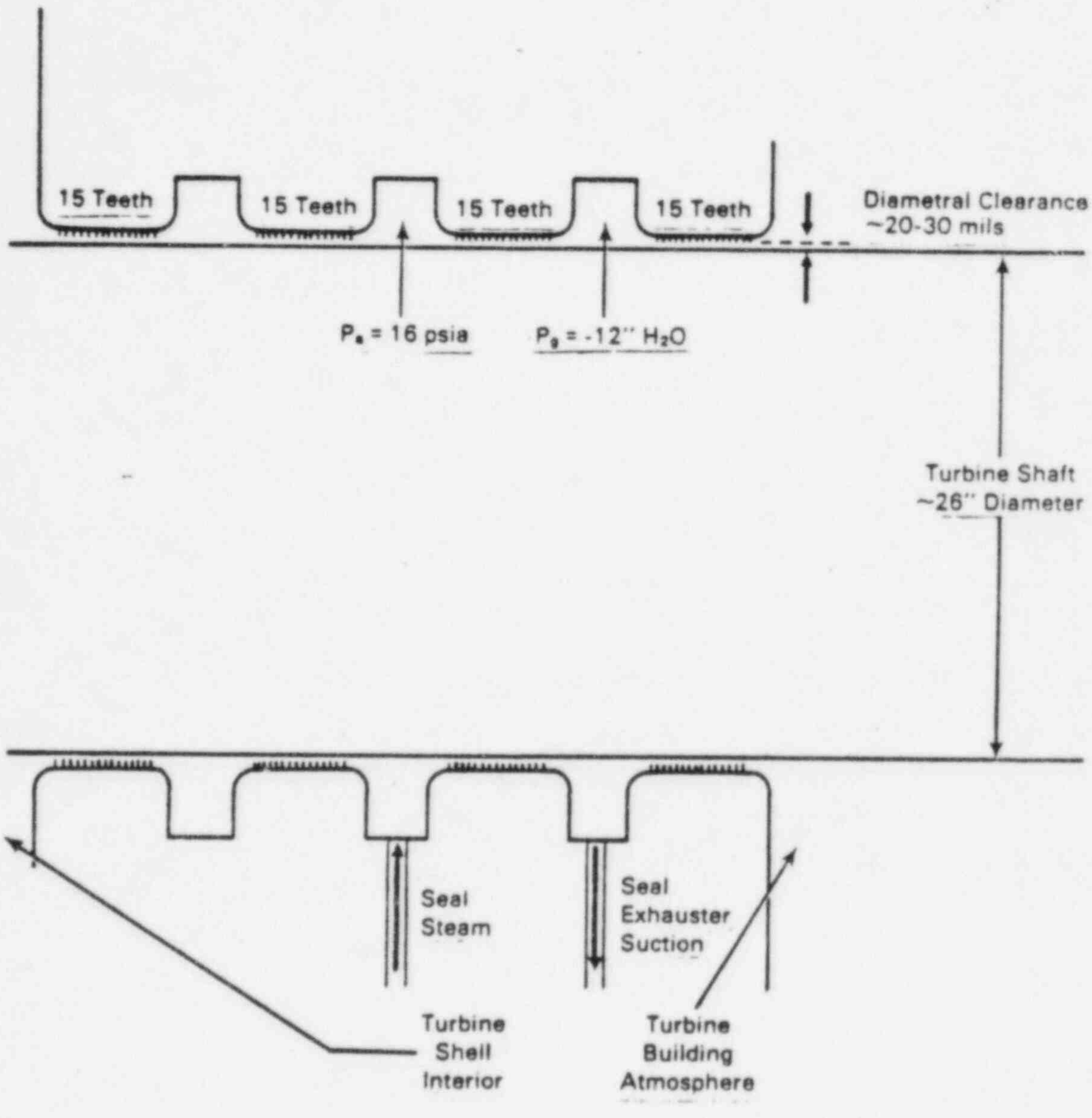


Figure 4.2. Turbine labyrinth seal schematic

turbine shell and the condenser would attempt to come to atmospheric pressure after shutdown by drawing air through the low pressure turbine seals. Normal operating procedure at WNP-2 under such conditions is to open the condenser vacuum breaker panels on the condenser to avoid drawing air through the turbine. Opening the vacuum breaker panels allows the condenser pressure to come to atmospheric in seconds. We assume that the condenser vacuum breaker panels can be reclosed in a condenser confinement strategy, but leakage past the low pressure turbine seals would still maintain the condenser pressure as essentially atmospheric. Upstream of the valves in either Path A or Path B, we expect the vapor to be steam or a steam-air mixture at some pressure modestly above atmospheric. This modest pressure change across turbine stop, turbine control, and turbine bypass valves is expected because all are large valves designed for very large mass flow rates (order of 10^7 lbm/hr) and designed to be fast acting. None are designed to achieve the tight seals that would be required for isolation or even to seriously inhibit a flow of a few tenths of pounds per hour.

We will analyze the flow division between Paths A and B with these assumptions:

1) The pressure P_u upstream of the turbine stop valve is approximately the same as that upstream of the turbine bypass valves.

2) Pressure drops in leaking through turbine seals after MSIV closure are negligible. Hence pressure P_A in the high pressure turbine shell and pressure P_B in the condenser are both approximately atmospheric.

3) Pressure drops across each valve are related to flow velocity and mass flow rate by

$$\Delta P = K \frac{1}{2} \rho V^2 = K \frac{\dot{M}^2}{2\rho A^2} \qquad (4.1)$$

where ΔP is pressure drop, ρ is mixture density, V is linear velocity in the valve region, K is the form loss factor for the valve in

closed position, $\dot{M}$ is the mass flow rate through the valve, and A is the effective leak area through the valve. Note density change is neglected, and K and A go together for a closed valve.

Applying these assumptions to flow branch A gives:

$$P_u - P_{A1} = \frac{\dot{M}_A^{\ 2}}{2\rho A^2_{\ A1}} \quad P_{A1} - P_A = K_{A2}\frac{\dot{M}_A^{\ 2}}{2\rho A^2_{A2}} \tag{4.2}$$

Applying these assumptions to flow branch B gives:

$$P_u - P_B = K_B\frac{\dot{M}_B^{\ 2}}{2\rho A_B^2} \tag{4.3}$$

In Equations 4.2 and 4.3 we have

K_{A1}, A_{A1} = form loss coefficient and flow area for turbine stop valve (closed)

K_{A2}, A_{A2} = form loss coefficient and flow area for turbine control valve (closed)

K_B, A_B = form loss coefficient and flow area for turbine bypass valves in parallel

$\dot{M}_A$, $\dot{M}_B$ = mass flow rates through Branch A (high pressure turbine) and branch B (condenser).

Add corresponding sides of Equation 4.2:

$$P_u - P_A = \dot{M}_A^{\ 2}\left(\frac{K_{A1}}{2\rho A_{A1}^{\ 2}} + \frac{K_{A2}}{2\rho A_{A2}^{\ 2}}\right) \tag{4.4}$$

Assuming $P_A = P_B$ in Equations 6.3 and 6.4, equating the pressure drops in the two branches gives

$$\dot{M}_A^{\,2}\left(\frac{K_{A1}}{2\rho A_{A1}^{\,2}} + \frac{K_{A2}}{2\rho A_{A2}^{\,2}}\right) = \dot{M}_B^{\,2}\,\frac{K_B}{2\rho A_B^{\,2}} \qquad (4.5)$$

or

$$\frac{\dot{M}_A}{\dot{M}_B} = \left(\frac{K_B/A_B^{\,2}}{K_{A1}/A_{A1}^{\,2} + K_{A2}/A_{A2}^{\,2}}\right)^{1/2} \qquad (4.6]$$

If each of the valves is similar in flow area and form loss friction coefficient, i.e., if

$$\frac{K_B}{A_B^{\,2}} = \frac{K_{A1}}{A_{A1}^{\,2}} = \frac{K_{A2}}{A_{A2}^{\,2}} \qquad (4.7)$$

then

$$\frac{\dot{M}_A}{\dot{M}_B} = \frac{1}{\sqrt{2}} = 0.707 \qquad (4.8)$$

Valve information to characterize the division of flow between Paths A and B according to Equation 4.6 is not readily available. One can, however, make the assumptions of Equation 4.7 with the implied flow split of Equation 4.8. We anticipate, however, that such a large flow through the high pressure turbine would result in excessive releases of radionuclides to the turbine building. This may necessitate a strategy of operator intervention to open the turbine bypass valves under leaking MSIV conditions.

We anticipate that an open turbine bypass valve system with 100 to 200 square inches of flow area would draw the major share of the leakage flow as compared with closed turbine stop and turbine control valves with on the order of 0.2 in^2 of flow area.

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APPENDIX F

Analysis of Condensation Effects

ANALYSIS OF CONDENSATION EFFECTS

1. INTRODUCTION

The strategy being investigated is allowing the leakage from the main steam isolation valves (MSIV) following a recirculation line break to flow down the main steam lines and into the condenser. It is assumed that the turbine bypass valve has been opened and that the turbine control valve and turbine stop valve remain closed, so that leakage into the turbine directly from the main steam line is small compared with the flow through turbine bypass into the condenser. Phenomena of interest for radionuclide release control with this strategy are: 1) the progression of radionuclide-contaminated vapor down the steam line and into the condenser, 2) deposition processes on surfaces, and 3) radionuclide release from the condenser. The volume flow rate of the leaked vapor down the steam lines is influenced by the amount of condensation in the steam line. The patterns of concentrations and deposition are in turn affected.

We will here investigate the effect of condensation on the total release by looking at two extreme cases: 1) no condensation, and 2) rapid condensation down to a noble gas flow. We will do this for two radionuclide contaminant types: 1) noble gases, and 2) an aerosol of 0.184 micron radius particles.

2. MODELING

For this investigation, we consider the steam line and condenser to be a series of well-mixed compartments with flow from each to the next. The quantity N_i in the i-th compartment is assumed to obey a differential equation of the form:

$$\frac{dN_i}{dt} = \dot{\tau}_i^{(1)} C_{i-1} - \dot{\tau}_i^{(2)} \frac{N_i}{V_i} - \lambda N_i - \underset{\substack{m \\ \text{(deposition} \\ \text{methods)}}}{\sum} k_i^m A_i^m \left(\frac{N_i}{V_i} - C^m_{e,i}\right) \qquad (1)$$

$$+ K_{i-1,i} A_{i-1,i} (C_{i-1} - C_i) - k_{i,i+1} A_{i,i+1} (C_i - C_{i+1})$$

The symbols are as follows:

$\dot{\tau}_i^{(1)}$, $\dot{\tau}_i^{(2)}$ = volume flow rates into (superscript 1) or out of (superscript 2) the i-th compartment

V_i = volume of i-th compartment

$C_i = \frac{N_i}{V_i}$ = concentration in i-th compartment

λ = decay constant ($\ln 2$/half-life) of radionuclide

k_i^m, A_i^m = transport coefficient and deposition area in the i-th compartment for the m-th deposition process

$C_{e,i}^m$ = equilibrium concentration at deposition surface in the i-th compartment for the m-th deposition process

$k_{i-1,i}$ = axial mass transfer coefficient between compartment i-1 and compartment i (and similarly for $k_{i,i+1}$)

$A_{i-1,i}$ = mixing mass transfer area between compartment i-1 and compartment i

For this study, we set λ to zero. This is because the radionuclides in the source compartment (compartment 0, the pressure vessel) and the subsequent compartments decay with the same decay constant, so it can be accounted for in a subsequent calculation. We also set $k_{i-1,i}$ and $k_{i,i+1}$ to zero on the assumption that reasonably nonturbulent, nonmixing boundary locations can be found as interfaces between compartments. For the particulate deposition, we set $C_{e,i}^m$ to zero on the assumption that particles that contact the walls adhere by Van der Walls attraction and do not re-entrain.

During the blowdown phase of the recirculation line break, the temperature and pressure in the reactor pressure vessel will have dropped dramatically due to flashing. We accordingly take the conditions in the reactor pressure vessel

as steam saturation at 25 psia during the period when radionuclide leakage is occurring. During the first hours of the leakage, the pipe walls will be hotter than the leakage steam. We have estimated that the major part of the cooling of the pipe wall occurs in a time on the order of 48 hours.

While the pipe walls are significantly hotter than the leakage steam flow, thermophoretic repulsion can inhibit the gravitational deposition of particles, particularly for particles smaller than approximately 0.3 microns radius. Accordingly, we conservatively assume no gravitational settling in the initially hot part of the flow path for the first 48 hours after the break. We also assume no condensation occurs in the initially hot parts of the steam lines for 48 hours. The volume flow rate should increase with distance down the flowstream during the time while the pipe is still hot because of the thermal expansion.

Note that in Equation 1 there is no requirement that the volume flow rate into and out of the i-th compartment be the same. This allows us to accommodate flow mergers, flow splits, condensation, and thermal expansion. For the present study, in the no-condensation case, we assume that the steam superheats to 550°F at atmospheric pressure after leaking past the MSIV during the first 48 hours, but reaches 100°C in the steam line thereafter. For the maximum condensation case, we assume those same conditions for the first 48 hours. After 48 hours, however, we assume that all of the steam condenses in the very first compartment after the MSIV. A flow of noble gases continues down the pipe. The amount of this noble gas flow was determined by assuming that in 24,900 pounds (11,290 kg) of steam there is 1,520 pounds (688 kg) of noble gas, predominantly xenon.

The condenser outflow rate is assumed to average 97 ft^3/hr due to daily and weather front-related barometric changes. A 21-compartment model to and including the condenser was used in these calculations (Figure 1).

The deposition in the steam lines and condenser is assumed to occur by gravitational settling for the particles, with settling velocity given by the Stokes expression (with Cunningham correction for particles not necessarily large compared with vapor molecule mean free paths). No deposition of noble gases is assumed to occur.

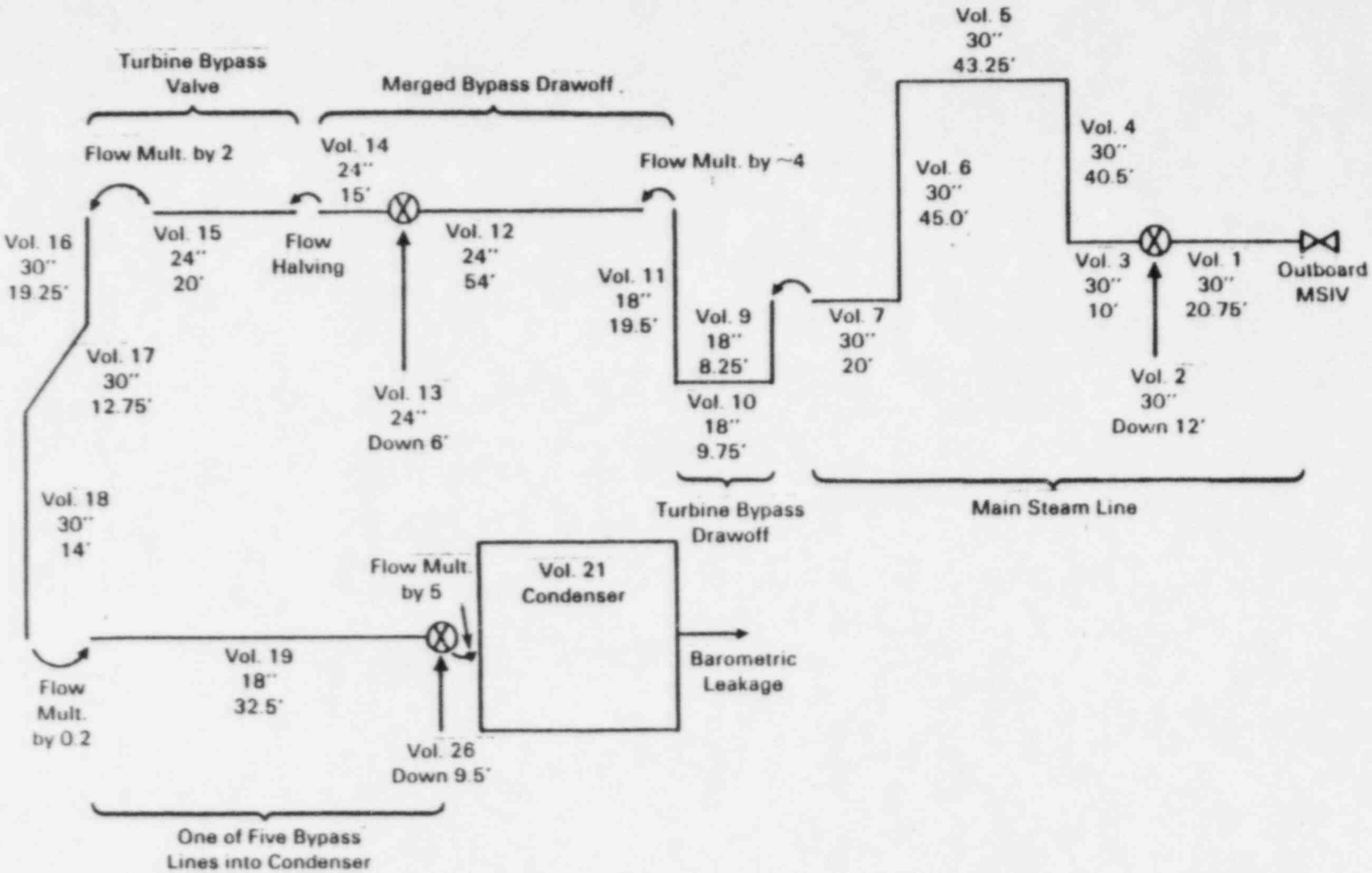

Figure 1. BWR steam line schematic

The fraction of the cumulative MSIV leakage of 0.184 micron radius particles that has leaked from the condenser is shown in Figure 2 as a function of the base 10 logarithm of elapsed time, with maximum steam line condensation and with no steam line condensation. Similar release fraction information is shown in Figure 3 for noble gases. Figure 4 compares the fraction of the cumulative noble gas release retained in the condenser with and without condensation in the steam line. The calculations for these figures were done with a program that uses the analytic solutions to the differential equation set 1.

As can be seen from Figure 2, the fraction released of the 0.184 micron radius aerosol is fairly insensitive to whether or not condensation occurs (~30% variation). This insensitivity occurs because the particles settle reasonably well in the steam lines after the thermophoretic repulsion abates, and only small additional benefits come from lengthening the transit time.

For the noble gases, however, the fraction released shows greater sensitivity to whether or not condensation occurs. The released fraction at 96 hours without steam line condensation is 12% and with maximum condensation is 6%, and at 30 days the fraction released is 21% without and 0.9% with condensation. The released quantities for a particular radionuclide would still be multiplied by a decay factor characteristic of that radionuclide's decay. The benefits of sending the noble gases down the steam line and into the condenser for 30 days of leakage as compared to release to the atmosphere without holdup would be greater than the reduction to 21% of the amount that leaked past MSIVs in the no-condenstion case because of the decay during the holdup.

Tables 1, 2, and 3 summarize release and containment information for the two limiting cases of steam line condensation. Note that after 30 days and no steam line condensation assumed, 71% of the noble gases leaked past the MSIVs is contained within the condenser and 21% has been leaked. With maximum condensation, 1.5% is contained within the condenser and 0.9% has been leaked. Thus the effect of extensive condensation in the steam lines is to delay the radionuclide flow to the condenser.

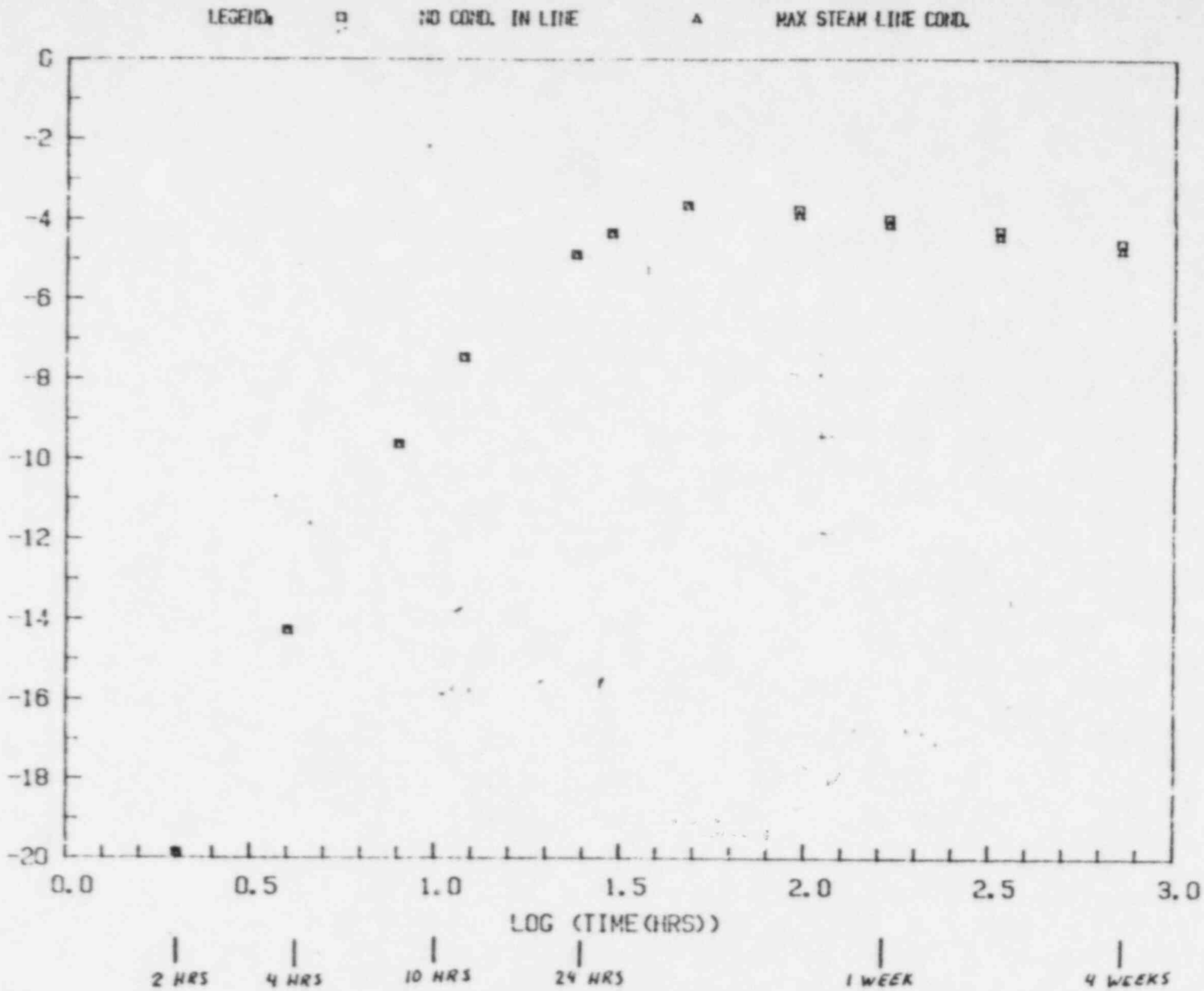

Figure 2. Leakage fraction released from condenser with and without condensation. 11.5 cu. ft./hr/valve, barometric respiration 48 hour dep. delay, 0.184 micron particles

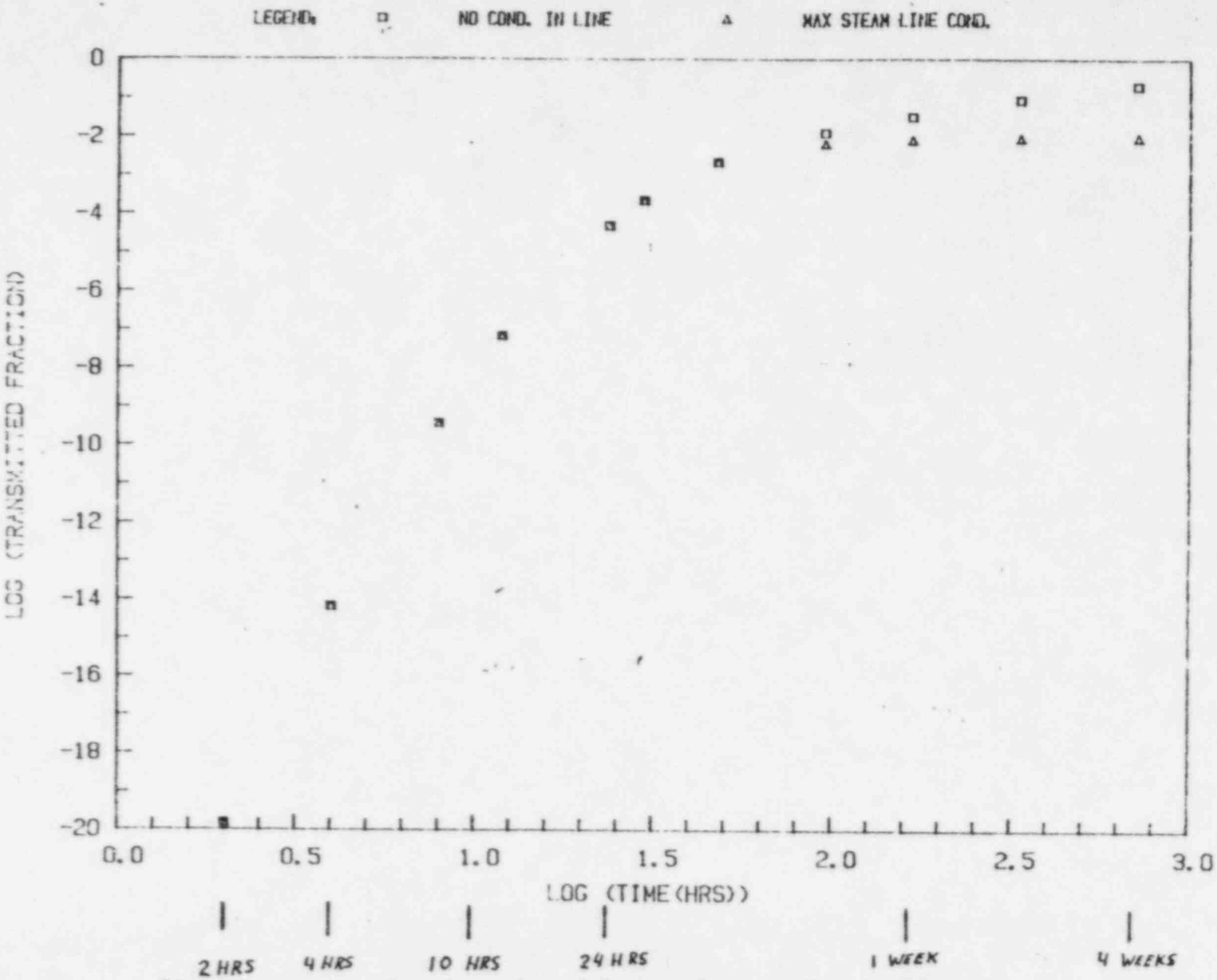

Figure 3. Leakage fraction released from condenser with and without condensation, 11.5 cu. ft./hr/valve, barometric respiration, 48 hour cond. delay, noble gases

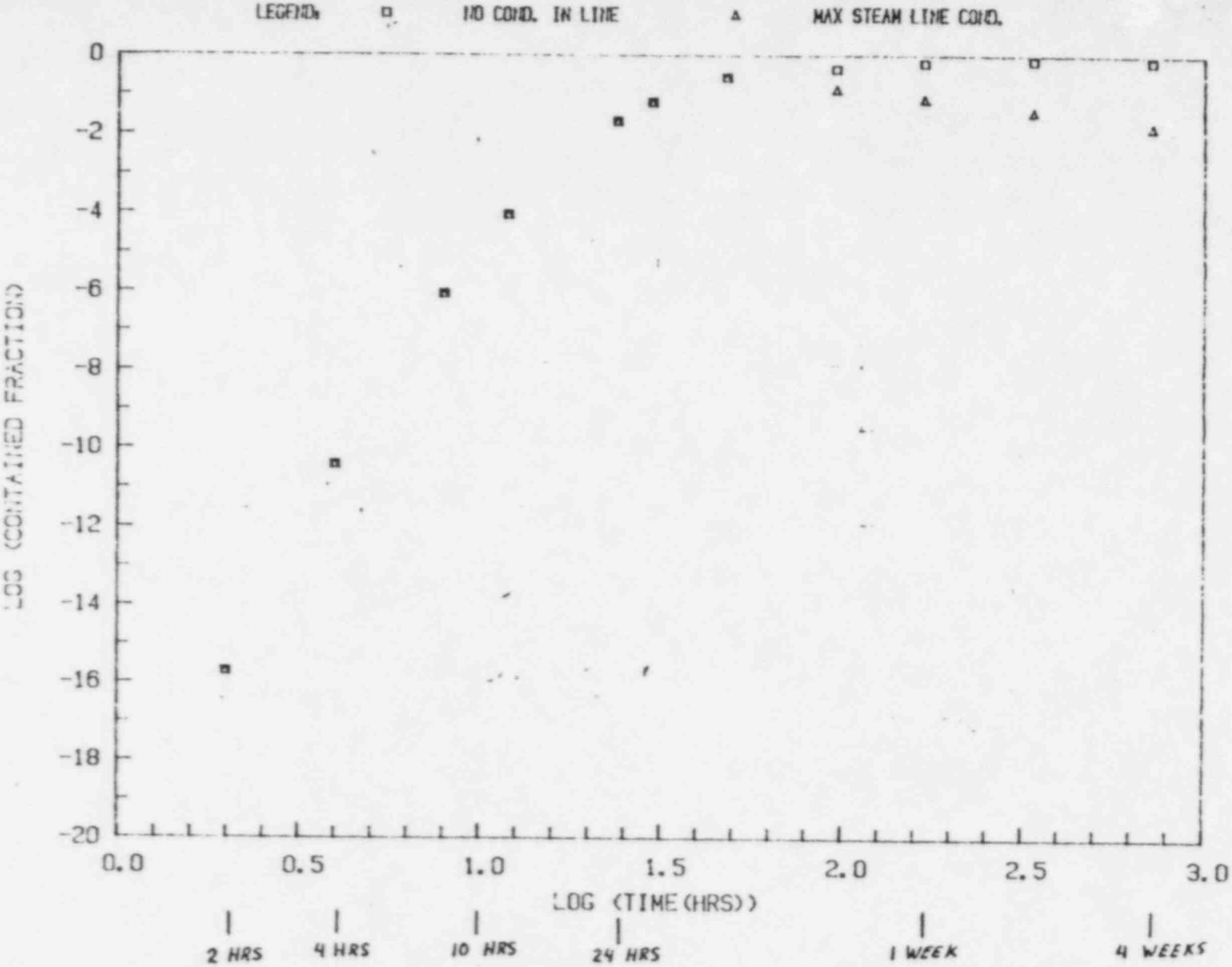

Figure 4. Leakage fraction retained in condenser with and without condensation, 11.5 cu. ft./hr/valve, barometric respiration, 48 hour cond. delay, noble gases

Table 1. Radionuclide concentrations+ in steam line and condenser compartments at selected times after a recirculation line break with and without condensation in the steam line. form assumed is a 0.184 micron radius aerosol.

Vol. No.	Conc. t=48 hr	Conc. t=96 hr No cond.	Conc. t=96 hr Max. cond.	Conc. t=30 days No cond.	Conc. 5=30 days Max. cond.
1	.98E-6	.86E-6	.20E-5	.86E-6	.20E-5
2*	.98E-6	.86E-6	.12E-5	.86E-6	.20E-5
3	.98E-6	.63E-6	.35E-7	.63E-6	.60E-7
4	.98E-6	.26E-6	.59E-9	.26E-6	.47E-9
5	.97E-6	.10E-6	.33E-9	.10E-6	.34E-11
6	.95E-6	.39E-7	.32E-9	.39E-7	.24E-13
7	.93E-6	.23E-7	.31E-9	.23E-7	.37E-15
8*	.93E-6	.23E-7	.40E-6	.23E-7	.13E-11
9	.93E-6	.19E-7	.26E-7	.19E-7	.88E-13
10	.92E-6	.16E-7	.15E-8	.16E-7	.49E-14
11	.91E-6	.11E-7	.44E-10	.11E-7	.14E-15
12	.90E-6	.83E-8	.31E-10	.83E-8	.46E-17
13*	.90E-6	.83E-8	.82E-7	.83E-8	.71E-17
14	.90E-6	.75E-8	.10E-7	.75E-8	.75E-18
15	.77E-6	.59E-8	.57E-9	.58E-8	.32E-19
16	.70E-6	.50E-8	.23E-9	.50E-8	.22E-20
17	.65E-6	.45E-8	.22E-9	.45E-8	.23E-21
18	.61E-6	.40E-8	.21E-9	.40E-8	.22E-22
19	.40E-6	.22E-8	.71E-11	.21E-8	.30E-24
20*	.40E-6	.22E-8	.23E-6	.21E-8	.79E-10
21	.83E-9	.33E-11	.38E-11	.30E-11	.13E-14

+ concentrations are in fractions of the initially volatized release/cubic feet

* compartments with no settling surfaces assumed

Table 2. Fraction of cumulative MSIV leakage transmitted from the condenser at various elapsed times after the recirculation line break for radionuclides in noble gas and in 0.184 micron radius aerosol forms

Time (hr)	Transmitted Fraction No condensation 0.184 micron radius aerosol	Transmitted Fraction Max. condensation 0.184 micron radius aerosol	Transmitted Fraction No condensation Noble gas	Transmitted Fraction Max. condensation Noble gas
4	.53E-14	.53E-14	.66E-14	.66E-14
8	.23E-9	.23E-9	.37E-9	.6[illegible]-7
12	.34E-7	.34E-7	.68E-7	[illegible]-7
24	.13E-4	.13E-4	.49E-4	.[illegible]9E-4
30	.45E-4	.45E-4	.22E-3	.22E-3
48	.22E-3	.22E-3	.22E-2	.22E-2
96	.17E-3	.75E-4	.33E-1	.82E-2
168	.99E-4	.75E-4	.33E-1	.82E-2
336	.51E-4	.38E-4	.90E-1	.91E-2
720	.25E-4	.18E-4	.21E-0	.93E-2

Table 3. Fraction of the noble gas released through leaking MSIVs that is contained in the condenser at various times after recirculation line break with and without condensation

Time (hr)	Fraction Contained in Condenser. No Condensation in Steam Line	Fraction Contained in Condenser. Maximum Condensation in Steam Line
4	.38E-10	.38E-10
8	.86E-6	.86E-6
12	.88E-4	.88E-4
24	.21E-1	.21E-1
30	.65E-1	.65E-1
48	.28	.28
96	.46	.14
168	.64	.76E-1
336	.75	.36E-1
720	.71	.15E-1

3. CONCLUSIONS

The inclusion of condensation effects in an assessment of the merits of a steam line-condenser strategy would require a more elaborate thermal analysis for each plant for which it is done. We have shown here that the total release of particulates of 0.184 micron radius is not altered much by such condensation. The release of smaller particles would be affected more, however, but most of the mass of aerosols released in a recirculation line-break scenario would be in sizes larger than this after a modest agglomeration time. The release of noble gases is more strongly altered by condensation in the steam lines through the reduction in linear velocity that accompanies condensation. A more complete assessment should consider noble gas decay during holdup.

APPENDIX G

Analysis of Mixing Interchange Between Volumes

ANALYSIS OF MIXING INTERCHANGE BETWEEN VOLUMES

D. L. Lessor and W. R. Krotiuk

INTRODUCTION

A simple approach to modeling the propagation of radionuclides from a leaking MSIV through the main steam line and condenser is to consider this system as connected compartments with sequential flow. The internal flows generated by convection within each compartment can conservatively be taken as sufficient to assure a well-mixed condition within each compartment. A simpler description of the mass transfer between compartments results if the interfaces between compartments coincide with quiescent surfaces between convective cells. Discussed herein is a model for the propagation, deposition, and delay processes for the leaking main steam isolation valve scenario, including a description of the transfer processes between compartments.

AXIAL MASS INTERCHANGE BETWEEN CONVECTION CELLS IN MAIN STEAM LINES

Temperature differences in the axial direction will result from the nonuniform cooling of BWR main steam lines following shutdown. The nonuniform cooling comes primarily from the heat loss through pipe supports. A convection cell extends from either side of the pipe support location to a location roughly half way to the next pipe support. With leaking MSIVs, there will be a net flow from a convection cell to the next cell downstream. This flow will carry a concentration of contaminant radionuclides typical of the upstream convection cell. An additional mass transfer of radionuclides may occur between convection cells because of the physical contact across the interface. This additional transfer can occur by (Brownian) diffusion or by fluid motion-induced mixing (eddy mixing or dispersion). Turbulent mixing or turbulent diffusion occurs only minimally because of the low velocities involved.

Simulations of the fluid flow in a BWR main steam line cooling transient using the TEMPEST (Reference 1) code confirm the existence of convection cells,

and of a region of comparatively uniform radial and azimuthal velocities at a location between the heat sinks. This region of uniform nonaxial velocities serves as a barrier to radionuclide mass transport by processes other than the bulk fluid flow. The interface between convection cells at the pipe hanger location is less effective as a barrier because of the more intricate velocity distribution there. This will be discussed in more detail later.

MATHEMATICAL DESCRIPTION OF COMPARTMENT MODEL

These considerations can be embodied in differential equations which describe the change of the quantity N_i of a radionuclide in compartment i:

$$\frac{dN_i}{dt} = \underbrace{\dot{\tau}_i^{(1)}\, C_{i-1}}_{\text{flow in}} \quad \underbrace{- \dot{\tau}_i^{(2)}\, C_i}_{\text{flow out}} \quad \underbrace{- \lambda N_i}_{\text{radioactive decay}}$$

$$\underbrace{+ k_{i-1,i}\, A_{i-1,i}\, (C_{i-1} - C_i) - k_{i,i+1}\, A_{i,i+1}\, (C_i - C_{i+1})}_{\text{diffusional or mixing interchanges between compartments}}$$

$$\underbrace{- \sum_m k_i^m\, A_i^m\, (C_i - C_{e,i}^m)}_{\text{deposition on surfaces}} \qquad (1)$$

The symbols are as follows:

N_i = quantity in compartment i

$\frac{dN_i}{dt}$ = rate of change with time of quantity in compartment i

$C_i = N_i/V_i$ = concentration in compartment i, which has volume V_i

$\dot{\tau}_i^{(1)}$, $\dot{\tau}_i^{(2)}$ = volume flow rate into and out of compartment i

k_i^m = deposition transport coefficient (dep. velocity) for m-th process in compartment i

A_i^m = effective area for deposition by process m in compartment i

$C_{e,i}^m$ = equilibrium concentration for process m at deposition surface in compartment i

$k_{i,i+1}$ = mass transfer coefficient for transfer from compartment i to compartment i+1

$A_{i,i+1}$ = area of contact between compartment i and compartment i+1

($k_{i-1,i}$ and $A_{i-1,i}$ are similarly defined)

We see from Equation 1 that the intercompartmental mass transfer coefficients have dimensions of velocity or of D/L, where D is a diffusion coefficient, and L is an intercompartment boundary layer thickness.

MICROSCOPIC ORIGINS OF MASS TRANSFER TERMS

The current density $\underline{J}$ of a dilute solute can be written as the sum of two parts:

$$\underline{J} = c\underline{V} - D\nabla c \tag{2}$$

$c\underline{V}$ = current of solute carried by fluid flow (3)

$-D\nabla c$ = diffusion current of the solute, driven by Brownian motion for particle suspensions or molecular motion for molecular solutes (4)

Here c is concentration of the solute and $\underline{V}$ is the fluid velocity. The current density $\underline{J}$ is in units of solute transferred per unit area normal to the solute flow per unit time, and is directed in the direction of maximum solute flow. (We use an underline to indicate vector quantities, and the symbol ∇c to

indicate the vector quantity concentration gradient.) Equations 2 through 4 assume that the quantities c, $\underline{V}$, and $\underline{J}$ are defined on a distance scale several times the intermolecular spacing and a time scale of many molecular collisions.

There can, however, be variations in c and $\underline{V}$ that occur on larger time and distance scales but still small compared with system evolution times and system dimensions. Fluid turbulence generates such variations in $\underline{V}$. $\underline{V}$ and c can be written as sums of time-averaged parts (indicated by a bar over the symbol) and a rapidly varying part (indicated by a prime):

$$\underline{V} = \overline{\underline{V}} + \underline{V}'$$

$$c = \overline{c} + c' \tag{5}$$

By definition of the averaging, we have

$$\overline{\underline{V}'} = 0$$

$$\overline{c'} = 0 \tag{6}$$

The corresponding average solute current is

$$\overline{\underline{J}} = \overline{c}\ \overline{\underline{V}} + \overline{c'\underline{V}'} - D\nabla\overline{c} \tag{7}$$

The time average of the product $c'\underline{V}'$ does not necessarily vanish because the fluctuations in concentration and the fluctuations in velocity may be correlated.

The first term on the right hand side of Equation 7 gives rise to the first two terms on the right hand side of Equation 1, while the other right hand side terms in Equation 7 give the fourth and fifth terms on the right hand side of Equation 1, as we shall see.

The axial component $\overline{J}_z$ in a flow in a pipe, given by Equation 7 as

$$\overline{J}_z = \overline{cV}_z + \overline{c'V'_z} - D\,\frac{d\overline{c}}{dz} \tag{8}$$

would have a nonnegligible value for $\overline{c'V'_z}$ if the positive velocity fluctuations ($V'_z > 0$) carried solute with a consistently different concentration than that carried by fluctuations with ($V'_z < 0$). For this to occur, the velocity fluctuations must persist for a distance over which the normal concentration also varies significantly. The flow Reynolds number provides a criterion for the existence and the range of turbulent fluctuations. At low Reynolds numbers, turbulent fluctuations damp out with either time or distance in the flow direction. Above a Reynolds number on the order of 1800, turbulent fluctuations can grow in time or persist for some distance in space. The Reynolds numbers for "forced flow" in BWR main steam lines due to leaking MSIVs are in the range from less than 10 to a few hundred. If one chooses pipe diameter as the distance parameter for the Reynolds number of natural convection in BWR steam lines due to nonuniform cooling, one calculates Reynolds numbers on the order of a few hundred. The low Reynolds numbers lead one to expect a low dispersive $c'V'_z$ contribution. To estimate or bound the contribution of $\overline{c'V'_z}$ to the mass transport of a dissolved or suspended species, one needs an empirical form relating $\overline{c'V'_z}$ to other flow parameters and a "boundary layer thickness" over which the concentration varies significantly.

Empirical forms for the velocity fluctuation-induced transport (dispersion) have been presented by Prandtl, by Von Karman (Reference 2) and by Sherwood et al (Reference 3) in the form:

$$\overline{c'V'_x} = -\,E_x\,(d\overline{c}/dx)$$

$$\overline{c'V'_y} = -\,E_y\,(d\overline{c}/dy)$$

$$\overline{c'V'_z} = -E_z\,(d\bar{c}/dz)$$

$$\overline{c'V'_R} = -E_R\,(d\bar{c}/dr),\ \text{etc.} \tag{9}$$

The dispersion coefficients E_x, E_y, E_z, E_R, etc. are directly analogous to diffusion coefficients.

Von Karman proposed a form applicable to the case of fluid motion in the x direction and a concentration gradient in the z direction:

$$E_z = \kappa_2^{\,2} \left| \frac{(dV_x/dz)^3}{(d^2V_x/dz^2)^2} \right| \tag{10}$$

Here κ_2 is a constant whose value is taken as 0.36 or 0.40 based on tube velocity profile data and a momentum transport analog to mass transport. Equation 10 might be generalized as

$$E_z = \kappa_2^{\,2} \left| \frac{(dV_\perp/dz)^3}{(d^2V_\perp/dz^2)^2} \right| \tag{11}$$

where

$$V_\perp = (V_x^{\,2} + V_y^{\,2})^{1/2} \tag{12}$$

or

$$V_\perp = (V_R^{\,2} + V_\theta^{\,2})^{1/2} \tag{13}$$

for cylindrical coordinates. (We note that Equation 11 will not necessarily agree with Equation 10 if a velocity component changes sign. Equation 10 is better if only one velocity component is nonzero.

We see from Equations 10 or 11 that the Von Karman expression gives a vanishing axial dispersion coefficient E_z in a pipe at a region where the transverse velocities are locally uniform, as they are at the quiescent plane between convection cells at a location intermediate between heat sinks like pipe supports. Equations 10 or 11 are used quantitatively with velocity profiles calculated with TEMPEST.

An empirical correlation for E_R for simple fluid flow in pipes was presented by Sherwood, et al (Figure 4.11 of Reference 3), based directly on experimental data from a number of sources. This figure is reproduced as Figure 1. Simple fluid flow in pipes is defined as flow in the axial direction. E_R is defined as the radial dispersion coefficient in pipes, as defined in the last of Equations 9. The radial dispersion coefficient E_R for simple fluid flow in pipes is the dispersion coefficient $E_\perp$ for mass transport perpendicular to the primary fluid flow. For a BWR main steam line during the cooling transient, the flow at the quiescent boundary surface between convection cells is primarily radial and azimuthal, not axial. Hence for mass transport between convection cells, the desired dispersion coefficient $E_\perp$ (perpendicular to the fluid velocity) should be similar to the E_R values given by Sherwood, et al, for simple flow in pipes.

Figure 4.11 in Reference 3 gives E_R data values plotted as a function of $V_{av}d_{pipe}$, where V_{av} is average linear velocity and d_{pipe} is pipe diameter. The dispersion coefficient E_R varies approximately linearly with $V_{av}d_{pipe}$, with most data points lying in the range

$$\frac{V_{av}d_{pipe}}{1000} < E_R < \frac{V_{av}d_{pipe}}{250} \tag{14}$$

From the TEMPEST simulations, we find a velocity at the quiescent plane midway between the major heat sinks of two pipe hangers

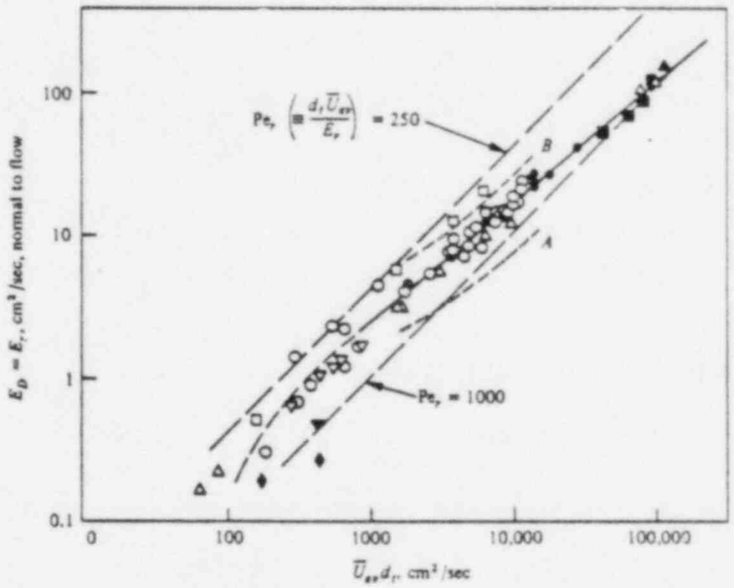

Figure 1. Correlation of Data for Radial Dispersion Coefficient in Pipes, Taken from Sherwood, et al (Reference 2)

$$V = (V_R{}^2 + V_\theta{}^2)^{1/2}$$

$$= \begin{array}{l} 0.078 \text{ ft/sec maximum} \\ 0.025 \text{ ft/sec typical} \end{array} \qquad (15)$$

Using velocities of this order in Equation 14 for the 2.27-ft inside diameter main steam line we obtain from Equation 14 the bounds

$$0.64 \text{ ft}^2/\text{hr} = 1.77 \times 10^{-4} \text{ ft}^2/\text{sec} < E_R < 7.08 \times 10^{-4} \text{ ft}^2/\text{sec} = 2.55 \text{ ft}^2/\text{hr} \qquad (16)$$

using V of 0.078 ft/sec and

$$0.204 \text{ ft}^2/\text{hr} = 5.675 \times 10^{-5} \text{ ft}^2/\text{sec} < E_R < 2.27 \times 10^{-4} \text{ ft}^2/\text{sec} = 0.82 \text{ ft}^2/\text{hr} \qquad (17)$$

using V = 0.025 ft/sec. These dispersion coefficient values are to be compared with molecular diffusion coefficients for Xe in steam of 0.82 ft^2/hr at 240°F and 0.65 ft^2/hr at 550°F (see Appendix A).

The E_R values of Equation 17 are fair estimates of the dispersion coefficient $E_\perp$ relevant to mass transport through the quiescent plane. We have, of course, taken pipe diameter as the distance parameter in Equation 14 to get $E_\perp$ from the E_R data summarized by Equation 14. Equation 14 could be rewritten as

$$\frac{V_{av}}{500} < \frac{E_\perp}{r} < \frac{V_{av}}{125} \qquad (18)$$

where now r is the distance over which mass diffusion perpendicular to the dominant velocity is occurring. Equation 18 then gives a parameter $E_\perp/r$ with the dimensions and the character of the axial mass transport coefficients $k_{i,i+1}$ in Equation 1.

Note that Equation 18 provides a means of comparing the eddy mixing or dispersion contribution to radionuclide transport between compartments in Equation 1 with the flow contribution. For a uniform pipe region, we compare the eddy mixing or dispersion factor $k_{i,i+1} = E_\perp/r$ with the flow velocity $\dot{t}^{(1)}/A$. In the BWR main steam line cooling transient with modest MSIV leakage, $V_{av}(=V_{conv})$ from convection is on the order of 10 to 70 times the bulk flow velocity $\dot{t}/A$, but $E_\perp/r$ will be only two to eight thousandths of V_{av}. Thus we expect the following inequality to hold

$$k_{i,i+1} = \frac{E_\perp}{r} < \frac{\dot{t}}{A} < V_{conv} \tag{19}$$

This says that the compartments should be well mixed, but that radionuclide flow between compartments should be predominantly carried by bulk flow.

TEMPEST SIMULATION

The purpose of this simulation was to determine the nature of the convection currents that might exist in a section of BWR main steam line during a cooling transient. The section of main steam line modeled representated a typical pipe segment between two pipe hangers separated by 15 ft, plus a 7 ft distance on either side. The pipe inner and outer radii were 27.25 in. and 30 in., respectively.

For sections of the pipe significantly downstream from the outboard MSIV at a time significantly into the cooling transient, the leakage steam temperature is expected to differ only modestly from that of the pipe wall. Also, the pressure in the steam line is expected to be near atmospheric.

To obtain initial conditions for the TEMPEST calculation, a near-steady-state wall temperature profile was first calculated without a fluid flow

calculation. Pipe wall temperatures were calculated assuming heat transfer coefficients characteristic of low fluid velocities from an interior fluid at 240°F and to exterior surroundings at 80°F. Supplementary heat transfer coefficients to the surroundings were specified in the region of the pipe hangers to simulate their role as heat sinks. The wall temperature profile from this calculation was used in the starting conditions in the TEMPEST simulation.

Further discussion of the TEMPEST thermal transient and hydrodynamic simulations appears in Appendix C.

The TEMPEST simulation used the node structure indicated in Figures 2 and 3. The fluid flow was allowed to evolve for 300 seconds from the quasi-steady thermal condition previously described.

Difficulty was encountered in trying to simulate the convection in this pipe section in the presence of leakage flow because of the problem of specifying the inlet and exit boundary conditions in a way that does not unrealistically perturb the natural convection. Hence the TEMPEST simulation reported here had zero flow conditions at the entry and exit pipe cross sections.

The wall temperatures for this simulation ranged from about 221.5°F near the hangers to 225.5°F at a point midway between them. Thus axial convection is driven by approximately 4°F of temperature difference. The fluid temperatures ranged to over 237°F in the pipe interior at the end of the 300-second TEMPEST calculation. Thus azimuthal and radial convection was also driven by a temperature difference on the order of 10°F between bulk fluid and wall. The wall temperature for this calculation is plotted in Figure 4. The resulting fluid temperatures are indicated in Figure 5 for a cross section at a hanger location and in Figure 6 for a plane midway between hangers.

The velocities obtained in this TEMPEST simulation are shown in Figures 7 through 14. Salient conclusions from the velocity plots and printouts are:

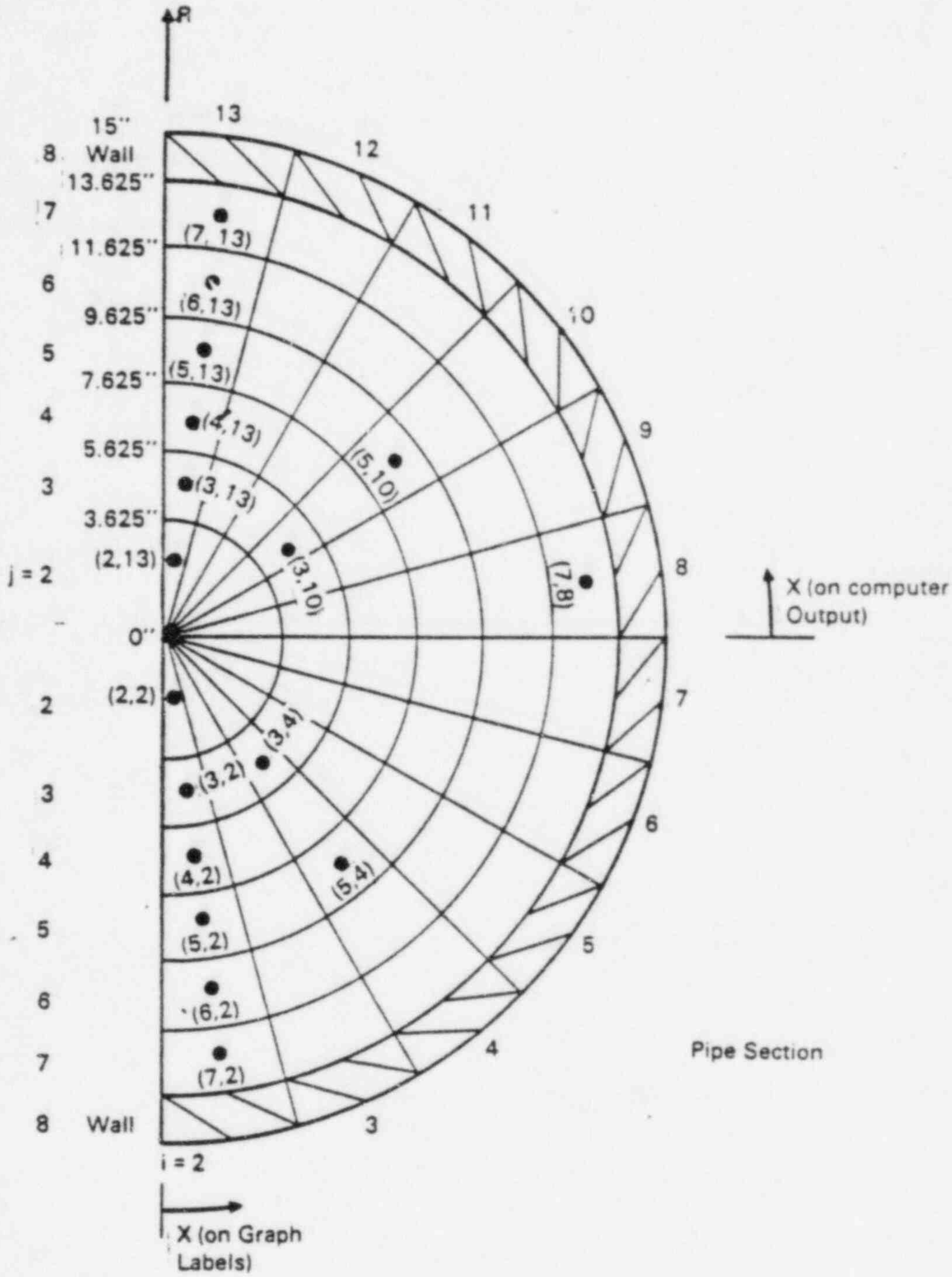

Figure 2. Radial and azimuthal nodalization for TEMPEST simulation of BWR main steam line

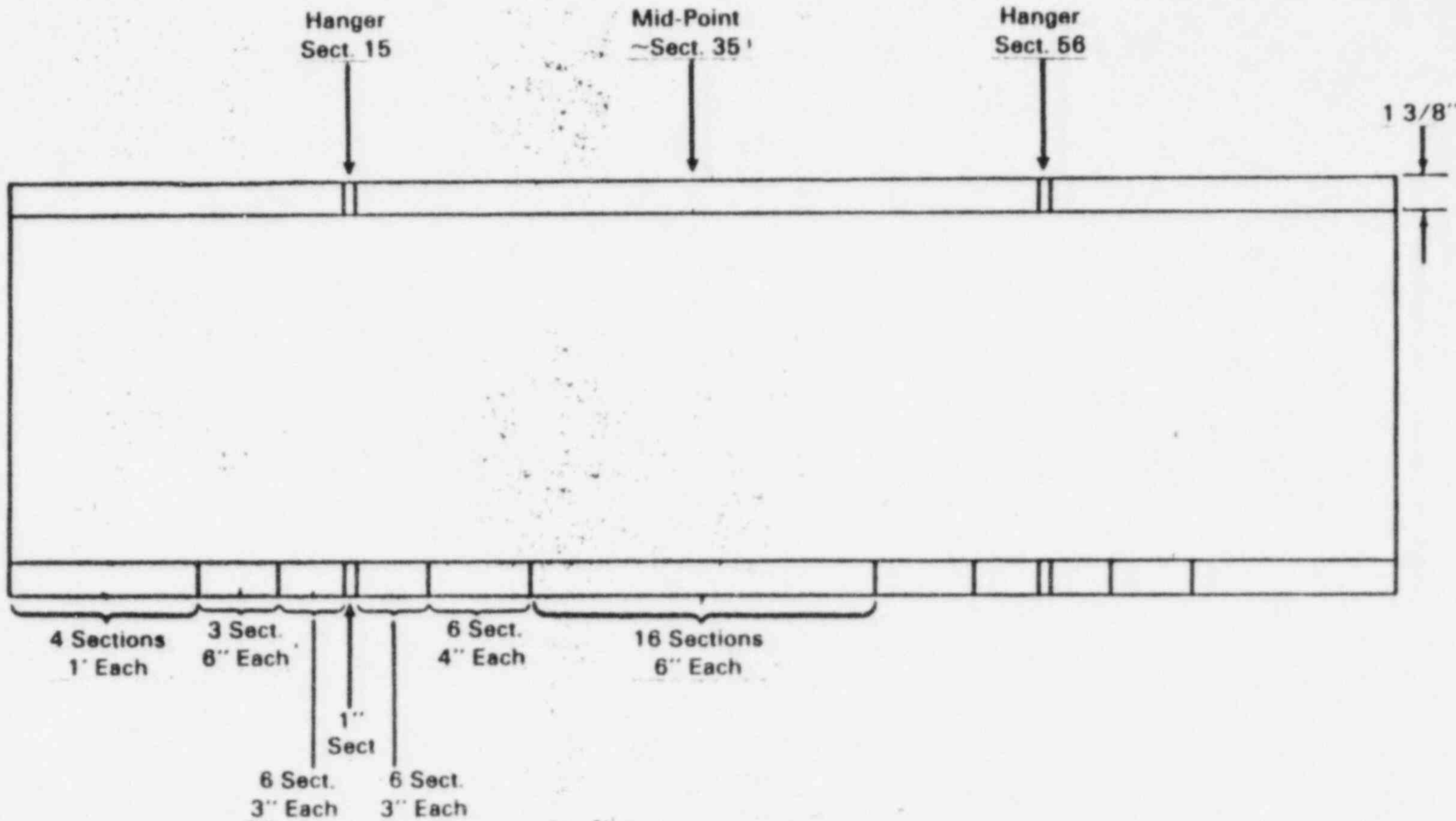

Figure 3. Summary of axial nodalization for TEMPEST simulation (not to scale).

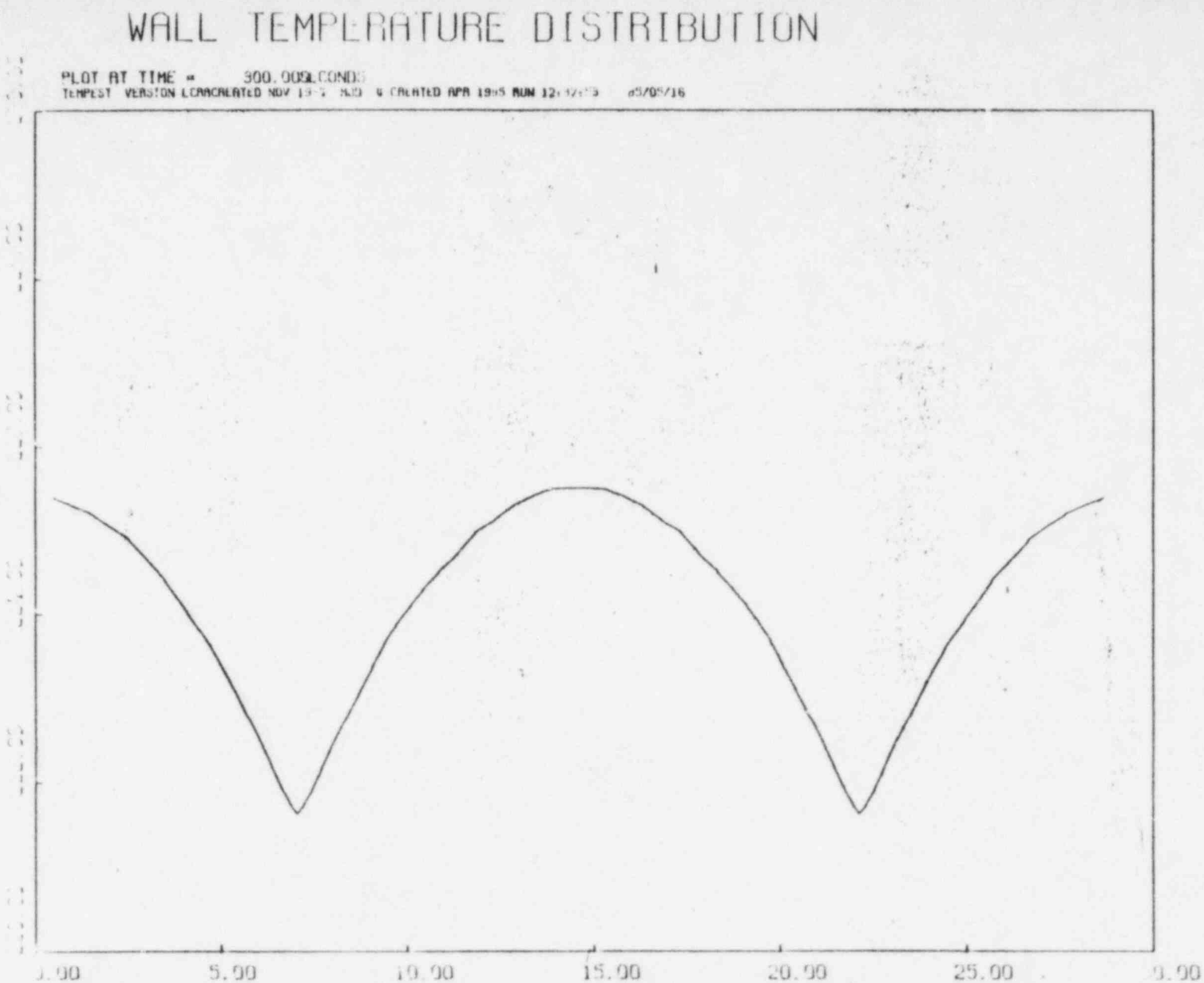

Figure 4. Axial pipe temperature profile for TEMPEST simulation

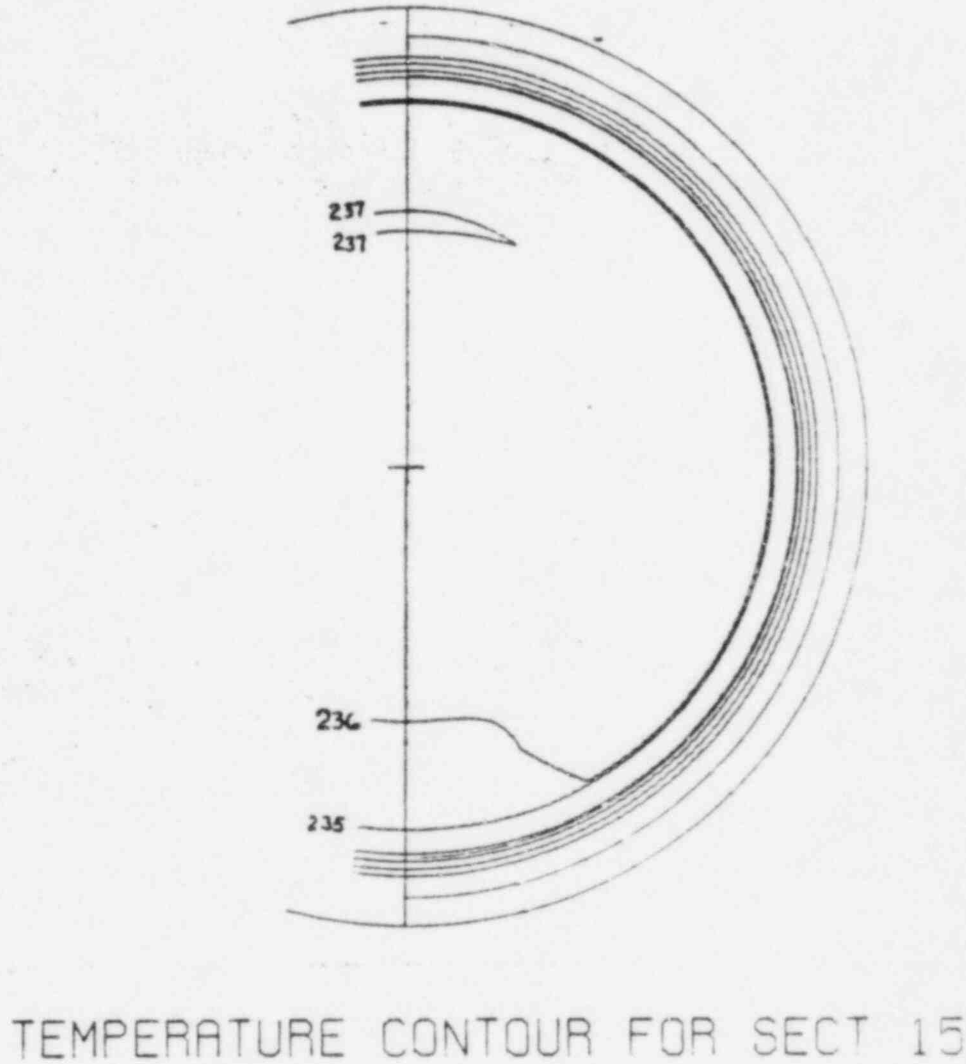

Figure 5. Temperature contours at pipe hanger

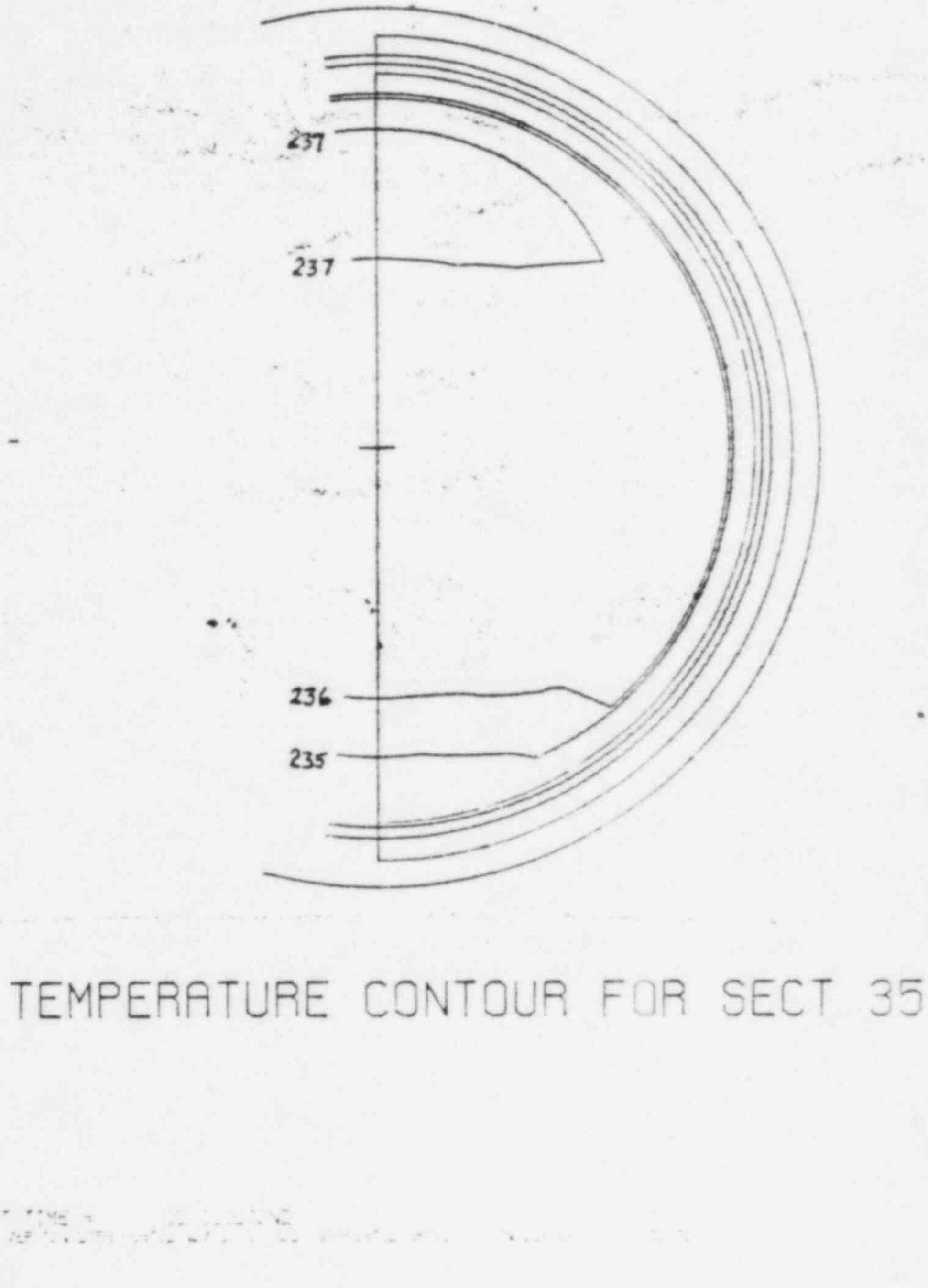

Figure 6. Temperature contours at quiescent plane between pipe hangers

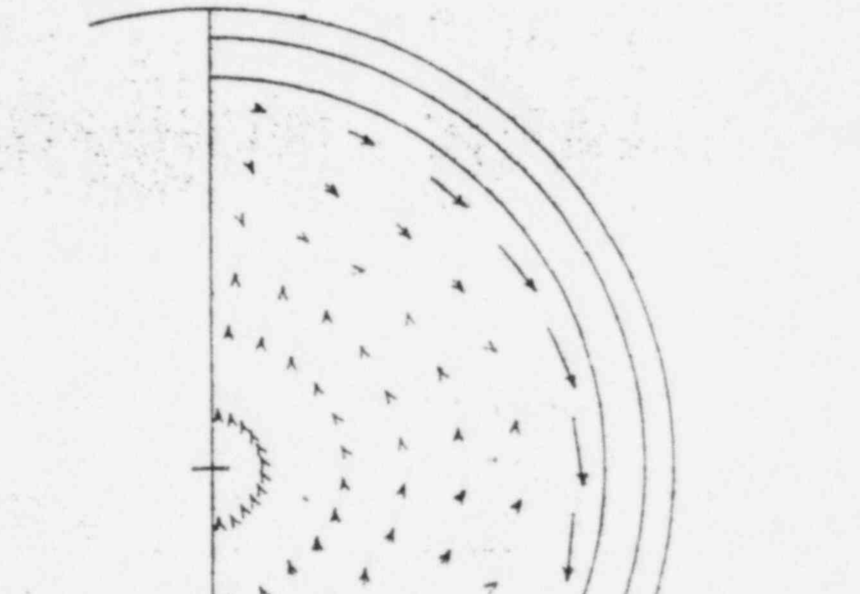

Figure 7. Velocities at the pipe hanger section, from the TEMPEST simulation

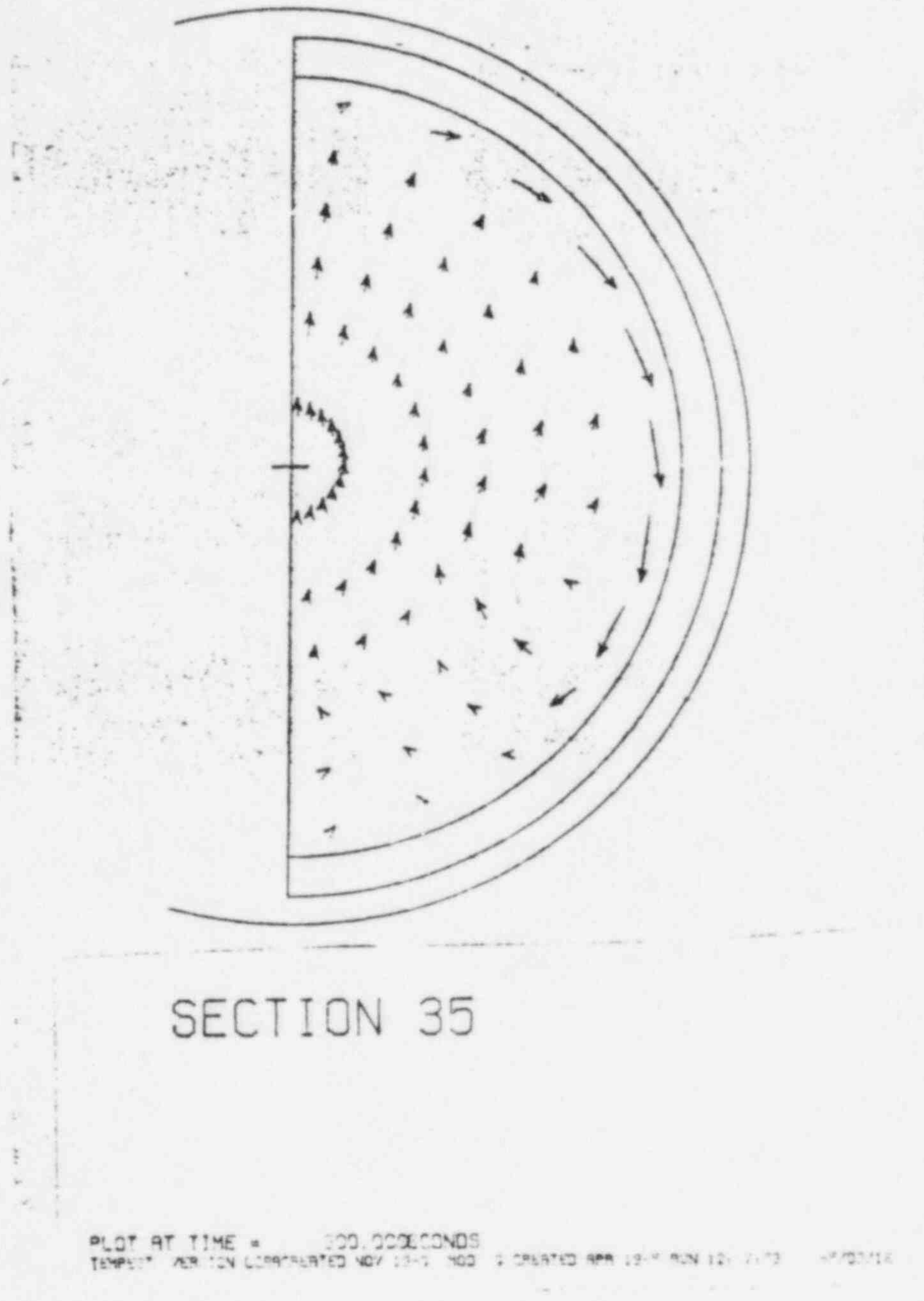

Figure 8. Velocities at the quiescent plane between pipe hangers, from the TEMPEST simulation

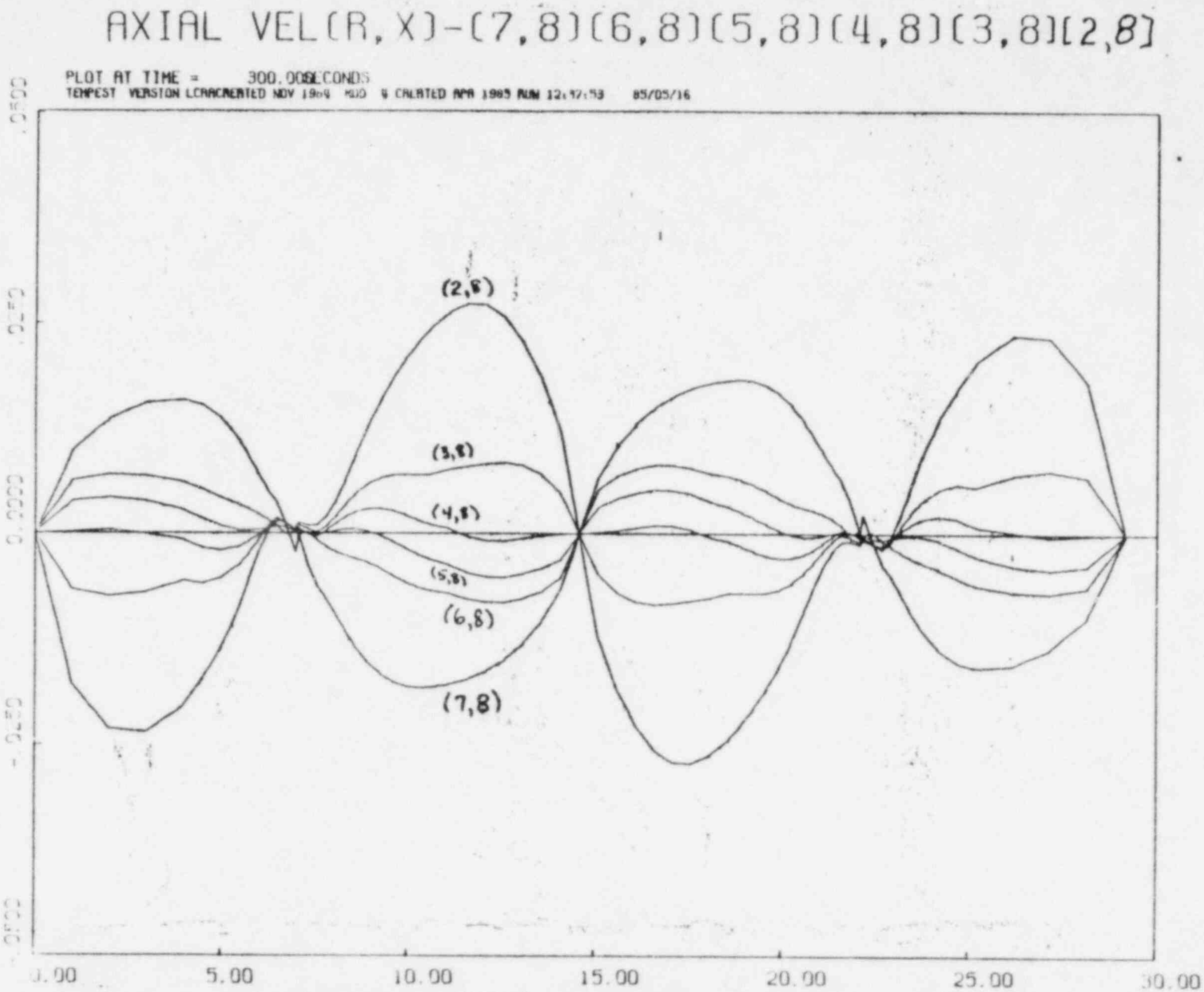

Figure 9. Axial velocities (ft/sec) versus distance (ft) along pipe from the TEMPEST simulation at various (R,θ) nodes

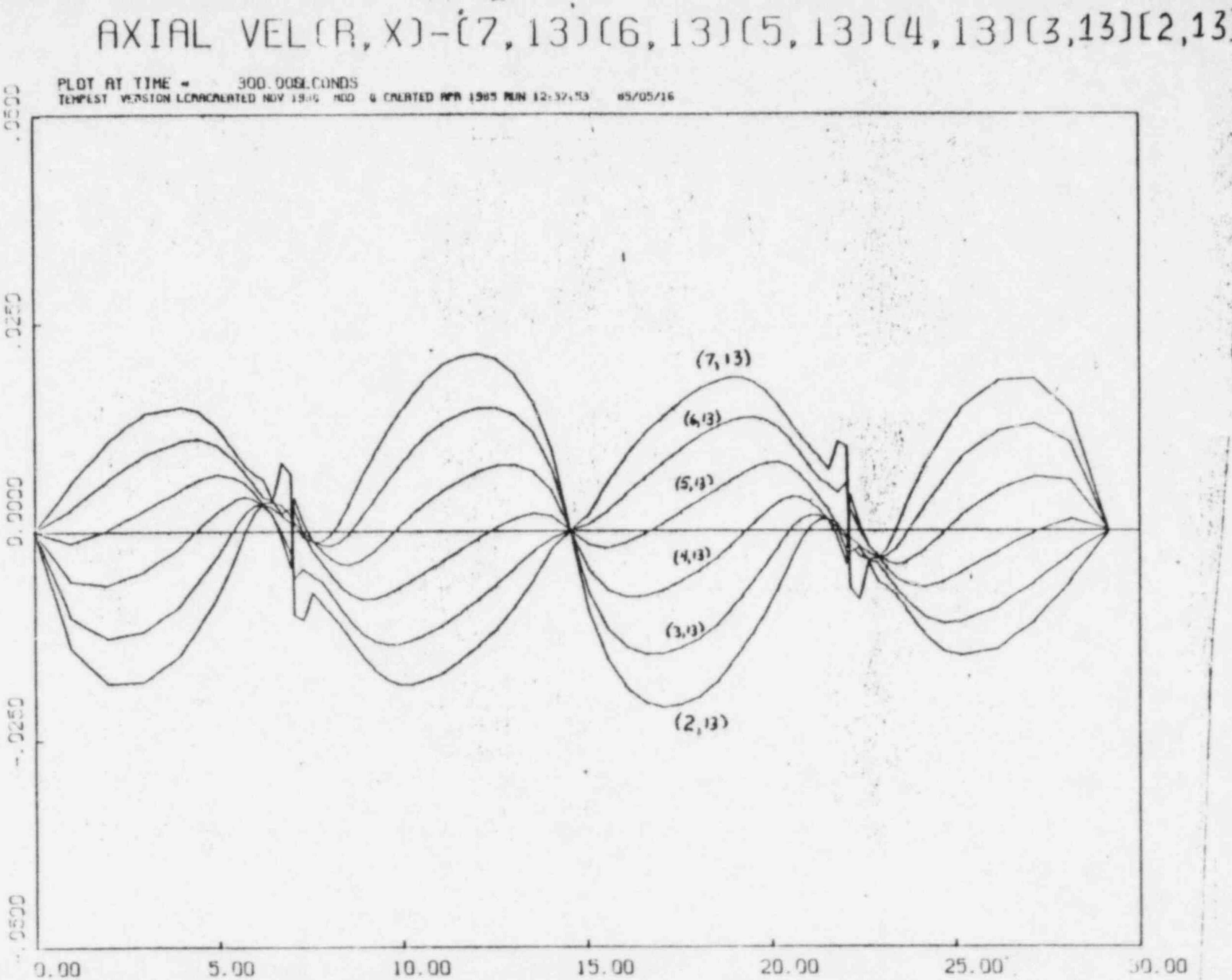

Figure 10. Axial Velocities (ft/sec) versus distance (ft) along pipe from the TEMPEST Simulation at additional (R, θ) nodes.

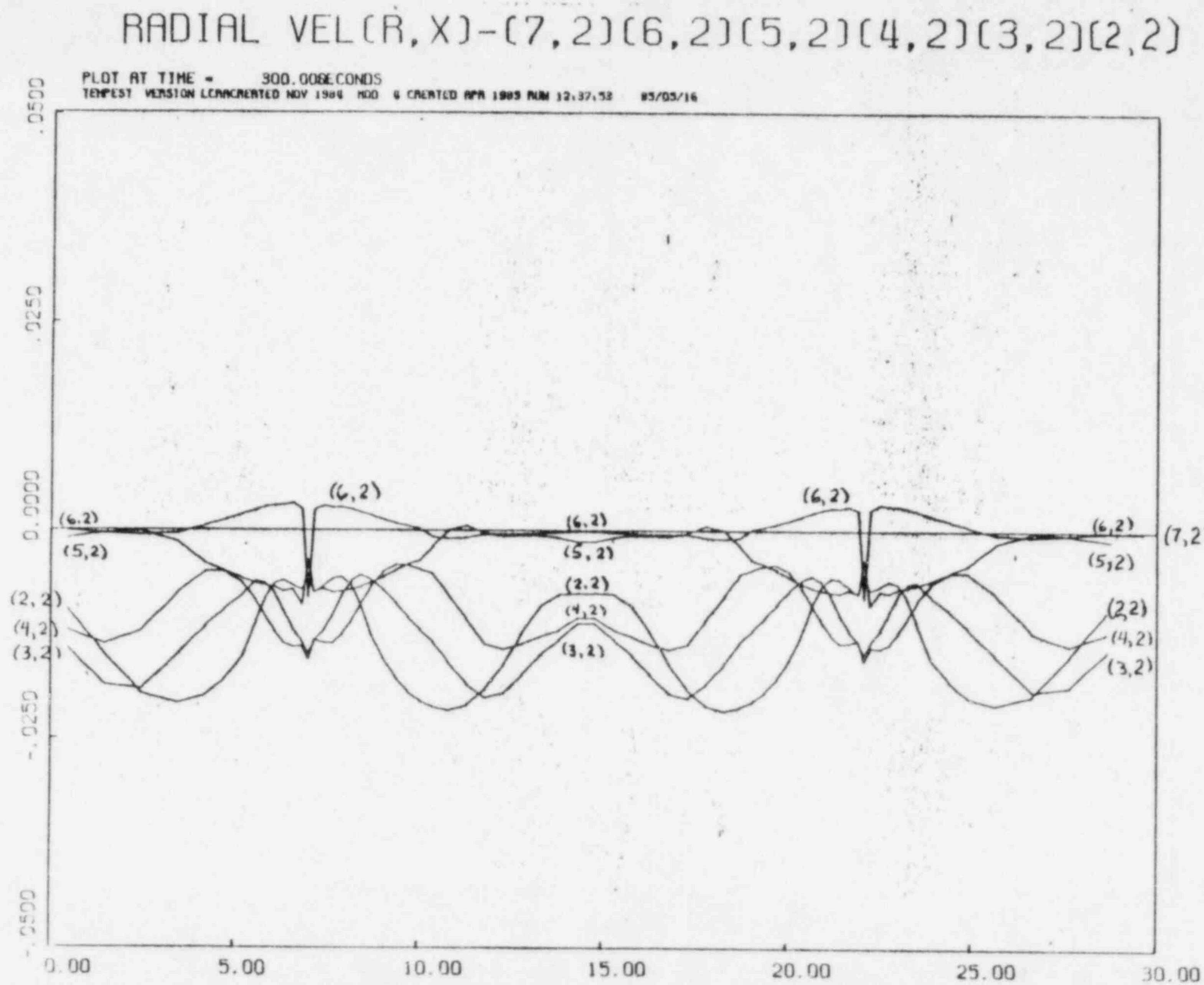

Figure 11. Radial velocity (ft/sec) versus distance (ft) along pipe from the TEMPEST simulation at various (R, θ) nodes

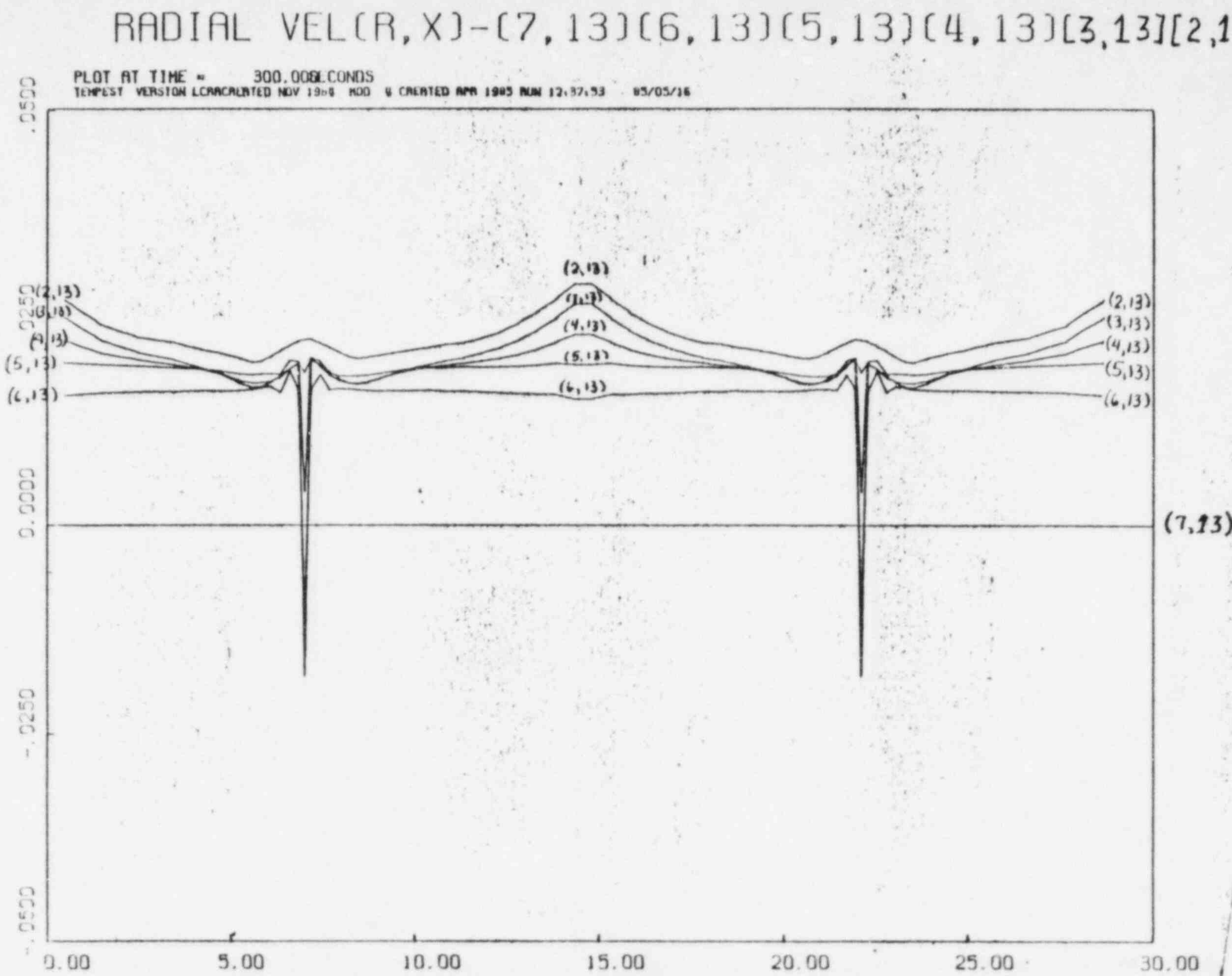

Figure 12. Radial Velocity (ft/sec) versus distance (ft) along pipe from the TEMPEST Simulation at additional (R, θ) nodes.

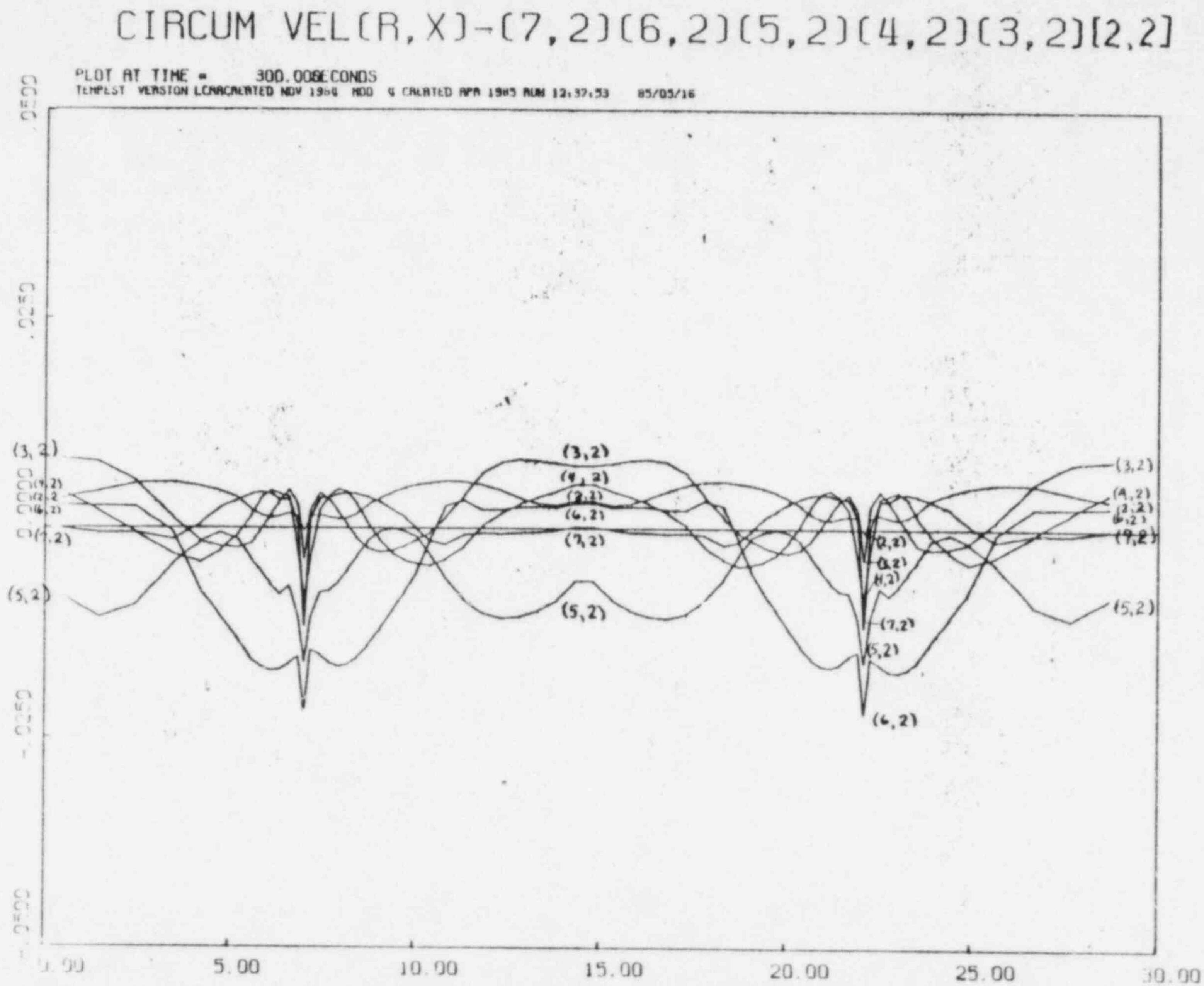

Figure 13. Circumferential velocity (ft/sec) versus distance (ft) down pipe from TEMPEST simulations at various (R, θ) nodes

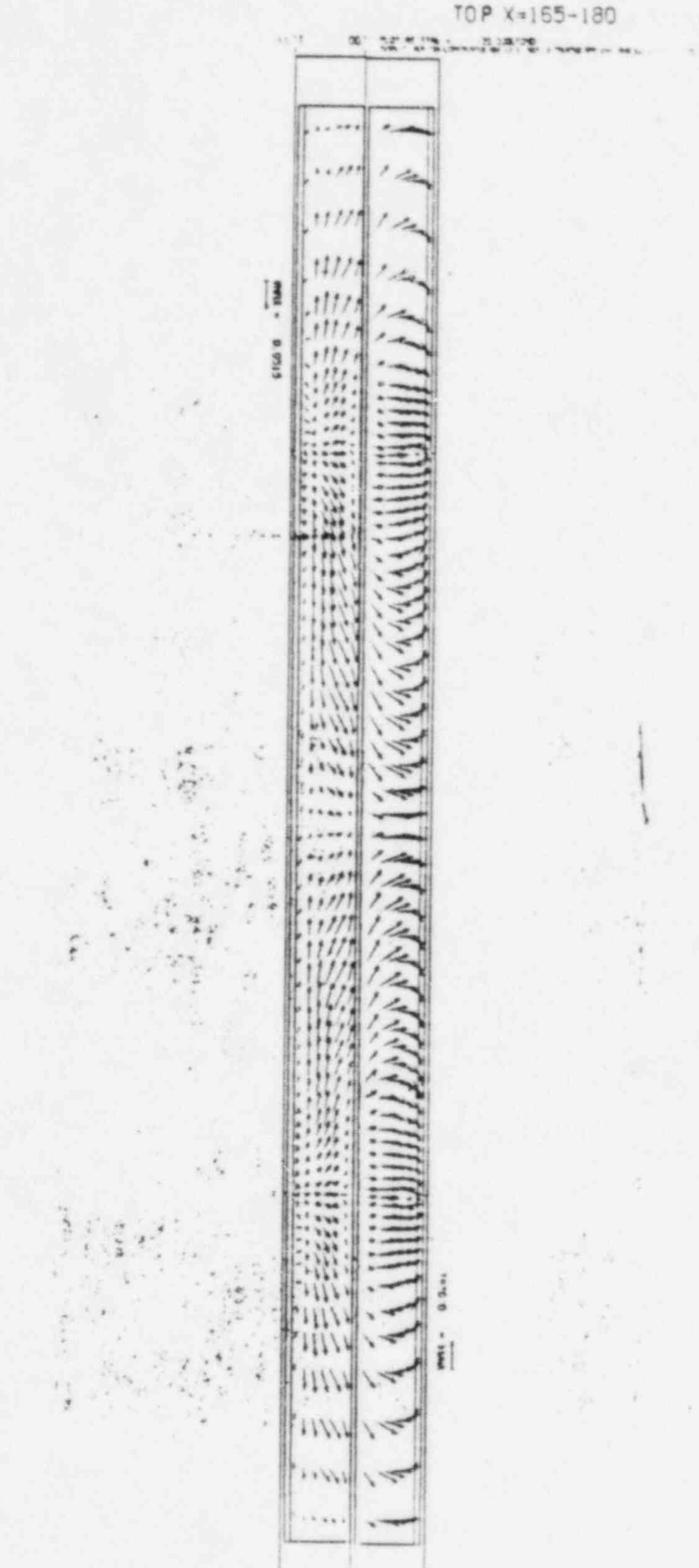

Figure 14. Axial and radial velocities at upper and lower azimuthal sections

1. Maximum axial velocity found is 0.0515 ft/sec. This is in approximate agreement with the value expected theoretically for a pipe section 15 ft long with hot and cold closed end plates and a temperature difference of 4°F (References 4, 5, 6, 7).

2. Maximum transverse (nonaxial) velocities found in two planes of interest were:

$$V_{\perp,max} = 0.13 \text{ ft/sec} \qquad \text{Sec. 15, hanger plane}$$
$$V_{\perp,max} = 0.078 \text{ ft/sec} \qquad \text{Sec. 35, quiescent plane between hangers} \tag{20}$$

The maximum velocities are in approximate agreement with transverse velocities expected from a convective Reynolds number correlation for steam that was developed for the TRAP/MELT code (Reference 7), namely

$$FRE = (Gr/70)^{0.5} \tag{21}$$

where Gr is the Grashof number and FRE is a convective Reynolds number.

3. Axial velocities were found to cross the zero value at the "quiescent plane" midway between pipe hangers for all locations in the pipe cross section. This supports the choice of such locations as "compartment boundaries".

4. Axial velocities were found to cross zero in the vicinity of the pipe hangers (Sections 15 and 56), though not in as simple a way nor for all cross sections at exactly the same location.

5. A region of axially uniform radial and axial velocities is centered about the "quiescent plane" between pipe hangers. There is a region of axially uniform wall temperature there, too, of course, but this simulation represents a late time when the axially uniform temperature region has become small.

6. Both the axial and the transverse convection velocities found are large compared with the bulk axial velocity corresponding to the standard technical specification MSIV leak rates. Consider an MSIV leaking at 0.705 lbm/hr, corresponding to 11.5 ft^3 of 25 psia steam per hour. If the leakage steam drops in pressure to atmospheric and equilibrates to pipe temperature T_{pipe}, then the bulk axial velocity in a 27.25 in. I.D. steam line is

$$V_{bulk} = \begin{cases} 7.13 \text{ ft/hr} = 1.98 \times 10^{-3} \text{ ft/sec if } T_{pipe} = 550°F \\ 4.94 \text{ ft/hr} = 1.37 \times 10^{-3} \text{ ft/sec if } T_{pipe} = 240°F \\ 4.67 \text{ ft/hr} = 1.30 \times 10^{-3} \text{ ft/sec if } T_{pipe} = 212°F \end{cases} \qquad (22)$$

Thus the peak axial convective velocity at 240°F is ~ 38 times the bulk axial velocity at the nominal leak rate, and the peak transverse convective velocity is 95 times the bulk velocity at Section 15 (hanger) and 57 times the bulk velocity at Section 35 (quiescent plane).

VON KARMAN EDDY MIXING FROM TEMPEST SIMULATION

The TEMPEST simulation and the Von Karman dispersion coefficient expression (Equation 10) or its extension (Equation 11) provide an alternate estimate for the eddy mixing between compartments at the quiescent plane. To apply Equation 11 to the TEMPEST simulation results, one approximates the first and second derivatives by first and second differences. We identify Section 35 (or k = 35) in the TEMPEST simulation as the quiescent plane. (The quiescent plane actually lies between sections 35 and 36.) The computed velocities at planes 35, 36, and 37 are used to obtain these differences.

The second derivative approximation from these planes is

$$\frac{d^2V_\perp}{dz^2} \approx \left(\frac{V_\perp^{(37)} - V_\perp^{(36)}}{Z^{(37)} - Z^{(36)}} - \frac{V_\perp^{(36)} - V_\perp^{(35)}}{Z^{(36)} - Z^{(35)}}\right) / \left(\frac{Z^{(37)} - Z^{(35)}}{2}\right) \qquad (23)$$

We can choose from three possible approximations to the first derivative $dV_\perp/dz$ needed for the Von Karman dispersion coefficient expression

$$\left(\frac{\Delta V_\perp}{\Delta z}\right)_- = \frac{V_\perp^{(36)} - V_\perp^{(35)}}{Z^{(36)} - Z^{(35)}}$$

$$\left(\frac{\Delta V_\perp}{\Delta z}\right)_0 = 2\,\frac{V_\perp^{(37)} - V_\perp^{(35)}}{Z^{(37)} - Z^{(35)}} \tag{24}$$

$$\left(\frac{\Delta V_\perp}{\Delta z}\right)_+ = \frac{V_\perp^{(37)} - V_\perp^{(36)}}{Z^{(37)} - Z^{(36)}}$$

We define three approximations $E_z^{(-)}$, $E_z^{(o)}$, $E_z^{(+)}$ to the Von Karman expression (Equation 11) for the axial dispersion coefficient across the quiescent plane boundary in the TEMPEST simulation according to which of the first difference approximations (Equations 24) we use. Table 1 presents values of $E_z^{(-)}$, $E_z^{(o)}$, and $E_z^{(+)}$ at selected R and θ node indices. The dispersion coefficients in Table 1 were calculated using Equation 10 if one of the nonaxial velocity components was zero (the x direction then being defined as the direction of the nonzero velocity component), but by its extension Equation 11 if both V_θ and V_R were nonzero.

From Table 1 we see that using planes 35 and 36 for the first derivative approximation gives $E_z^{(-)} = 0$, due to the symmetry velocity profile near the quiescent plane. $E_z^{(o)}$ values are 0.01 to 0.06 ft^2/hr. The gradient of the nonaxial velocity increases as a point moves away from the quiescent plane. For comparison, the molecular diffusion coefficient D_{Xe,H_2O} for xenon in

TABLE 1. Axial Dispersion Coefficients Near the Quiescent Plane Between Pipe Hangers Calculated From the TEMPEST Simulation Using Equation 11 or Equation 10

Azimuthal Node	Radial Node	Azimuthal Velocity (ft/sec)			Radial Velocity (ft/sec)			Dispersion Coefficient (ft^2/hr)		
I	J	k=35	k=36	k=37	k=35	k=36	k=37	$E_z^{(-)}$	$E_z^{(+)}$	
2	6	2.962E-3	2.962E-3	2.436E-3	-1.859E-4	-1.859E-4	-3.098E-4	0.	1.843E-2	0.1475
10	5	9.931E-3	9.931E-3	1.201E-2	9.157E-3	9.157E-3	7.172E-3	0.	1.728E-2	0.1383
2	7	2.119E-4	2.120E-4	-2.250E-4	0.	0.	0.	1.51E-12	1.571E-2	0.1258
13	6	0.	0.	0.	1.510E-2	1.510E-2	1.568E-2	0.	2.088E-2	0.1670
10	3	1.015E-2	1.015E-2	1.055E-2	1.143E-2	1.143E-2	8.415E-3	0.	6.488E-2	0.5159
4	3	1.364E-2	1.364E-2	1.226E-2	6.290E-3	6.290E-3	5.825E-3	0.	5.209E-2	0.4167
4	5	3.999E-3	3.999E-3	3.611E-3	6.673E-3	6.673E-3	8.448E-3	0.	5.068E-2	0.4055
8	7	-7.533E-2	-7.533E-2	-7.632E-2	0.	0.	0.	0.	3.564E-2	0.2851
2	4	5.251E-3	5.251E-3	4.385E-3	-1.052E-2	-1.052E-2	-1.200E-2	0.	3.666E-2	0.2933

superheated steam at 1 atmosphere pressure is 0.82 ft^2/hr at 240°F and 0.65 ft^2/hr at 550°F. Note also that the $E_z^{(+)}$ values of Table 1 are on the same order though somewhat lower than the values in Equation 17 deduced from empirical radial deposition correlations in pipes.

MASS TRANSFER COEFFICIENTS

We have discussed the dispersion coefficient and diffusion coefficient for mass transport by eddy mixing and diffusion, respectively. The relevant quantity $k_{i-1,i}$ or $k_{i-1,i}$ for the compartment model (Equation 1) is a mass transfer coefficient, which could simplistically be obtained by dividing the sum of the dispersion and diffusion coefficients by an effective "boundary layer" distance through which the transfer occurs if the D and E were constant and the boundary layer thickness known. For the transfer between compartments across the quiescent plane boundary, a "boundary layer" distance is difficult to identify, though one would intuitively expect that boundary layer to be some fraction or small multiple of the pipe diameter. We will here arrive at a mass transfer coefficient by a number of models, arguments, and correlations.

SHERWOOD-PIGFORD-WILKE CORRELATION

A discussion was presented in the vicinity of Equation 18 to reinterpret the radial dispersion coefficient correlation for pipes with simple flow to obtain a mass transfer coefficient $E_\perp/r$ for transfer normal to the dominant fluid velocity. If we use the typical velocity at the quiescent plane from the TEMPEST simulation, V_{av} = 0.025 ft/sec, we obtain from Equation 18

$$0.18 \text{ ft/hr} = 0.5 \times 10^{-4} \text{ ft/sec} < \frac{E_\perp}{r} < 2. \times 10^{-4} \text{ ft/sec} = 0.72 \text{ ft/hr} \tag{25}$$

Using instead the maximum velocity at the quiescent plane in Equation 18 gives

$$0.56 \text{ ft/hr} < \frac{E_\perp}{r} < 2.25 \text{ ft/hr} \tag{26}$$

Note that these numbers for $k_{i,i+1} = E_{\perp}/r$ should be compared with a bulk flow velocity ṫ/A of the leakage steam, Equation 22.

PARALLEL JETS MODEL

From the TEMPEST simulation, we see (Figures 8, 9, 10) that flow at the quiescent plane consists of convective flow in the nonaxial direction, this flow being locally axially uniform. Suppose that the flow pattern consisted of fluid with a radionuclide concentration characteristic of its convection cell approaching the interface, then flowing parallel to and in direct contact with the fluid that approached the interface from the other convection cell. After some distance of parallel motion, the fluid elements separate and return in a convection path through their own compartments, where they again acquire concentrations characteristic of their own compartments. During the time of parallel motion at the interface, the fluid elements exchange solute mass by diffusion. The solute mass transfer rate is limited by the duration of the intimate contact of the fluid elements from different compartments as they move parallel to each other.

We idealize this picture to a solvable model as follows. Two half spaces are separated by a thin, impermeable membrane. All space is filled with uniformly flowing fluid, but the fluid on the two sides of the impermeable membrane has a different solute concentration. In the impermeable membrane separating the two half-space regions there is a gap of finite width in the flow direction (and long in the direction normal to flow, to make the problem two-dimensional). The average solute flux across this gap can be calculated as a function of total diffusion coefficient D, fluid velocity V, length of flowstream L for which the two fluids have unimpeded contact, and the difference in solute concentrations on the two sides of the membrane on the upstream side of the gap. In Appendix 2, the average total solute current density J_D due to diffusion is shown to be

$$J_D = \left(\frac{DV}{\pi L}\right)^{1/2}(C_L - C_R) \qquad (27)$$

where C_L and C_R are the solute concentrations in the left and right half spaces, respectively.

From the TEMPEST simulations, we see that the fluid velocity "tracks" across the quiescent plane are typically a pipe diameter long before a major direction reversal. (See the vector velocity plot for axial section 35.) The highest velocity occurs near the pipe wall, and there the path length before reversal appears to be almost π times the diameter long.

We are thus lead in the compartment model to set

$$k_{i,i+1} = \left(\frac{DV}{\pi d}\right)^{1/2} \tag{28}$$

where V is the nonaxial velocity at the compartment interface and d is pipe inside diameter. Using the typical value V = 0.025 ft/sec at the quiescent plane we obtain the estimates for xenon

$$k_{i,i+1} = \begin{matrix} 8.92 \times 10^{-4} \text{ ft/sec} = 3.21 \text{ ft/hr at } 240^{0}\text{F} \\ 7.97 \times 10^{-4} \text{ ft/sec} = 2.87 \text{ ft/hr at } 550^{0}\text{F} \end{matrix} \tag{29}$$

These values should be compared with the nominal bulk flow velocities in Equation 22 and with the conjectured values $k_{i,i+1} = E_{\perp}/r$ given by the extended Sherwood-Pigford-Wilke correlation in Equations 25 and 26. We used the molecular diffusion coefficient as the total diffusion coefficient in getting Equation 29, in part because the Von Karman dispersion coefficient vanishes exactly at the quiescent plane (see $E_z^{(-)}$ in Table 1), and also because the assumptions are of very intimate contact between cells.

The parallel jets model gives mass transfer coefficients that are approximately a factor of our higher than those given in Equation 25. The Equation 29 values are too high because most of the flow at the quiescent plane as calculated by TEMPEST is due to the 11.5°F temperature difference between wall and bulk fluid there and hence essentially flows around within an axial section. The 4°F axial temperature difference in the pipe is the part that drives a convective flow that brings fluid toward and away from the quiescent plane. The part of the flow originating with the axial temperature difference

brings fluid whose composition is characteristic of the compartment to the interface, whereas the flow within an axial section is not comparably refreshed. Also, the contact between material from different compartments is not as intimate as assumed in the parallel jets model.

The parallel jets model provides an upper bound on the mass transfer coefficients between main steam line compartments.

VERTICAL PLATE MODEL

The following mass transfer correlation has been proposed and substantiated (Reference 9, p. 295) for a vertical plate of vertical length L, along which fluid flows at asymptotic velocity V (at some distance from the surface)

$$\frac{\overline{k}L}{D} \quad 0.626 \left(\frac{LV\rho}{\mu}\right)^{1/2} \left(\frac{\mu}{\rho D}\right)^{1/3} \tag{30}$$

Here $\overline{k}$ is the average mass transfer coefficient to or from the vertical plate, μ is the fluid viscosity, D is the diffusion coefficient, and ρ is the fluid density. To apply this form to the mass transfer across a quiescent plane in a BWR main steam line, we take L to be pipe diameter. Note that Equation 30 is expressed in terms of the dimensionless Sherwood number $\overline{k}L/D$, Reynolds number $LV\rho/\mu$, and Schmidt number $\mu/\rho D$. Hence large amounts of data for many fluids and solutes support this correlation.

The inconsistency in applying Equation 30 to radionuclide transport across the quiescent plane is that Equation 30 was verified for vertical plates for which the velocity goes to zero at the surface, and a boundary layer profile consistent with this develops vertically. The shear, not the velocity, goes to zero at the quiescent plane between convection cells in the main steam line, and the "boundary layer" is quite different. Nevertheless, numbers from Equation 30 are informative.

The values of $\overline{k}$ were calculated using Equation 30 for xenon in superheated steam at temperatures of 550°F and 240°F using the following values:

$T = 550^0F = 561.28^0K$
$\mu = 198.1 \times 10^{-6}$ poise
$\rho = 3.91 \times 10^{-4}$ gm/cm^3
$L = 27.5 * 2.54$ cm
$V = 0.025$ ft/sec = 0.762 cm/sec
$D = 0.168$ cm^2/sec

$T = 240^0F = 388.7^0K$
$\mu = 131.3 \times 10^{-6}$ poise
$\rho = 5.65 \times 10^{-4}$ gm/cm^3
$L = 27.5 * 2.54$ cm
$V = 0.025$ ft/sec = 0.762 cm/sec
$D = 0.211$ cm^2/sec

From these we obtain:

$$\bar{k} = 2.23 \times 10^{-2} \text{ cm/sec} = 7.32 \times 10^{-4} \text{ ft/sec} = 2.64 \text{ ft/hr} \quad (550^0F)$$

$$\bar{k} = 2.95 \times 10^{-2} \text{ cm/sec} = 3.49 \text{ ft/hr} \quad (240^0F) \tag{32}$$

Note that the Equation 32 values are in good agreement with the Equation 29 values.

The values in Equation 32 are too high for the same reason that the parallel jets model results (Equation 29) are too high: both models assume initially "fresh" material moving past the interchange surface rather than at least partially cycling there.

BOUNDARY LAYER DIFFUSION MODEL

Axial velocities are seen from the TEMPEST simulations (with no net flow) to cross zero at the quiescent plane between pipe hangers. Hence the diffusion and dispersion processes must carry the radionuclides from the vicinity where axial velocities die away through the interface to the location far enough into the next cell that convection can again carry it away. We need to find an upstream location distance w_o from the interface such that

$$(C_u - C_o)|V_z(w_o)| \approx \frac{D^{(tot)}}{w_o}(C_u - C_o) \tag{33}$$

where $V_z(w)$ is the axial convection velocity at distance w from the quiescent plane, C_u is the upstream solute concentration, and C_0 is the solute concentration at the quiescent plane. $V_z(w)$ will be dramatically different depending on the (R,θ) positions. Nevertheless, velocities can be taken at a few locations to get a w value and hence an order of magnitude confirmation on the mass transfer coefficient $D^{(tot)}/w$.

From the TEMPEST plots (Figures 9 and 10), the axial velocity near the quiescent plane are seen to satisfy

$$V_z = w \frac{dV_z}{dw} \tag{34}$$

Equations 33 and 34 imply

$$w_0 = \left|\frac{D}{dV_z/dw}\right|^{1/2}$$

$$k = \frac{D}{w_0} \tag{35}$$

The following $|dV_z|dw|$, w_0, and k values were deduced from the Figures 9 and 10 and Equations 35.

I_θ	J_R	$\lvert dV_z \rvert dw\rvert$	w_0	k	
13	7	6.4×10^{-3} ft/sec	0.188 ft	4.34 ft^2/hr	
8	7	1.1×10^{-2}	0.144	5.69	(36)
8	2	2.09×10^{-2}	0.104	7.84	

We have used the molecular diffusion correlation as $D^{(tot)}$ in obtaining the results of Equation 36. This is justified by the smallness of the effective layer half-thickness w_0 and the idealization into convection and diffusion regions.

The values of D/w in Equation 36 differ by only a factor of 2 from those of Equation 29 and Equation 32. This is resonable agreement for such a rough procedure. We advise against the use of the procedure which we have just

reported (Equations 33-36), because it requires developing a velocity profile near the quiescent plane. Nevertheless, it provides an order of magnitude confirmation of values obtained by other means.

CONCLUSIONS

The model of the cooling steam line as a sequence of well-mixed compartments with sequential flow has been supported by the convection patterns calculated by TEMPEST. The convection velocities far exceed the bulk flow velocity at low leakage rates, and at high leakage rates no significant error should result from the well-mixed compartment assumption.

The contribution of the dispersion or eddy mixing and of diffusion to the mass transfer across the quiescent boundary between convection cells has been estimated using four methods: 1) an extension of a Sherwood-Pigford-Wilke correlation for radial mass transfer in pipes, 2) a parallel jets model, 3) the correlation for mass transfer to a vertical plate, and 4) a boundary layer diffusion model using the velocities calculated with TEMPEST. Methods 2 and 3 gave substantially the same estimate for the mass transfer of xenon from diffusion-dispersion, while method 4 gave about 50% more, and method 1 gave a factor of 4 less. All of the methods contained some uncertainty, e.g., which velocity to use, so these comparisons are somewhat qualitative. Method 2 is felt to give a conservatively large mass transfer by diffusion-dispersion, and lends itself to a prescription that can be easily used by utilities. Method 1 uses too bold an extension of the correlated results of experiments to a different geometry. Hence it should not be used without experimental verification.

Mass transfer coefficients for moving fluids are typically given by correlations with a D^b dependence on diffusion coefficient, with exponent b lying in the range $0 < b < 1$. The b=1 case applies to zero velocity. Because of the positive power b to which the diffusion coefficient appears and the smallness of the diffusion coefficients for aerosol particles of interest (Appendix B), the diffusion-dispersion contribution to particle transport between compartments can be neglected. This is consistent with the observation

that the horizontal motion of the aerosol particles to macroscopic walls is slow. The horizontal motion of aerosols, other than with flow, into the adjacent convection cell is comparably slow.

RECOMMENDATIONS

The compartmental flow model stated mathematically by Equation 1 is a tool for analyzing radionuclide propagation and release by MSIV leakage. The mass transfer coefficients $k_{i,i+1}$ and $k_{i-1,i}$ should be set to zero for aerosol particulates. For radionuclide gases, the values of $k_{i-1,i} A_{i-1,i}$ and $k_{i,i+1} A_{i,i+1}$ are no longer negligible compared with $\dot{v}_i^{(1)}$ and $\dot{v}_i^{(2)}$, being perhaps 80% (though more likely less than 30%) as large at the current low leakage flow rates of the standard technical specifications for MSIVs.

The main steam line should be divided into a number of compartments no more than and preferably less than the number of major heat sinks, like pipe hangers, for the analysis. Each compartment will then include at least two convective cells, one on either side of the heat sink. The interface between convective cells at the heat leak would be neglected as a barrier to radionuclide transport, as appropriate because of the high temperature gradients occurring there. The existence, rather than the exact location, of quiescent planes between heat sinks would be the important consideration.

For radionuclide gases, the mass transfer coefficients $k_{i,i+1}$ for subsequent calculations should be conservatively calculated using the following procedure:

1. Determine a representative nonaxial velocity magnitude at the quiescent planes. If it is preferred not to do a two- or three-dimensional fluid flow calculation, use the procedure described here:

   a. Calculate a Grashof number Gr for transverse convective flow

$$Gr = \frac{d^3 \rho^2 g \Delta T}{\mu^2 T}$$

d = pipe inside diameter in centimeters

ρ = steam density in gm/cm^3

g = acceleration of gravity (980 cm/sec^2)

T = mean fluid temperature in degrees Kelvin

μ = viscosity in poise

ΔT = temperature difference between pipe wall and bulk steam in degrees Kelvin

This Gr number is dimensionless and can be calculated in any other consistent unit system. If a better upper bound of temperature difference ΔT is not available, use $\Delta T = 7^0K$ or 12.6^0F. Do this calculation assuming a pressure of 1 atmosphere and an intermediate temperature between initial and ambient.

(Note that $\mu^2 T$ will vary roughly as T^2).

b. Obtain a "free convection Reynolds number" FRE from

$$FRE = (Gr/70)^{1/2}$$

as described in Reference 8.

c. Estimate the typical velocity at the interface from

$$V = 1/3 \frac{\mu}{\rho d} * FRE$$

The factor 1/3 is an appropriate ratio of typical to maximum convection velocity.

2. Calculate diffusion coefficient D for the gas (use Xe for noble gases) from available expressions and tabulation, such as the Chapman-Enskog theory. Assume the intermediate temperature.

3. Calculate the mass transfer coefficients from

$$k_{i,i+1} = \left(\frac{DV}{\pi d}\right)^{1/2}$$

The calculation of the radionuclide migration and release transient should then be done using a numerical method for solving the system of equations of the form of Equation 1.

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APPENDIX 1

APPENDIX 1

DIFFUSION COEFFICIENTS

Xenon in Steam

An expression for the calculation of diffusion coefficients for a pair of gases was developed by Chapman and Enskog (Ref. 9), and has been widely propagated in the literature. We will use the Chapman-Enskog expression with accompanying tabulated values from E. L. Cussler (Ref. 9, p. 108):

$$D = 1.86 \times 10^{-3} \frac{\sqrt{T^3 \left(\frac{1}{M_1} + \frac{1}{M_2}\right)}}{p\, \sigma_{12}^2\, \Omega} \tag{1.1}$$

where

D = diffusion coefficient in cm^2/sec

T = temperature (°K)

M_1, M_2 = molecular weight of gases 1 and 2 in amu

p = pressure in atmospheres

σ_{12} = $1/2\ (\sigma_1 + \sigma_2)$ = collison diameter of the two species in Angstroms

Ω = collison integral expression from the detailed theory on assumption of Lennard-Jones potential interactions, tabulated as a function of e_{12}/kT

e_{12} = $(e_1 e_2)^{1/2}$ = interaction energy parameter.

The values of σ_i and e_i are tabulated for a number of gases.

From Reference 9, we obtain

$\sigma_{H_2O} = 2.641$

$$\sigma_{Xe} = 4.047$$

$$\frac{e_{H_2O}}{k} = 809.1°K \qquad (1.2)$$

$$\frac{e_{Xe}}{k} = 231.0^0K \qquad (1.3)$$

Hence:

$$\frac{e_{12}}{k} = \left(\frac{e_{H_2O}\ e_{Xe}}{k^2}\right)^{1/2} = 432.32^0K \qquad (1.4)$$

Hence also:

$$\frac{kT}{e_{12}} = \begin{matrix} 0.899 \text{ for } T = 240^0F = 388.7^0K \\ 1.298 \text{ for } T = 550^0F = 561.28^0K \end{matrix} \qquad (1.5)$$

From the table of values for Ω, we obtain

$$\Omega = \begin{matrix} 1.517 \text{ for } T = 240^0F = 388.7^0K \\ 3.3 \text{ for } T = 550^0F = 561.28^0K \end{matrix} \qquad (1.6)$$

Using the molecular weights

$$M_{H_2O} = 18.016$$

$$M_{Xe} = 131.3 \qquad (1.7)$$

in Equation 1.1, we obtain from Equation 1.1 for xenon in superheated steam at 1 atmosphere pressure

$$D = \begin{cases} 0.2109\ cm^2/sec = 2.2703 \times 10^{-4}\ ft^2/sec = 0.8173\ ft^2/hr \text{ for } T = 240\,^0F \\ 0.1682\ cm^2/sec = 1.8109 \times 10^{-4}\ ft^2/sec = 0.6519\ ft^2/hr \text{ for } T = 550\,^0F \end{cases} \tag{1.8}$$

Aerosol Particles

The diffusion coefficient for spherical aerosol particles can be found using the Einstein relation with the more modern Cunningham correction for slip at the surface of small particles:

$$D = \frac{kT}{6\pi\eta r} F \tag{1.9}$$

$$F = 1 + A\frac{\ell}{r} + B\frac{\ell}{r} \exp\left(-c\frac{r}{\ell}\right) = \text{Cunningham slip correction} \tag{1.10}$$

k = Boltzman constant, 1.380662×10^{-16} erg/°K

T = absolute temperature

η = viscosity of fluid medium (poise)

r = radius of particle in cm

ℓ = molecule mean free path

A = 1.257 B = 0.40 C = 1.10

The mean free path can be approximated by

$$\ell = \eta/(0.499\rho\bar{c}) \tag{1.11}$$

$$\bar{c} = \sqrt{\frac{8kT}{\pi m}} = \sqrt{\frac{8N_A kT}{\pi M}} \tag{1.12}$$

m = mass per gas molecule

M = molecular weight of gas in amu

N_A = Avagadro's number

Consider a steam medium at three temperatures, 212°F, 240°F, and 550°F, but at atmospheric pressure. We take:

$T = 212^0F = 373^0K$ $\rho = 5.977 \times 10^{-4} gm/cm^3$ $\eta = 126.68 \times 10^{-6}$ poise

$T = 240^0F = 388.706^0K$ $\rho = 5.648 \times 10^{-4}\ gm/cm^3$ $\eta = 131.41 \times 10^{-6}$ poise

$T = 550^0F = 561.278^0K$ $\rho = 3.9117 \times 10^{-4} gm/cm^3$ $\eta = 198.15 \times 10^{-6}$ poise

This gives for molecula- velocity and mean free path in steam (M = 18.016) from Equations 1.12 and 1.11:

$$\bar{c} = \begin{matrix} 6.62 \times 10^4 cm/sec \\ 6.76 \times 10^4 cm/sec \\ 8.12 \times 10^4 cm/sec \end{matrix} \qquad \ell = \begin{matrix} 6.415 \times 10^{-6}\ cm \\ 6.899 \times 10^{-6}\ cm \\ 1.250 \times 10^{-5}\ cm \end{matrix} \quad \text{at} \quad \begin{matrix} 212^0F \\ 240^0F \\ 550^0F \end{matrix}$$

We can thus obtain from Equation 1.10 the following diffusion coefficients for aerosol particles in steam at one atmosphere pressure:

Particle Radius (microns)	T = 212°F D(cm²/sec)	D(ft²/hr)	T = 240°F D(dm²/sec)	D(ft²/hr)	T = 550°F D(cm²/sec)	D(ft²/hr)
0.05	$1.22\text{x}10^{-5}$	$4.73\text{x}10^{-5}$	$1.29\text{x}10^{-5}$	$5.01\text{x}10^{-5}$	$1.99\text{x}10^{-5}$	$7.70\text{x}10^{-5}$
0.2	$1.52\text{x}10^{-6}$	$5.88\text{x}10^{-6}$	$1.56\text{x}10^{-6}$	$6.04\text{x}10^{-6}$	$1.90\text{x}10^{-6}$	$7.35\text{x}10^{-6}$
1.0	$2.33\text{x}10^{-7}$	$9.03\text{x}10^{-7}$	$2.35\text{x}10^{-7}$	$9.12\text{x}10^{-7}$	$2.40\text{x}10^{-7}$	$9.30\text{x}10^{-7}$

APPENDIX 2

APPENDIX 2

PARALLEL JETS MODEL FOR INTERCHANGE

Consider all space to be filled with fluid moving with uniform velocity V in the positive x direction, but a thin impermeable membrane in the plane y=0 separates the fluid into two parts. The fluid in the region y < 0 carries solute concentration C_L, while that in the region y > 0 carries solute concentration C_u in the region X < 0. Now suppose that the impermeable membrane is missing in the region 0 < X < L, so that fluids of different solute concentration can exchange material across the gap. The steady-state equation

$$\nabla \cdot (C\underline{V} - D\nabla C) = 0 \tag{2.1}$$

becomes

$$V \frac{\partial C}{\partial x} = D \left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2}\right) \tag{2.2}$$

If the flow rate V in the x direction is larger than diffusion velocities, we can neglect diffusion in the flow direction to obtain

$$\frac{\partial C}{\partial x} = \frac{D}{V} \frac{\partial^2 C}{\partial y^2} \tag{2.3}$$

with the conditions

$$\begin{aligned} C &\rightarrow C_u \text{ as } y \rightarrow +\infty \\ C &\rightarrow C_L \text{ as } y \rightarrow -\infty \end{aligned} \tag{2.4}$$

$$C = C_u \text{ for } y > 0 \text{ and } x < 0$$
$$C = C_L \text{ for } y < 0 \text{ and } x < 0 \qquad (2.5)$$

Assume that

$$\frac{C}{C_u - C_L} = \phi(\eta) \qquad (2.6)$$

where

$$\eta = \frac{y}{\sqrt{4\gamma x}} \qquad (2.7)$$

and

$$\gamma = \frac{D}{V} \qquad (2.8)$$

Then we have from Equations 2.6 and 2.7

$$\frac{\partial C}{\partial x} = (C_u - C_L)\ \phi'(\eta)\ \frac{d\eta}{dx} \qquad (2.9)$$

$$\frac{\partial C}{\partial y} = (C_u - C_L)\ \phi'(\eta)\ \frac{d\eta}{dy} \qquad (2.10)$$

$$\frac{\partial^2 C}{\partial y^2} = (C_u - C_L)\ [\phi''(\eta)\ (\frac{d\eta}{dy})^2 + \phi'(\eta)\ \frac{d^2\eta}{dy^2}] \qquad (2.11)$$

$$\frac{d\eta}{dx} = -\frac{1}{2x}\eta \qquad (2.12)$$

$$\frac{d\eta}{dy} = \frac{1}{\sqrt{4\gamma x}} \qquad (2.13)$$

$$\frac{d^2\eta}{dy^2} = 0 \tag{2.14}$$

Substitution of this assumed form, Equations 2.6 through 2.14, into Equation 2.2 gives

$$- 2\eta\phi'(\eta) = \phi''(\eta) \tag{2.15}$$

Letting $\psi(\eta) = \phi;(\eta)$, we see that Equation 15 gives

$$d \ln \psi = - 2\eta d\eta \tag{2.16}$$

$$\psi(\eta) = C_1 e^{-\eta^2} \tag{2.17}$$

This implies

$$\phi(\eta) = \int_o^\eta \psi(\xi)d\xi + C_2 \tag{2.18}$$

$$= C_1 \int_o^\eta e^{-\xi^2} d\xi + C_2 \tag{2.19}$$

From Equation 2.6, we have

$$C = (C_U - C_L)\phi(\eta) \tag{2.20}$$

At $y = 0$ for $x > 0$, we require

$$C(x,o) = \frac{C_u + C_L}{2} = (C_1 * 0. + C_2)(C_u - C_L) \tag{2.21}$$

Hence

$$C_2 = \frac{1}{2} \frac{C_u + C_L}{C_u - C_L} \tag{2.22}$$

$$C = (C_u - C_L)[C_1 \int_o^{\eta} e^{-\xi^2} d\xi + \frac{1}{2} \frac{C_u + C_L}{C_u - C_L}] \tag{2.23}$$

At $y = + \infty$, we have $C = C_u$. Noting that

$$\int_o^{\infty} e^{-\xi^2} d\xi = \frac{\sqrt{\pi}}{2} \tag{2.24}$$

we obtain from Equation 2.24

$$C_u = (C_u - C_L) C_1 \frac{\sqrt{\pi}}{2} + \frac{1}{2} (C_u + C_L) \tag{2.25}$$

or

$$C_1 = \frac{1}{\sqrt{\pi}} \tag{2.26}$$

We have arrived with

$$C(x,y) = (C_u - C_L) \frac{1}{\sqrt{\pi}} \int_o^{\eta} e^{-\xi^2} d\xi + \frac{1}{2} (C_u + C_L) \tag{2.27}$$

where η is defined in Equation 2.7.

The current density of solute in the y direction will be

$$J_y(x,y) = - D \frac{\partial C}{\partial y} \tag{2.28}$$

$$= -D (C_u - C_L) \frac{1}{\sqrt{\pi}} \exp \left(- \frac{y^2}{4\gamma x}\right) \cdot \frac{1}{\sqrt{4\gamma x}} \tag{2.29}$$

The total flow rate $\dot{N}$ of solute through the strip of length L in the x direction and length L_z in the z direction will be

$$\dot{N} = L_z \int_o^L J_y(x,o)dx \tag{2.30}$$

$$= - L_z D (C_u - C_L) \frac{1}{\sqrt{\pi}} \int_o^L \frac{dx}{\sqrt{4\gamma x}} \tag{2.31}$$

$$= - L_z D (C_u - C_L) \sqrt{\frac{L}{\pi\gamma}} \tag{2.32}$$

The average current density from diffusion the strip is then

$$\langle J_y \rangle = \frac{\dot{N}}{L L_z} = - D (C_u - C_L) (\pi\gamma L)^{-1/2} \tag{2.33}$$

$$= - \left(\frac{DV}{\pi L}\right)^{1/2} (C_u - C_L) \tag{2.34}$$

APPENDIX 3

APPENDIX 3

TEMPEST SIMULATIONS OF THERMAL TRANSIENT AND HYDRODYNAMICS IN A COOLING STEAM LINE SECTION

Thermal Transient

The thermal transient in the pipe walls of a representative segment of main steam line was first simulated without an accompanying hydrodynamics calculation. The pipe segment simulated extended from one pipe hanger 7.5 ft toward the next pipe hanger, which was assumed to be 15 ft away. An interior temperature of 240°F was specified, and a heat transfer coefficient appropriate for slow MSIV leakage flow was specified for the pipe inner surface. The outer pipe wall was taken as perfectly insulated. (The pipe actually cools by heat loss to the surroundings in a period of about 2 days, but this was not included because of insufficient information on off-design heat transfer of mirror insulation.) The heat loss through the pipe hanger was simulated by a circumferentially uniform heat transfer coefficient for the axial section at the hanger location. The heat transfer to the hanger was taken as approximately 75% of that to a 1 in. diameter rod protruding 3 ft beyond the insulation. The 75% factor is to account for thermal contact resistance between pipe and hanger plus resistance to heat flow in the pipe hanger inside the pipe insulation.

This model should be representative of pipe hangers as heat sinks, though pipe hangers obviously vary in mass, shape, and contact resistance.

Figure 3.1 shows the axial temperature profile calculated at a time 5×10^4 sec (13.9 hours) into the thermal transient in this simulation. An axial temperature difference of ~ 10.5°F has developed, but the temperature profile is flat in the region away from the pipe hanger. The cooling of the pipe from the initial 550°F temperature in this simulation has an axially uniform contribution from the 240° interior fluid and the axially localized part from the pipe hangers, though in practice a second uniform cooling contribution comes from exterior losses.

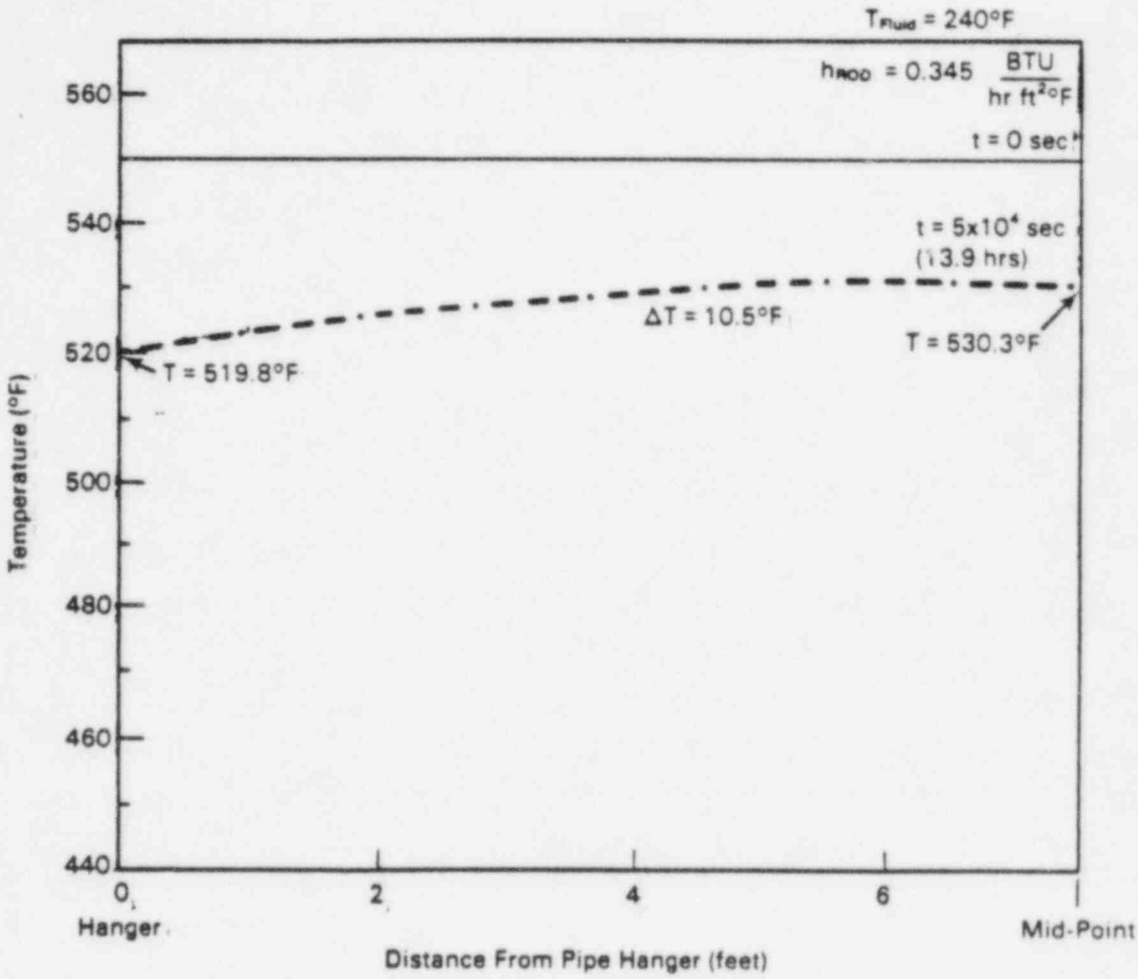

Figure 3.1 Pipe wall temperatures versus distance from pipe hanger from thermal transient simulation

The axial temperature difference found at 13.9 hours (or even at 1 hour) is sufficient to drive axial convection. Two additional features were desired in the starting point or assumptions for the TEMPEST hydrodynamics (as opposed to thermal only) calculations:

1. A modest temperature difference between bulk fluid and pipe wall was desired, typical of locations in the main steam line far enough from the MSIVs that the pipe wall and fluid are nearly thermally equilibrated.
2. The axial temperature drop due to the pipe hanger heat sinks was desired to have propagated to nearer the midpoint between pipe hangers. This should give a "worst case" for eddy-induced mixing at the interface between convection cells at this location.

For these reasons, the thermal transient described here was continued to steady state for use in the TEMPEST hydrodynamics simulation. Figure 3.2 shows the resulting steady-state axial temperature profile in the pipe. The axial temperature difference has dropped to 4°F for this steady-state condition, and the pipe wall has dropped below the interior temperature by 15 to 18°F.

This calculation assumed a uniform temperature inside a pipe and used a heat transfer coefficient typical of a slow fluid flow (Nusselt No. = 4).

This thermal transient calculation has shown the magnitude of axial temperature differences which will occur during the first days of main steam line. The axial temperature difference causes the formation of axial convection cells. The convection during the first 2 days of main steam line cooling is particularly important for radionuclide propagation because: 1) that is a filling period for the main steam line, and hence mixing can enhance propagation, and 2) the hot pipe prohibits condensation of leakage steam during this time.

The radial temperature difference (fluid to pipe wall) can vary in either direction during this time. In the first few hours, the pipe walls may be hotter than the MSIV leakage steam, with the temperature difference reversing as the pipe cools. This radial temperature difference drives radial and circumferential convection currents which can enhance eddy mixing, but large

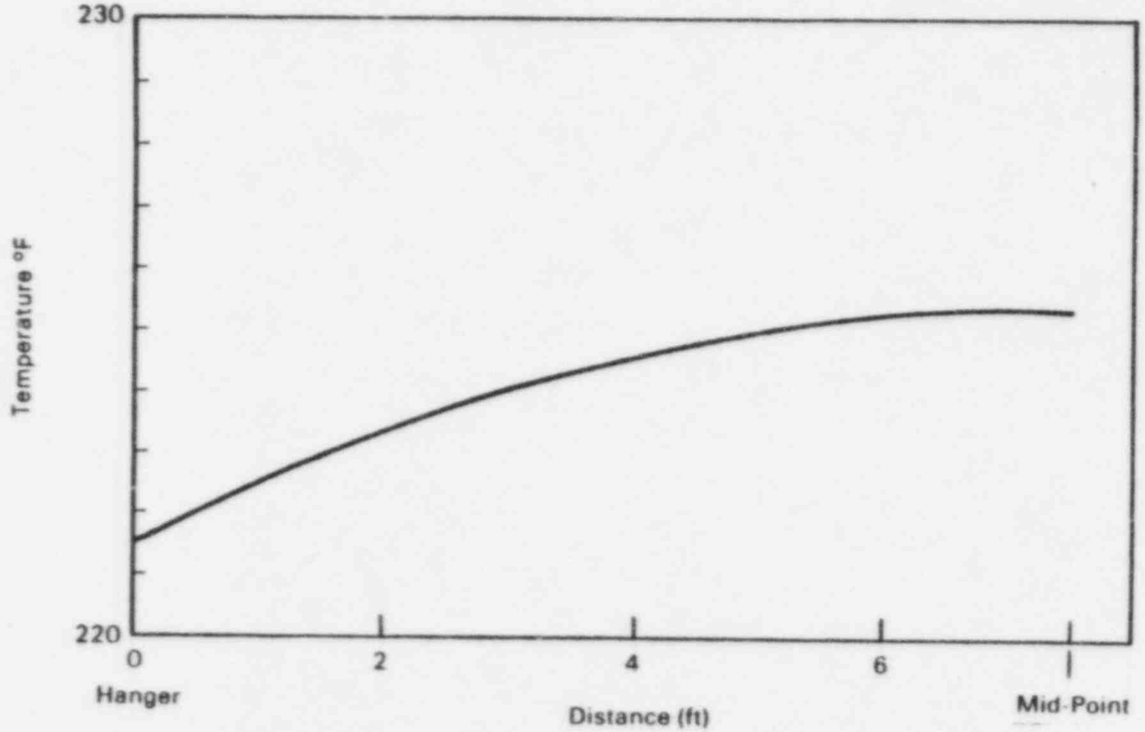

Figure 3.2 Pipe wall temperature versus distance from pipe hanger in steady state from thermal transient simulation

temperature differences between fluid and wall can not persist over a significant axial distance at low flow rates, as shown in Appendix 4.

Hydrodynamics Simulation

The pipe segment for this simulation was the main steam line between two pipe hangers separated by 15 ft, plus a 7 ft distance on either side. The initial pipe wall conditions were taken from the steady-state results of the thermal transient calculation previously described in this Appendix, with extensions using symmetry. The pipe interior initially contained superheated steam at 240°F and 1 atmosphere pressure. Zero flow conditions were specified at the ends. The fluid and heat flow was allowed to evolve for 300 seconds simulated time, setting up a quasi-steady condition of flow. Because the system was closed for fluid flow in this 300 seconds, the fluid temperature dropped slightly.

APPENDIX 4

APPENDIX 4

THERMAL EQUILIBRATION DISTANCE FOR MSIV LEAKAGE STEAM AND MAIN STEAM LINE WALLS

Superheated steam flowing in the main steam line should exchange heat with pipe walls and change temperature according to:

$$\dot{m}C_p \frac{dT}{dx} = - hP(T - T_w) \qquad (4.1)$$

where

$\dot{m}$ = steam mass flow rate

C_p = steam specific heat

T = steam temperature

$\frac{dT}{dx}$ = rate of change of steam temperature with distance in flow direction

h = heat transfer coefficient between steam and pipe wall

P = pipe inside perimeter

T_w = wall temperature

If we neglect wall temperature change, Equation D1 gives

$$T - T_w = (T - T_{w_o}) \exp \left(- \frac{hP}{\dot{m}C_p} x\right) \qquad (4.2)$$

For very low flow rates, the heat exchange will satisfy

$$\frac{hd}{k} \approx 4 \qquad \text{(Nusselt No.)} \tag{4.3}$$

where k is the thermal conductivity of the steam.

The temperature difference between steam and pipe drops to 1/e or 36.8% of its initial value in traveling a thermal equilibration distance X_T given by

$$X_T = \frac{\dot{m}C_p}{hP} \tag{4.4}$$

$$= \frac{\dot{m}C_p}{P} \cdot \frac{d}{4k} \tag{4.5}$$

$$= \frac{\dot{m}C_p}{4\pi k} \tag{4.6}$$

$$= \frac{\dot{m}}{4\pi} \left(\frac{C_p\mu}{k}\right) \cdot \frac{1}{\mu} \tag{4.7}$$

For steam at 240°F, we have

$$\frac{C_p\mu}{k} \approx 1.06 \tag{4.8}$$

$$\mu \approx 3.18 \times 10^{-2} \frac{\text{lbm}}{\text{ft-hr}} \tag{4.9}$$

These values give

$$X_T \approx 1.87 \text{ ft} \tag{4.10}$$

This example shows the shortness of the distance for which leakage steam temperature could differ significantly from wall temperature.

APPENDIX H

Input Description and Code Listing
for Decontamination Programs
DECON and DECONM

Input Description and Code Listing for Decontamination Programs DECON and DECONM

The programs DECON (DECONtamination) and DECONM (DECONtamination with dispersive Mixing) solve the set of differential equations for the quantity of radionuclides in a set of connected compartments with sequential flow. The input to the codes must describe the concentration as a function of time for the source compartment (compartment zero), the volume flow rates into and out of the successive compartments, the deposition velocities (transport coefficients) and deposition areas in these compartments, and their volumes. Quantities calculated by the codes include:

- quantities contained at discrete, user-specified times within the compartments
- concentrations contained
- quantities transmitted from each compartment in discrete time intervals and cumulatively
- quantities deposited within compartments

Program DECONM differs from DECON in that it includes diffusive, dispersive, or turbulent mixing between compartments as a contributor to radionuclide transport between them. DECON, by contrast, neglects this term as small compared with transport by flow. DECON uses an analytic solution of the system of differential equations, whereas DECONM uses a stepwise numerical procedure contained in the International Mathematics and Statistics Library (IMSL) routine DVERK.

The set of differential equations for DECONM is:

$$\frac{dN_i}{dt} = \underbrace{t_i^{(1)} C_{i-1}}_{\text{flow in}} \; \underbrace{- t_i^{(2)} C_i}_{\text{flow out}} \; \underbrace{- \lambda N_i}_{\text{radioactive decay}} \tag{1}$$

$$\underbrace{+ k_{i-1,i} A_{i-1,i} (C_{i-1} - C_i) - k_{i,i+1} A_{i,i+1} (C_i - C_{i+1})}_{\text{diffusional or mixing interchanges between compartments}}$$

$$- \sum_{m} k_i^m A_i^m (C_i - C_{e,i}^m)$$

decomposition on surfaces

for compartments i = 1, 2, . . . , NVOLS.

The symbols are as follows:

N_i = quantity in compartment i

$\frac{dN_i}{dt}$ = rate of change with time of quantity in compartment i

$C_i = N_i/V_i$ = concentration in compartment i, which has volume V_i

C_o = concentration in the source compartment

$\tau_i^{(1)}, \tau_i^{(2)}$ = volume flow rate into and out of compartment i

k_i^m = deposition transport coefficient (dep. velocity) for m-th process in compartment i

A_i^m = effective area for deposition by process m in compartment i

$C_{e,i}^m$ = equilibrium concentration for process m at deposition surface in compartment i

$k_{i,i+1}$ = mass transfer coefficient for transfer from compartment i to compartment i+1

$A_{i,i+1}$ = area of contact between compartment i and compartment i+1 ($k_{i-1,i}$ and $A_{i-1,i}$ are similarly defined)

The equations for DECON are similar but do not include the diffusional or mixing interchanges between compartments, or, equivalently, have $k_{i-1,i}$ and $k_{i,i+1}$ set to zero.

The listing of DECONM appears in Figure 1. That for DECON appears in Figure 2. The input variables are generally described in comments in the code listings and are read in free field format.

Input for DECONM

NVOLS - number of compartments after the source compartment (compartment zero)

VOL (J), J=1, NVOLS - volume of the compartments. Same as V_i in Equation 1.

NTIMS - number of time points

TIME(K), K=1, NTIMS - time periods for computations, from starting time TIME(1) (which need not be zero) to final time TIME(NTIMS).

IFLOC - a logical variable, which, if set .TRUE., means that the flow changes between at least some of the time intervals. If IFLOC=.FALSE., only the flow rates at the first time need be supplied.

[(TFLOW(J,L,K), L=1,2),J=1,NVOLS] - TFLOW(J,L,K) is an average volume flow rate for compartment J for the period TIME(K) to TIME(K+1), flow in for L=1 and flow out for L=2. Thus TFLOW(J,1,K) = $\dot{\tau}_j^{(1)}$ and TFLOW (J,2,K) = $\dot{\tau}_j^{(2)}$ for the period TIME(K) to TIME(K+1). The user must account for volumetric flow rate changes due to temperature and pressure changes that cause a density change. Flow splits and flow mergers can be accommodated by setting TFLOW(J,1,K) not necessarily equal to TFLOW(J-1,2,K).

CφT(K), K=1, NTIMS - Concentration CφT(K) is the average concentration in the source compartment from TIME(K) to TIME(K+1).

!COPT - A source compartment concentration option. If ICOPT is less than 1, the input concentrations CφT(K) is used for all the time intervals. If ICOPTφ1, CφT(1) is used to set the average source compartment concentration values for K=2,3...,NTIMS on the assumption that concentration in the source compartment is depleted by and only by leakage flow out. For the option ICOPT>1, the code at present assumes that the source volume is 1./CφT(1).

FLEAKS - If ICOPT>1, total flow rate out of the source volume, is assumed to be FLEAKS*TFLOW(1,1,K) for purposes of calculating depletion of the concentration in the source volume.

[EN(J,1),J=1,NVOLS] - The quantity of radionuclides in compartment J at starting time TIME(1).

ELAM - radioactive decay constant _ = ln2/half-life for the material being considered. This should be set to zero if a post-processing correction is to be done for radioactive decay.

[ADEP(J),J=1,NVOLS] - deposition area in the j-th compartment.

WEIGHT - a radionuclide spectrum share to which the next set of deposition velocity x area products, deposition velocities, and VACSUM values apply.

MORE - a flag variable which, if greater than zero, indicates more entries in the radionuclide spectrum are coming after the current ones.

IFDEC - a logical flag variable (if deposition changes) which, if .TRUE., indicates that the VASUM, VACSUM, and VDEP values change with time and must be read for each time entry. If IFDEC = .FALSE., the values at TIME(1) will be used for TIME(2), TIME(3), ... TIME(NTIMS).

[VASUM(J,K),J=1,NVOLS] - a partial contribution to the sum of the products of deposition velocity times deposition area in compartment J in the interval (TIME(K) to TIME(K+1). This is part of the sum $\Sigma A_j^m k_j^m$.

[VACSUM(J,K),J=1,NVOLS] - the equilibrium concentration x deposition velocity x deposition area sum for compartment J in the interval. TIME(K) to TIME(K+1). This is the term $\sum_m k_j^m A_j^m C_{e,j}^m$ in the differential equation.

[VDEP(J,K),J=1,NVOLS] - deposition velocity in compartment J for the expression $\Sigma k_j^m A_m^m$ = VASUM(J,K)+ADDEP(J)*VDEP(J,K) in the time interval TIME(K) to TIME(K+1).

[(ADT(J,L), L=1,2),J=1,NVOLS] - turbulent, diffusive, or dispersive transport area between compartment J and the adjacent compartments. ADT (J,1) is the transfer area between compartment J-1 and compartment J. ADT(J,2) is the transfer area between compartment J and compartment J+1. Note that for flow splits and flow mergers, ADT (J,1) is not necessarily ADT(J-1,2).

IFDISC - a logical variable which, if .TRUE., indicates that dispersive transfer changes with time, and hence dispersive transfer coefficients DTK(J,K) must be read for K=1 to K=NTIMS. IFDISC = .FALSE. indicates that the values remain at the values for K=1, so input of DTK values for K.G > T.1 is omitted.

[DTK(J,K),J=1,NVOLS-1] - dispersive transport coefficient for transfer between compartment J and compartment J+1 in the interval TIME(K) to TIME(K+1).

IND - a variable related to tolerance criteria for differential equation solving routine DVERK. IND=1 gets default values. Other values of IND will call for more input values whose significance can be found in IMSL writeups for subroutine DVERK.

TOL - the magnitude of the relative error to be tolerated in subroutine DVERK. Values in the range 10^{-8} to 10^{-13} are recommended.

Input for DECON

Input to DECON is similar to that for DECONM, with notable exceptions. Since DECON neglects dispersive interchange, the variables ADT, IFDISC, and DTK are not used. Because DECON uses an analytic solution to the system of differential equations, the numerical differential equation solver routine parameters IND and TOL are not used.

Figure 1.

```
      program deconm(input,output,tape5=input,tape6=output)
c  program to calculate the decontamination and release transient
c  from flow through a sequence of connected volumes.
c
c  input
c    nvols...no. of compartments (not including the zero-th
c            or source volume) in the sequence
c    vol(j),j=1,nvols...volume in the j-th compartment
c    ntims...no. of times at which conditions will be described,
c            including time(1) as the starting time
c    time(k),k=1,ntims...the k-th of the times at which conditions
c                        are to be described
c    tflow(j,l,k)...volume flow rate for the j-th volume at the k-th
c                   time, flow in for l=1, flow out for l=2. for the
c                   interval time(k) to time(k+1), use tflow(j,l,k).
c                   if the flow rate is varying continuously, make
c                   tflow(j,l,k) an average for the interval time(k)
c                   to time(k+1).
c    c0t(k)...concentration of the material (units/volume) in the source
c             compartment at time(k). for the interval time(k) to
c               time(k+1), use concentration c0t(k), so c0t(k) can
c               consistently be the average for the interval time(k)
c               to time(k+1).
c
c  note that the volume units of vol and tflow and the reciprocal
c  volume units in cot should be the same.
c
c    elam...decay constant ln(2)/half-life for the material.
c
c  note that the reciprocal time units of tflow and elam should
c  be the same.
c    ((vasum(j,k),j=1,nvol),k=1,ntims)...the sum of the products of
c                   the deposition area times the deposition velocity
c                   in the j-th volume at time(k)
c    ((vacsum(j,k),j=1,nvol),k=1,ntims)...the sum of the products of the
c                   deposition area times the deposition velocity times the
c                   equilibrium concentration just outside the deposition
c                   surfaces in volume j.
c    ifloc,ifdec...logical variables for input specifications, where
c                  ifloc should be set true if flow changes and ifdec set true
c                  if the deposition velocity-area-eq. conc. changes.
c    en(j,1),j=1,nvols...starting quantity (concentration*volume) in
c                        compartment j vapor space at time(1)
c    adt(j,1),j=1,nvols...area for dispersion transfer of the solute
c                         to vol. j from vol. j-1
c    adt(j,2),j=1,nvols...area for dispersion transfer of the solute
c                         to vol. j+1 from vol. j
c    ((dtk(j,k),j=1,nvols+1),k=1,ntims)...dispersion transport coefficient
c                                         to vol. j from vol. j-1 from
c                                         time(k) to time(k+1)
c
```

Figure 1. (Continued)

```
c
c  output
c    ((en(j,k),j=1,nvols),k=2,ntims)...quantity of the substance in
c                                      compartment j vapor space at time(k)
c    ((depn(j,k),j=1,nvols),k=2,ntims)...quantity of the substance deposited
c                                        on surfaces in compartment j during
c                                        the interval time(k-1) to time(k)
c    ((tran(j,k),j=1,nvols),k=2,ntims)...quantity of the substance transmitted
c                                        out of volume j during the interval
c                                        time(k-1) to time(k).
c
      parameter(nvmax=26,nvmaxp=nvmax+1,ntmax=16,nw=2*nvmax,nc=nw+30)
      dimension w(nw,9),y(nw),c(nc)
      external dndt
      common/depio/nvols,vol(nvmaxp),c0t(ntmax),en(nvmax,ntmax),
     $tnq(nvmax,ntmax),time(ntmax),tflow(nvmax,2,ntmax),rr0,
     $rr(nvmax),sr(nvmax),dtk(nvmaxp,ntmax),adt(nvmax,2),
     $vasum(nvmax,ntmax),vacsum(nvmax,ntmax),depn(nvmax,ntmax),
     $tran(nvmax,ntmax),ctran(nvmax,ntmax),cdepn(nvmax,ntmax),
     $adep(nvmax),vdep(nvmax,ntmax),ktime,weight,wtrans(nvmax,ntmax)
      logical ifloc,ifdec,ifdisc
c
      data tol/1.e-10/,ind/1/
c
c  read no. of compartments and their volumes.
      read(5,*)nvols,(vol(j),j=1,nvols)
      nvol2=nvols*2
      vol(nvols+1)=1.e+25
c  read no. of times and their values.
      read(5,*)ntims,(time(k),k=1,ntims)
c  read volume flow rate in pairs (flow rate in, flow rate out) for
c  each compartment in turn.
      read(5,*)ifloc
      k=1
   40 continue
      read(5,*)((tflow(j,l,k),l=1,2),j=1,nvols)
      if(k.ge.ntims)go to 50
      k=k+1
c  if flow changes, read the flow rates at subsequent times. if not, dont.
      if(ifloc)go to 40
c  deplicate the entry for the first time, as flow doesn't change.
      do 48 kk=2,ntims
      do 46 j=1,nvols
      tflow(j,1,kk)=tflow(j,1,1)
      tflow(j,2,kk)=tflow(j,2,1)
   46 continue
   48 continue
   50 continue
c
```

Figure 1. (Continued)

```
c  read the source volume concentrations for the ntims time values.
c  icopt.ge.1 is a flag to calculate source volume concentrations
c  starting from the first and allowing for depletion by
c  fleaks flows at tflow(1,1,k) from time(k) to time(k+1).
      read(5,*)(c0t(k),k=1,ntims),icopt,fleaks
      if(icopt.lt.1)go to 60
c
c  get average concentration in source volume, allowing
c  for depletion by fleaks flows. assume source concentration c0t(1)
c  input as 1./source vol.
      cstart=c0t(1)
      volsrc=1./c0t(1)
      ntimsm=ntims-1
      gammat=(time(2)-time(1))*tflow(1,1,1)*fleaks/volsrc
      cend=cstart
      if(gammat.lt.1.e-4)go to 52
      cend=cstart*exp(-gammat)
      c0t(1)=(cstart-cend)/gammat
   52 continue
      do 55 k=2,ntimsm
      cstart=cend
      gammat=(time(k+1)-time(k))*tflow(1,1,k)*fleaks/volsrc
      c0t(k)=cend
      if(gammat.lt.1.e-4)go to 55
      cend=cstart*exp(-gammat)
      c0t(k)=(cstart-cend)/gammat
   55 continue
c
   60 continue
c  read the quantities in the compartments at time(1).
      read(5,*)(en(j,1),j=1,nvols)
c  read the decay constant, ln(2)/half-life.
      read(5,*)elam
c  read deposition areas in the compartments for processes not
c  included in vasum.
      read(5,*)(adep(j),j=1,nvols)
c
  130 continue
c  read the relative weight of the forthcoming deposition characteristics
c  as part of a spectrum of released material types to be summed.
      read(5,*)weight,more
c
c
c  read the deposition area-deposition velocity product sums vasum
c  and deposition area-deposition velocity-equilib. conc. sums vacsum.
c  first read whether these quantities change.
      read(5,*)ifdec
      k=1
  140 continue
      read(5,*)(vasum(j,k),j=1,nvols)
      read(5,*)(vacsum(j,k),j=1,nvols)
      read(5,*)(vdep(j,k),j=1,nvols)
```

Figure 1. (Continued)

```
      do 144 j=1,nvols
  144 vasum(j,k)=vasum(j,k)+adep(j)*vdep(j,k)
c
      if(k.ge.ntims)go to 150
      k=k+1
c  if vasum changes with time, read vasum at subsequent times.
      if(ifdec)go to 140
      do 148 kk=2,ntims
      do 146 j=1,nvols
      vasum(j,kk)=vasum(j,1)
      vacsum(j,kk)=vacsum(j,1)
  146 continue
  148 continue
  150 continue
c
c  read the dispersion transper areas adt
      nvolsp=nvols+1
      read(5,*)((adt(j,l),l=1,2),j=1,nvols)
c  read the dispersion transfer coefficients dtk between
c  compartments. first read whether they change with time.
      read(5,*)ifdisc
      k=1
  160 continue
      read(5,*)(dtk(j,k),j=1,nvolsp)
      if(k.ge.ntims)go to 165
      k=k+1
c  if dtk changes with time, read dtk at subsequent times.
      if(ifdisc)go to 160
      do 164 kk=2,ntims
      do 162 j=1,nvolsp
      dtk(j,kk)=dtk(j,1)
  162 continue
  164 continue
  165 continue
c  read convergence specs for diff. eq. routine dverk.
      read(5,*)ind,tol
c  bypass read of c array if defaults taken.
      if(ind.eq.1)go to 168
c  read the first 12 entries of c array.
      read(5,*)(c(ll),ll=1,12)
      icl=int(c(1))
c  read the error weighting specs for individual y(j) if
c  their use is requested.
      if(icl.eq.4.or.icl.eq.5)read(5,*)(c(30+ll),ll=1,nvol2)
  168 continue
c
      rr0=0.
      do 200 j=1,nvols
      cdepn(j,1)=0.
      ctran(j,1)=0.
      depn(j,1)=0.
      tran(j,1)=0.
  200 continue
```

Figure 1. (Continued)

```
c
c
c  write the input quantities
      write(6,1001)nvols
 1001 format(1h1,///,t5,"filling,deposition, and release",
     $" transient for",i3," compartments with seqential flow")
      write(6,1002)
      write(6,1003)(j,vol(j),j=1,nvols)
 1002 format(1h0,t5,"volumes of compartments")
 1003 format(5(i6,e15.8,2x))
      write(6,1004)
 1004 format(1h0,t5,"calculation and display times.",
     $" time(1)=starting time.")
      write(6,1003)(k,time(k),k=1,ntims)
      write(6,1005)
 1005 format(1h0,t5,"concentration in source volume at calculation",
     $" times")
      write(6,1003)(k,c0t(k),k=1,ntims)
      write(6,1006)
 1006 format(1h0,t5,"volume flow rates")
      jst=1
      jfin=3
  170 continue
      jf=min0(jfin,nvols)
      write(6,1007)(j,j,j=jst,jf)
 1007 format(t6,"time",t11,6(10x,"vol",i3,4x))
      write(6,1008)("in ","out",j=jst,jf)
 1008 format(t7,"no.",t11,3(12x,a3,17x,a3,5x))
      do 175 k=1,ntims
      write(6,1009)k,(tflow(j,1,k),tflow(j,2,k),j=jst,jf)
 1009 format(t6,i3,t11,6e20.8)
  175 continue
      jst=jst+3
      jfin=jfin+3
      if(jf.lt.nvols)go to 170
      write(6,1010)nvols,time(1)
 1010 format(1h0,t5,"starting quantities in",i3," compartments",
     $" at time(1)=",e15.8)
      write(6,1003)(j,en(j,1),j=1,nvols)
      write(6,1011)nvols,time(1)
 1011 format(1h0,t5,"starting concentrations in",i3," compartments",
     $" at time(1)=",e15.8)
      write(6,1003)(j,en(j,1)/vol(j),j=1,nvols)
      write(6,1012)elam
 1012 format(1h0,t5,"material decay constant ln(2)/half-life=",
     $e15.8)
      write(6,1017)weight
 1017 format(1h0,t5,"relative weight of forthcoming deposition",
     $" characteristics=",e15.8)
      write(6,1013)
 1013 format(1h0,t5,"deposition velocity*area product sums")
```

Figure 1. (Continued)

```
      jst=1
      jfin=6
  180 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
 1014 format(t6,"time",t11,6(10x,"vol",i3,4x))
      write(6,1015)
 1015 format(t7,"no.")
      do 185 k=1,ntims
      write(6,1009)k,(vasum(j,k),j=jst,jf)
  185 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 180
      write(6,1016)
 1016 format(1h0,t5,"deposition area-velocity-eq. conc.",
     $" products")
      jst=1
      jfin=6
  190 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 195 k=1,ntims
      write(6,1009)k,(vacsum(j,k),j=jst,jf)
  195 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 190
c
      write(6,1018)
 1018 format(1h0,t5,"dispersional interchange transport coefficients")
      jst=1
      jfin=6
  210 continue
      jf=min0(jfin,nvolsp)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 215 k=1,ntims
      write(6,1009)k,(dtk(j,k),j=jst,jf)
  215 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvolsp)go to 210
c  write dispersional interchange areas
      write(6,1022)
 1022 format(1h0,t5,"dispersional interchange areas")
      write(6,1023)("in","out",j=1,3)
 1023 format(t11,3(11x,a3,15x,a3,8x))
```

Figure 1. (Continued)

```
      jst=1
      jfin=3
  217 continue
      jf=min0(jfin,nvols)
      write(6,1021)(j,(adt(j,l),l=1,2),j=jst,jf)
 1021 format(t11,3(i3,1x,e16.8,2x,e16.8,2x))
      jst=jst+3
      jfin=jfin+3
      if(jf.lt.nvols)go to 217
c  write convergence specs for diff. eq. routine dverk.
      write(6,1024)
 1024 format(1h0)
      write(6,1025)ind,tol
      ind0=ind
 1025 format(t5,"dif.eq. routine dverk parameter ind=",i5,
     $5x,"convergence parameter tol=",e15.8)
      if(ind.eq.1)go to 218
      jfin=12
      if(icl.eq.4.or.icl.eq.5)jfin=30+nvol2
      write(6,1026)
 1026 format(t5,"dverk option array c=")
      write(6,1027)(c(ll),ll=1,jfin)
 1027 format(8x,8e15.8)
  218 continue
c
      do 380 j=1,nvols
      y(j)=en(j,1)
      y(nvols+j)=0.
      tnq(j,1)=0.
  380 continue
      do 400 k=2,ntims
      do 300 j=1,nvols
      rr(j)=elam+(tflow(j,2,k-1)+vasum(j,k-1)+dtk(j,k-1)*adt(j,1)
     $+dtk(j+1,k-1)*adt(j,2))/vol(j)
      sr(j)=vacsum(j,k-1)
  300 continue
      nderrs=0
  304 continue
      tstart=time(k-1)
      ktime=k
c
c  diagnostic write
      print 4027, k,ind,ier,nderrs
      print 4033, tstart,time(k),tol
      if(ind.lt.1.or.ind.gt.3) print 4035, c
      if(ind.lt.1.or.ind.gt.3) print 4037, y
 4027 format(1h0,t5,"k,ind,ier,nderrs="/5x,6i6)
 4033 format(1h0,t5,"tstart,time(k),tol="/5x,3e16.8)
 4035 format(1h0,t5,"c="/6(5x,e15.8))
 4037 format(1h0,t5,"y="/6(5x,e15.8))
```

Figure 1. (Continued)

```
c
c  call imsl (international mathematics and statistics library) routine
c  dverk to numerically integrate the system of first order differential
c  equations.
c
      call dverk(nvol2,dndt,tstart,y,time(k),tol,ind,c,nw,w,ier)
c  test for errors in dverk.
      if(ind.eq.3)go to 318
c  dverk failed. reset tol and try again.
      write(6,1028)ind,ier,k,time(k),tol
 1028 format(t5,"**** dverk did not return a satisfactory solution**",
     $/,t5,"ind=",i5,5x,5x,"ier=",i5,5x,"at time(",i3,")=",
     $e15.8,5x,"with tol=",e15.8)
      nderrs=nderrs+1
      if(nderrs.gt.5)go to 410
c  loosen convergence test, reset, and try again
      do 316 j=1,nvols
      y(j)=en(j,k-1)
      y(nvols+j) =tnq(j,k-1)
  316 continue
      tol=tol*10.
      ind=ind0
      go to 304
  318 continue
c
      do 320 j=1,nvols
      en(j,k)=y(j)
      tnq(j,k)=y(nvols+j)
      depn(j,k)=(tnq(j,k)-tnq(j,k-1))*vasum(j,k-1)/vol(j)
     $-vacsum(j,k-1)*(time(k)-time(k-1))
      tran(j,k)=(tnq(j,k)-tnq(j,k-1))*(tflow(j,2,k-1)/vol(j)
     $+adt(j,2)*dtk(j+1,k-1)/vol(j))-(tnq(j+1,k)-tnq(j+1,k-1))
     $*adt(j,2)*dtk(j+1,k-1)/vol(j+1)
      cdepn(j,k)=cdepn(j,k-1)+depn(j,k)
      ctran(j,k)=ctran(j,k-1)+tran(j,k)
  320 continue
c
  400 continue
c
  410 continue
c
c  write results
      write(6,1031)
 1031 format(1h0//t5,"results of transient and deposition calculations")
      write(6,1032)
 1032 format(1h0,t5,"quantities contained")
      jst=1
      jfin=6
  580 continue
```

Figure 1. (Continued)

```
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 585 k=1,ntims
      write(6,1009)k,(en(j,k),j=jst,jf)
  585 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 580
      write(6,1033)
 1033 format(1h0,t5,"concentrations contained")
      jst=1
      jfin=6
  590 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 595 k=1,ntims
      write(6,1009)k,(en(j,k)/vol(j),j=jst,jf)
  595 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 590
      write(6,1034)
 1034 format(1h0,t5,"quantities transmitted in time step")
      jst=1
      jfin=6
  620 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 625 k=1,ntims
      write(6,1009)k,(tran(j,k),j=jst,jf)
  625 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 620
      write(6,1035)
 1035 format(1h0,t5,"quantities deposited in time step")
      jst=1
      jfin=6
  640 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 645 k=1,ntims
      write(6,1009)k,(depn(j,k),j=jst,jf)
  645 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 640
```

Figure 1. (Continued)

```
      write(6,1036)
 1036 format(1h0,t5,"cumulative quantities transmitted")
      jst=1
      jfin=6
  650 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 655 k=1,ntims
      write(6,1009)k,(ctran(j,k),j=jst,jf)
  655 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 650
      write(6,1037)
 1037 format(1h0,t5,"cumulative quantities deposited")
      jst=1
      jfin=6
  660 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 665 k=1,ntims
      write(6,1009)k,(cdepn(j,k),j=jst,jf)
  665 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 660
      write(6,1038)
 1038 format(1h0,t5,"cumulative fraction transmitted of cumulative",
     $" inflow at flowstream start",/,t5,"to get",
     $" fraction of total inflow transmitted, divide printed result",
     $" by flow multiplication factor after mergers.")
      jst=1
      jfin=6
  670 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      tflowd=0.
      do 675 k=1,ntims
      if(k.gt.1)tflowd=tflowd+tflow(1,1,k)*(time(k)-time(k-1))*c0t(k-1)
      tfd=tflowd
      if(tfd.le.0.)tfd=1.
      write(6,1009)k,(ctran(j,k)/tfd,j=jst,jf)
  675 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 670
```

Figure 1. (Continued)

```
      write(6,1039)
 1039 format(lh0,t5,"cumulative fraction deposited of cumulative",
     $" inflow at flowstream start",/,t5,"to get fraction of total",
     $" inflow deposited, divide printed result by flow multiplication"
     $," factor after flow mergers.")
      jst=1
      jfin=6
  680 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      tflowd=0.
      do 685 k=1,ntims
      if(k.gt.1)tflowd=tflowd+tflow(1,1,k)*(time(k)-time(k-1))*c0t(k-1)
      tfd=tflowd
      if(tfd.le.0.)tfd=1.
      write(6,1009)k,(cdepn(j,k)/tfd,j=jst,jf)
  685 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 680
c
      write(6,1040)
 1040 format(lh0,t5,"fraction contained of cumulative inflow",
     $" at flowstream start."/t5,"to get fraction of total inflow",
     $" contained within volume, divide printed result by flow",
     $" multiplication factor after flow mergers.")
      jst=1
      jfin=6
  690 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      tflowd=0.
      do 695 k=1,ntims
      if(k.gt.1)tflowd=tflowd+tflow(1,1,k)*(time(k)-
     $time(k-1))*c0t(k-1)
      tfd=tflowd
      if(tfd.le.0.)tfd=1.
      write(6,1009)k,(en(j,k)/tfd,j=jst,jf)
  695 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 690
c
c  increment the weighted sum of transmitted quantities for each time step.
      do 770 j=1,nvols
      do 760 k=1,ntims
      wtrans(j,k)=wtrans(j,k)+weight*tran(j,k)
  760 continue
  770 continue
```

Figure 1. (Continued)

```
c  cycle to next set of deposition charateristics in spectrum, if requested.
      if(more.gt.0)go to 130
  800 continue
c  write the weighted sums of the transmitted quantities.
      write(6,1041)
 1041 format(1h0,t5,"weighted sum of quantities transmitted in time step
     $")
      jst=1
      jfin=6
  820 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 825 k=1,ntims
      write(6,1009)k,(wtrans(j,k),j=jst,jf)
  825 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 820
c
      stop
      end
      subroutine dndt(n,t,y,dydt)
c  subroutine to calculate the derivative of the amount in
c  volume nn,nn=1,nvols, for diff. eq. solving routine
c  dverk, and the derivative of the time-integral of
c  the quantity in volume nn in dydt(nvols+nn) for nn=1
c  to nvols.
c  used in calculating the amount en(j,kt2),j=1,nvols
c  of a substance in each of the nvols connected compartments at
c  time time(ktime).
c
      parameter(nvmax=26,nvmaxp=nvmax+1,ntmax=16,nw=2*nvmax)
      real y(n),dydt(n)
      common/depip/nvols,vol(nvmaxp),c0t(ntmax),en(nvmax,ntmax),
     $tnq(nvmax,ntmax),time(ntmax),tflow(nvmax,2,ntmax),rr0,
     $rr(nvmax),sr(nvmax),dtk(nvmaxp,ntmax),adt(nvmax,2),
     $vasum(nvmax,ntmax),vacsum(nvmax,ntmax),depn(nvmax,ntmax),
     $tran(nvmax,ntmax),ctran(nvmax,ntmax),cdepn(nvmax,ntmax),
     $adep(nvmax),vdep(nvmax,ntmax),ktime,weight,wtrans(nvmax,ntmax)
c
c  inputs
c    nvols...no. of compartments
c    vol(j)...volume of the j-th compartment
c    c0t(ktl)...concentration in the 0-th (feeding or source) compartment
c              at time(ktl), assumed constant during the interval.
c              (could input an average value for the interval time(ktl)
c               to time(ktl+1) in c0t(ktl).)
c   time(k)...the k-th time of an input time list. time(1) is the overall
c            starting time, while time(ktime-1) is the starting time for
c            the current call.
```

Figure 1. (Continued)

```
c   en(j,ktl)...quantity in volume j at time(ktl)
c   tflow(j,l,ktl)...volume flow rate into (l=1) or out from (l=2) the
c                    j-th compartment at time(ktl)
c   rr(j)...the fractional removal rate quantity elam+tflow(j,2,ktl)/vol(j)
c           +sum(vm(j)*am(j)/vol(j))+dtk(j,k-1)*adt(j,1)/vol(j)
c           +dtk(j+1,k-1)*adt(j,2))/vol(j) where the sum
c           is over deposition types, and vm and am are deposition
c           velocity and deposition area for type m deposition.
c   sr(j)...the surface re-emission quantity sum(vm(j)*am(j)*cem(j)),
c           where cem(j) is the equilibrium concentration outside the
c           surface for type m deposition.
c
c
      k=ktime
      cjm=c0t(k-1)
      nvolsm=nvols-1
      do 100 j=1,nvolsm
      dydt(j)=-rr(j)*y(j)+tflow(j,1,k-1)*cjm+sr(j)
     $+dtk(j,k-1)*adt(j,1)*cjm+dtk(j+1,k-1)*adt(j,2)
     $*y(j+1)/vol(j+1)
      cjm=y(j)/vol(j)
  100 continue
      j=nvols
      dydt(j)=-rr(j)*y(j)+tflow(j,1,k-1)*cjm+sr(j)
     $+dtk(j,k-1)*adt(j,1)*cjm
c  now sec the derivatives of th y variables that are
c  to become the time integrals of the cuantities in the
c  compartments.
      do 200 j=1,nvols
      jj= nvols+j
      dydt(jj)=y(j)
  200 continue
      return
      end
```

Figure 2.

```
      program decon(input,output,tape5=input,tape6=output)
c  program to calculate the decontamination and release transient
c  from flow through a sequence of connected volumes.
c
c  input
c    nvols...no. of compartments (not including the zero-th
c            or source volume) in the sequence
c    vol(j),j=1,nvols...volume in the j-th compartment
c    ntims...no. of times at which conditions will be described,
c            including time(1) as the starting time
c    time(k),k=1,ntims...the k-th of the times at which conditions
c                        are to be described
c    tflow(j,l,k)...volume flow rate for the j-th volume at the k-th
c                   time, flow in for l=1, flow out for l=2. for the
c                   interval time(k) to time(k+1), use tflow(j,l,k).
c                   if the flow rate is varying continuously, make
c                   tflow(j,l,k) an average for the interval time(k)
c                   to time(k+1).
c    c0t(k)...concentration of the material (units/volume) in the source
c             compartment at time(k). for the interval time(k) to
c               time(k+1), use concentration c0t(k), so c0t(k) can
c               consistently be the average for the interval time(k)
c               to time(k+1).
c
c  note that the volume units of vol and tflow and the reciprocal
c  volume units in cot should be the same.
c
c    elam...decay constant ln(2)/half-life for the material.
c
c  note that the reciprocal time units of tflow and elam should
c  be the same.
c    ((vasum(j,k),j=1,nvol),k=1,ntims)...the sum of the products of
c                   the deposition area times the deposition velocity
c                   in the j-th volume at time(k)
c    ((vacsum(j,k),j=1,nvol),k=1,ntims)...the sum of the products of the
c                   deposition area times the deposition velocity times the
c                   equilibrium concentration just outside the deposition
c                   surfaces in volume j.
c    ifloc,ifdec...logical variables for input specifications, where
c                  ifloc should be set true if flow changes and ifdec set true
c                  if the deposition velocity-area-eq. conc. changes.
c    en(j,1),j=1,nvols...starting quantity (concentration*volume) in
c                        compartment j vapor space at time(1)
c
c
c  output
c    ((en(j,k),j=1,nvols),k=2,ntims)...quantity of the substance in
c                                      compartment j vapor space at time(k)
c    ((depn(j,k),j=1,nvols),k=2,ntims)...quantity of the substance deposited
c                                        on surfaces in compartment j during
c                                        the interval time(k-1) to time(k)
```

Figure 2. (Continued)

```
c     ((tran(j,k),j=1,nvols),k=2,ntims)...quantity of the substance transmitted
c                                         out of volume j during the interval
c                                         time(k-1) to time(k).
c
      parameter(nvmax=26,nvmaxp=nvmax+1,ntmax=16)
      implicit double precision(a-h,o-z)
      common/depio/nvols,vol(nvmax),c0t(ntmax),en(nvmax,ntmax),
     $tnq(nvmax,ntmax),time(ntmax),tflow(nvmax,2,ntmax),rr0,
     $rr(nvmax),sr(nvmax),emrt(nvmax),xx0(nvmaxp),xx(nvmax,nvmax),
     $vasum(nvmax,ntmax),vacsum(nvmax,ntmax),depn(nvmax,ntmax),
     $tran(nvmax,ntmax),ctran(nvmax,ntmax),cdepn(nvmax,ntmax),
     $adep(nvmax),vdep(nvmax,ntmax),weight,wtrans(nvmax,ntmax)
      logical ifloc,ifdec
c
c read no. of compartments and their volumes.
      read(5,*)nvols,(vol(j),j=1,nvols)
c read no. of times and their values.
      read(5,*)ntims,(time(k),k=1,ntims)
c read volume flow rate in pairs (flow rate in, flow rate out) for
c each compartment in turn.
      read(5,*)ifloc
      k=1
   40 continue
      read(5,*)((tflow(j,l,k),l=1,2),j=1,nvols)
      if(k.ge.ntims)go to 50
      k=k+1
c if flow changes, read the flow rates at subsequent times. if not, dont.
      if(ifloc)go to 40
c replicate the entry for the first time, as flow doesn't change.
      do 48 kk=2,ntims
      do 46 j=1,nvols
      tflow(j,1,kk)=tflow(j,1,1)
      tflow(j,2,kk)=tflow(j,2,1)
   46 continue
   48 continue
   50 continue
c
c read the source volume concentrations for the ntims time values.
c icopt.ge.1 is a flag to calculate source volume concentrations
c starting from the first and allowing for depletion by
c fleaks flows at tflow(1,1,k) from time(k) to time(k+1).
      read(5,*)(c0t(k),k=1,ntims),icopt,fleaks
      if(icopt.lt.1)go to 60
c
c get average concentration in source volume, allowing
c for depletion by fleaks flows. assume source concentration c0t(1)
c input as 1./source vol.
      cstart=c0t(1)
      volsrc=1./c0t(1)
```

Figure 2. (Continued)

```
      ntimsm=ntims-1
      gammat=(time(2)-time(1))*tflow(1,1,1)*fleaks/volsrc
      cend=cstart
      if(gammat.lt.1.e-4)go to 52
      cend=cstart*exp(-gammat)
      c0t(1)=(cstart-cend)/gammat
   52 continue
      do 55 k=2,ntimsm
      cstart=cend
      gammat=(time(k+1)-time(k))*tflow(1,1,k)*fleaks/volsrc
      c0t(k)=cend
      if(gammat.lt.1.e-4)go to 55
      cend=cstart*exp(-gammat)
      c0t(k)=(cstart-cend)/gammat
   55 continue
c
   60 continue
c  read the quantities in the compartments at time(1).
      read(5,*)(en(j,1),j=1,nvols)
c  read the decay constant, ln(2)/half-life.
      read(5,*)elam
c  read deposition areas in the compartments for processes not
c  included in vasum.
      read(5,*)(adep(j),j=1,nvols)
c
  130 continue
c
c  read the relative weight of the forthcoming deposition characteristics
c  as part of a spectrum of released material types to be summed.
      read(5,*)weight,more
c
c  read the deposition area-deposition velocity product sums vasum
c  and deposition area-deposition velocity-equilib. conc. sums vacsum.
c  first read whether these quantities change.
      read(5,*)ifdec
      k=1
  140 continue
      read(5,*)(vasum(j,k),j=1,nvols)
      read(5,*)(vacsum(j,k),j=1,nvols)
      read(5,*)(vdep(j,k),j=1,nvols)
      do 144 j=1,nvols
  144 vasum(j,k)=vasum(j,k)+adep(j)*vdep(j,k)
c
      if(k.ge.ntims)go to 150
      k=k+1
c  if vasum changes with time, read vasum at subsequent times.
      if(ifdec)go to 140
```

Figure 2. (Continued)

```
      do 148 kk=2,ntims
      do 146 j=1,nvols
      vasum(j,kk)=vasum(j,1)
      vacsum(j,kk)=vacsum(j,1)
  146 continue
  148 continue
  150 continue
      rr0=0.
      do 200 j=1,nvols
      depn(j,1)=0.
      tran(j,1)=0.
  200 continue
c
c
c  write the input quantities
      write(6,1001)nvols
 1001 format(1h1,///,t5,"filling,deposition, and release",
     $" transient for",i3," compartments with seqential flow")
      write(6,1002)
      write(6,1003)(j,vol(j),j=1,nvols)
 1002 format(1h0,t5,"volumes of compartments")
 1003 format(5(i6,e15.8,2x))
      write(6,1004)
 1004 format(1h0,t5,"calculation and display times.",
     $" time(1)=starting time.")
      write(6,1003)(k,time(k),k=1,ntims)
      write(6,1005)
 1005 format(1h0,t5,"concentration in source volume at calculation",
     $" times")
      write(6,1003)(k,c0t(k),k=1,ntims)
      write(6,1006)
 1006 format(1h0,t5,"volume flow rates")
      jst=1
      jfin=3
  170 continue
      jf=min0(jfin,nvols)
      write(6,1007)(j,j,j=jst,jf)
 1007 format(t6,"time",t11,6(10x,"vol",i3,4x))
      write(6,1008)("in ","out",j=jst,jf)
 1008 format(t7,"no.",t11,3(12x,a3,17x,a3,5x))
      do 175 k=1,ntims
      write(6,1009)k,(tflow(j,1,k),tflow(j,2,k),j=jst,jf)
 1009 format(t6,i3,t11,6e20.8)
  175 continue
      jst=jst+3
      jfin=jfin+3
      if(jf.lt.nvols)go to 170
      write(6,1010)nvols,time(1)
 1010 format(1h0,t5,"starting quantities in",i3," compartments",
     $" at time(1)=",e15.8)
```

Figure 2. (Continued)

```
      write(6,1003)(j,en(j,1),j=1,nvols)
      write(6,1011)nvols,time(1)
 1011 format(1h0,t5,"starting concentrations in",i3," compartments",
     $" at time(1)=",e15.8)
      write(6,1003)(j,en(j,1)/vol(j),j=1,nvols)
      write(6,1012)elam
 1012 format(1h0,t5,"material decay constant ln(2)/half-life=",
     $e15.8)
      write(6,1017)weight
 1017 format(1h0,t5,"relative weight of forthcoming deposition",
     $" characteristics=",e15.8)
      write(6,1013)
 1013 format(1h0,t5,"deposition velocity*area product sums")
      jst=1
      jfin=6
  180 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
 1014 format(t6,"time",t11,6(10x,"vol",i3,4x))
      write(6,1015)
 1015 format(t7,"no.")
      do 185 k=1,ntims
      write(6,1009)k,(vasum(j,k),j=jst,jf)
  185 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 180
      write(6,1016)
 1016 format(1h0,t5,"deposition area-velocity-eq. conc.",
     $" products")
      jst=1
      jfin=6
  190 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 195 k=1,ntims
      write(6,1009)k,(vacsum(j,k),j=jst,jf)
  195 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 190
c
c
c  cycle through the time steps.
      do 400 k=2,ntims
      do 300 j=1,nvols
      rr(j)=elam+(tflow(j,2,k-1)+vasum(j,k-1))/vol(j)
      sr(j)=vacsum(j,k-1)
  300 continue
```

Figure 2. (Continued)

```
      call dep(k-1,k)
  400 continue
c
c  write results
      write(6,1031)
 1031 format(1h0//t5,"results of transient and deposition calculations")
      write(6,1032)
 1032 format(1h0,t5,"quantities contained")
      jst=1
      jfin=6
  580 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 585 k=1,ntims
      write(6,1009)k,(en(j,k),j=jst,jf)
  585 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 580
      write(6,1033)
 1033 format(1h0,t5,"concentrations contained")
      jst=1
      jfin=6
  590 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 595 k=1,ntims
      write(6,1009)k,(en(j,k)/vol(j),j=jst,jf)
  595 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 590
      write(6,1034)
 1034 format(1h0,t5,"quantities transmitted in time step")
      jst=1
      jfin=6
  620 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 625 k=1,ntims
      write(6,1009)k,(tran(j,k),j=jst,jf)
  625 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 620
      write(6,1035)
 1035 format(1h0,t5,"quantities deposited in time step")
```

```
      jst=1
      jfin=6
  640 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 645 k=1,ntims
      write(6,1009)k,(depn(j,k),j=jst,jf)
  645 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 640
      write(6,1036)
 1036 format(1h0,t5,"cumulative quantities transmitted")
      jst=1
      jfin=6
  650 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 655 k=1,ntims
      write(6,1009)k,(ctran(j,k),j=jst,jf)
  655 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 650
      write(6,1037)
 1037 format(1h0,t5,"cumulative quantities deposited")
      jst=1
      jfin=6
  660 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 665 k=1,ntims
      write(6,1009)k,(cdepn(j,k),j=jst,jf)
  665 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 660
      write(6,1038)
 1038 format(1h0,t5,"cumulative fraction transmitted of cumulative",
     $" inflow at flowstream start",/,t5,"to get",
     $" fraction of total inflow transmitted, divide printed result",
     $" by flow multiplication factor after errors.")
      jst=1
      jfin=6
  670 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
```

Figure 2. (Continued)

```
      write(6,1015)
      tflowd=0.
      do 675 k=1,ntims
      if(k.gt.1)tflowd=tflowd+tflow(1,1,k)*(time(k)-time(k-1))*c0t(k-1)
      tfd=tflowd
      if(tfd.le.0.)tfd=1.
      write(6,1009)k,(ctran(j,k)/tfd,j=jst,jf)
  675 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 670
      write(6,1039)
 1039 format(1h0,t5,"cumulative fraction deposited of cumulative",
     $" inflow at flowstream start",/,t5,"to get fraction of total",
     $" inflow deposited, divide printed result by flow multiplication"
     $," factor after flow mergers.")
      jst=1
      jfin=6
  680 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      tflowd=0.
      do 685 k=1,ntims
      if(k.gt.1)tflowd=tflowd+tflow(1,1,k)*(time(k)-time(k-1))*c0t(k-1)
      tfd=tflowd
      if(tfd.le.0.)tfd=1.
      write(6,1009)k,(cdepn(j,k)/tfd,j=jst,jf)
  685 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 680
c
      write(6,1040)
 1040 format(1h0,t5,"fraction contained of cumulative inflow",
     $" at flowstream start."/t5,"to get fraction of total inflow",
     $" contained within volume, divide printed result by flow",
     $" multiplication factor after flow mergers.")
      jst=1
      jfin=6
  690 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      tflowd=0.
      do 695 k=1,ntims
      if(k.gt.1)tflowd=tflowd+tflow(1,1,k)*(time(k)-
     $time(k-1))*c0t(k-1)
      tfd=tflowd
      if(tfd.le.0.)tfd=1.
```

Figure 2. (Continued)

```
      write(6,1009)k,(en(j,k)/tfd,j=jst,jf)
  695 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 690
c
c
c  increment the weighted sum of transmitted quantities for each time step.
      do 770 j=1,nvols
      do 760 k=1,ntims
      wtrans(j,k)=wtrans(j,k)+weight*tran(j,k)
  760 continue
  770 continue
c  cycle to next set of deposition charateristics in spectrum, if requested.
      if(more.gt.0)go to 130
  800 continue
c  write the weighted sums of the transmitted quantities.
      write(6,1041)
 1041 format(1h0,t5,"weighted sum of quantities transmitted in time step
     $")
      jst=1
      jfin=6
  820 continue
      jf=min0(jfin,nvols)
      write(6,1014)(j,j=jst,jf)
      write(6,1015)
      do 825 k=1,ntims
      write(6,1009)k,(wtrans(j,k),j=jst,jf)
  825 continue
      jst=jst+6
      jfin=jfin+6
      if(jf.lt.nvols)go to 820
c
      stop
      end
      subroutine dep(kt1,kt2)
c  subroutine to calculate the amount en(j,kt2),j=1,nvols
c  of a substance in each of the nvols connected compartments at
c  time time(kt2), given amounts at time(kt1).
c
      parameter(nvmax=26,nvmaxp=nvmax+1,ntmax=16)
      implicit double precision(a-h,o-z)
      common/depio/nvols,vol(nvmax),c0t(ntmax),en(nvmax,ntmax),
     $tnq(nvmax,ntmax),time(ntmax),tflow(nvmax,2,ntmax),rr0,
     $rr(nvmax),sr(nvmax),emrt(nvmax),xx0(nvmaxp),xx(nvmax,nvmax),
     $vasum(nvmax,ntmax),vacsum(nvmax,ntmax),depn(nvmax,ntmax),
     $tran(nvmax,ntmax),ctran(nvmax,ntmax),cdepn(nvmax,ntmax),
     $adep(nvmax),vdep(nvmax,ntmax),weight,wtrans(nvmax,ntmax)
c
```

Figure 2. (Continued)

```
c  inputs
c    nvols...no. of compartments
c    vol(j)...volume of the j-th compartment
c    c0t(ktl)...concentration in the 0-th (feeding or source) compartment
c                at time(ktl), assumed constant during the interval.
c                (could input an average value for the interval time(ktl)
c                 to time(kt2) in c0t(ktl).)
c   ktl,kt2...indices of the starting and stopping times. starting
c             quantities are en(j,ktl) for the j-th volume. time
c             increment is time(kt2)-time(ktl).
c   time(k)...the k-th time of an input time list. time(l) is the overall
c             starting time, while time(ktl) is the starting time for
c             the current call.
c   en(j,ktl)...quantity in volume j at time(ktl)
c   tflow(j,l,ktl)...volume flow rate into (l=l) or out from (l=2) the
c                    j-th compartment at time(ktl)
c   rr(j)...the fractional removal rate quantity elam+tflow(j,2,ktl)/vol(j)
c           +sum(vm(j)*am(j)/vol(j)) for the j-th volume, where the sum
c           is over deposition types, and vm and am are deposition
c           velocity and deposition area for type m deposition.
c   sr(j)...the surface re-emission quantity sum(vm(j)*am(j)*cem(j)),
c           where cem(j) is the equilibrium concentration outside the
c           surface for type m deposition.
c
c  output
c   en(j,kt2)...quantity in the j-th compartment at time(kt2).
c   tnq(j,kt2)...time integral of the quantity in the j-th compartment
c                from time(ktl) to time(kt2). this is used in
c                evaluating total transmitted, total deposited, etc.
c
      rr0=0.
      t=time(kt2)-time(ktl)
      do 10 j=l,nvols
      emrt(j)=dexp(-rr(j)*t)
   10 continue
      ldum=0
      xx(l,ldum)=(tflow(l,l,ktl)*c0t(ktl)+sr(l))/rr(l)
c    ((ctran(j,k),j=l,nvols),k=2,ntims)...cumulative quantity transmitted
c                                         out of volume j during the interval
c                                         time(l) to time(k).
c    ((cdepn(j,k),j=l,nvols),k=2,ntims)...cumulative quantity deposited in
c                                         volume j during the interval time(l)
c                                         to time(k).
      xx(l,l)=en(l,ktl)-xx(l,ldum)
      en(l,kt2)=xx(l,l)*emrt(l)+xx(l,ldum)
      tnq(l,kt2)=xx(l,l)*(l.-emrt(l))/rr(l)+xx(l,ldum)*t
      if(nvols.eq.l)go to 35
      do 30 j=2,nvols
      jml=j-l
      xsum=0.
```

Figure 2. (Continued)

```
      enlsum=C.
      tnq(j,kt2)=0.
      do 20 l=1,jml
      if(rr(j).ne.rr(l))go to 22
      write(6,1001)j,l,rr(j),rr(l),ktl,kt2
 1001 format(t5,"the removal parameter rr(j) equals rr(l) for"
     $," j=",i3,", l=",i3,". ",/,
     $t5,"rr(j) is elam+tflow(j,2,ktl)/vol(j)+vasum(j)",
     $"/vol(j)",/,t5,"this code needs them unequal for any pair",
     $" of volumes j and l.",/,t5,"rr(j)=",el5.8,5x,"rr(l)=",
     $el5.8,/,t5,"equality was found for ",
     $"the time interval ktl=",i3," to kt2=",i3,/,
     $t5,"************************************")
      stop
   22 continue
      xx(j,l)=tflow(j,l,ktl)/vol(jml)*xx(jml,l)/(rr(j)-rr(l))
      xsum=xsum+xx(j,l)
      enlsum=enlsum+xx(j,l)*emrt(l)
      tnq(j,kt2)=tnq(j,kt2)+xx(j,l)*(l.-emrt(l))/rr(l)
   20 continue
      xx(j,ldum)=(tflow(j,l,ktl)/vol(jml)*xx(jml,ldum)+sr(j))/rr(j)
      xsum=xsum+xx(j,ldum)
      enlsum=enlsum+xx(j,ldum)
      xx(j,j)=en(j,ktl)-xsum
      en(j,kt2)=xx(j,j)*emrt(j)+enlsum
      tnq(j,kt2)=tnq(j,kt2)+xx(j,ldum)*t+xx(j,j)*(l.-emrt(j))/rr(j)
      if(en(j,kt2).le.0.)en(j,kt2)=0.
      if(tnq(j,kt2).le.0.)tnq(j,kt2)=0.
   30 continue
   35 continue
c
c  tnq(j,kt2) is the time integral of the quantity in the j-th
c  compartment from time(ktl) to time(kt2).
c
      do 40 j=l,nvols
      depn(j,kt2)=tnq(j,kt2)*vasum(j,ktl)/vol(j)
      tran(j,kt2)=tnq(j,kt2)*tflow(j,2,ktl)/vol(j)
      ctran(j,kt2)=ctran(j,ktl)+tran(j,kt2)
      cdepn(j,kt2)=cdepn(j,ktl)+depn(j,kt2)
   40 continue
c
      return
      end
```

APPENDIX I

Proposed Revision 2 to Regulatory Guide 1.96

APPENDIX I

Proposed Revision to Regulatory Guide 1.96

DESIGN OF MAIN STEAM ISOLATION VALVE LEAKAGE CONTROL SYSTEMS FOR BOILING WATER REACTOR NUCLEAR POWER PLANTS

A. Introduction

General Design Criterion 54, "Piping Systems Penetrating Containment," of Appendix A, "General Design Criteria," to 10 CFR Part 50, "Licensing of Production and utilization Facilities," requires, in part, that piping systems penetrating primary containment be provided with leak detection, isolation, and containment capabilities having redundancy, reliability, and performance capabilities that reflect the importance to safety of isolating these piping systems. This guide describes a basis acceptable to the NRC staff for implementing General Design Criterion 54 with regard to the design of a leakage control system for the main steam isolation valves of boiling water reactor (BWR) nuclear power plants to ensure that total site radiological effects do not exceed guidelines of 10 CFR Part 100, "Reactor Site Criteria," in the event of a postulated design-basis loss-of-coolant accident (LOCA). A method which uses no leakage control system may be acceptable provided that analysis similar to that in NUREG-1169, "Resolution of Generic Issue C-8", verifies that no system is required.

B. Discussion

Direct cycle boiling water nuclear power plants supply steam directly from the reactor vessel to the turbine via main steam lines. The main steam lines installed on current BWR plants are provided with dual quick-closing isolation valves. These valves function to isolate the reactor system in the event of a break in a steam line outside the primary containment, a design-basis LOCA, or other events requiring containment isolation. In the case of a steam line break, the isolation valves would terminate the blowdown of reactor coolant in sufficient time to prevent an uncontrolled release of radioactivity from the

reactor vessel to the environment. In the case of a LOCA, the valves would isolate the reactor from the environment and prevent the direct release of fission products from the containment.

The valves are part of the reactor coolant pressure boundary. As such, they are Quality Group A components and their integrity must be maintained by strict inservice inspection and testing requirements. However, operating experience has indicated that degradation has occasionally occurred in the leak-tightness of main steam isolation valves, and the specified low leakage requirements have not always been maintained.

The staff has considered additional features to ensure the low-leakage characteristics of the main steam isolation valves in the event of a postulated design-basis loss-of-coolant accident are not necessarily required.(1) The use of a leakage control system would reduce direct untreated leakage from the isolation valves when isolation of the primary system and the containment is required. Alternatively, using the condenser may provide a better means to reduce the offsite exposures and may permit a larger permissible leakage rate through the MSIVs. For example, the staff analyses have indicated that using the condenser, calculated doses resulting from a leakage rate of up to 1800 scfh may be equal to or less than the doses from 11.5 scfh using a leakage control system (LCS). Therefore a maximum allowable leakage rate of 11.5 scfh is required when using an LCS but a higher limit can conservatively be used with alternative methods, as discussed in NUREG-1169.

The position of the staff with respect to the seismic design classification of the steam system does not require Seismic Category I design requirements for the turbine stop and control valves, steam line piping beyond the stop valve, the turbine, the turbine condenser, or connecting piping of less than 2 1/2 inches in diameter. The staff believes that, due to the low probability of a LOCA with a safe shutdown earthquake and as MSIV failure, non-

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(1) In its letters on the construction permit reviews of the Duane Arnold and Shoreham plants (December 18, 1969) and the James A. FitzPatrick plant (January 27, 1970), the Advisory Committee on Reactor Safeguards noted that additional features to control main steam isolation valve leakage should be considered.

safety related systems can be relied on to remain intact and capable of providing significant dose reduction factors in postulated accident conditions. Therefore a leakage control system for main steam isolation valves need not be provided for new boiling water reactor plants.(2)

Staff analyses of the contribution of main steam isolation valve leakage to total calculated offsite doses in postulated design-basis loss-of-coolant accidents made with conservative allowances for transport delay effects show that the 2-hour site boundary dose is not affected by the subject leakage. The long-term dose in the low population zone, however, is affected for uncontrolled isolation valve leakage rates typical of current technical specification values. Thus the staff has concluded that a fully automatic quick-acting method to control leakage is not required to meet the objectives. A manually-initiated method capable of being actuated within about 20 minutes of an accident requiring use of the system would be acceptable.

It should be noted that any leakage from the stem packing of the outboard isolation valve would have an insignificant contribute to the 2-hour dose, since in most designs such leakage would escape to the turbine building and the environment via the steam tunnel. Reduction and control of steam packing leakage or other direct leakage to the steam tunnel from the outboard isolation valve should be considered.

C. Regulatory Position

The isolation function of the main steam isolation valves in boiling water reactor plants should be supplemented by a method to control the leakage as discussed in NUREG-1169. An acceptable approach for such a method is provided by the following design basis:

1. The results of a LOCA with the single active failure of an inboard MSIV to close should be evaluated using the offsite dose release discussed in NUREG-1169. The dose consequences of the MSIV leakage

(2) Part 100 guidelines, as used in this guide, refer to the radiation dose limits used in determining the boundaries of the exclusion area and the low population zone pursuant to 10 CFR Part 100.

when combined with the consequences from all other contributors, shall be within the exposure guidelines of 10 CFR Part 100, paragraph 11.

2. The maximum allowable MSIV leak rate may be determined by determining the maximum MSIV leakage (in SCFH) which meets the guidelines of Position C.1.

3. The components used may be non-safety related provided that either 1) they fail on a loss of offsite power to the proper position, 2) the operator can properly align the equipment within 20 minutes assuming the loss of offsite power, or 3) the operator can load the appropriate components onto a diesel generator from the control room. Components which rely on auxiliary steam from another unit or an auxiliary boiler may be used provided that the analysis does not take credit for those components until 20 minutes after the time required, and demonstrated to be necessary, to have the components on line.

D. Implementation

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

This guide reflects current regulatory practice. Therefore, except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein is being and will continue to be used in evaluating submittals for construction permit and operating license applications. Although this guide may recommend backfitting in certain cases that have already been docketed, as described below, it does not require it. Such requirements will be formulated on an individual basis pursuant to 10 CFR § 50.109.

1. In the case of boiling water reactor plants for which construction permits were issued prior to January 1, 1986, applicants and licensees should continue the established inservice inspection programs to ensure that isolation valves are maintained in such a

manner that leakage is within Technical Specification limits. If the valve inspections show recurring problems with excessive leakage, the staff recommends that consideration be given to meeting the Regulatory Positions of this Regulatory Guide.

2. In the case of boiling water reactor plants for which construction permits have been issued after January 1, 1986, the staff recommends that applicants and licensees provide the results of an analysis which supports using the selected method for controlling leakage through the MSIVs and propose the plant specific maximum allowable MSIV leakage rate. Each plant will be reviewed on a case-by-case basis.

APPENDIX J

Proposed Revision 3 to Standard Review Plan Section 6.7

APPENDIX J

Proposed Standard Review Plan Section 6.7

6.7 MAIN STEAM ISOLATION VALVE LEAKAGE CONTROL (BWR)

REVIEW RESPONSIBILITIES

Primary - Plant Systems Branch (PSB) - Division of BWR Licensing

Secondary - None

I. AREAS OF REVIEW

Direct cycle boiling water reactor (BWR) plants have redundant quick-acting isolation valves on each main steam line from the reactor to the turbine. In the event of a loss-of-coolant accident (LOCA), any leakage of contaminated steam through these valves is controlled. An offsite dose release calculation is provided which demonstrates an acceptable release rate, as discussed in NUREG-1169 and the acceptability of the method to control leakage through the main steam isolation valves (MSIV) and satisfies the requirements of General Design Criteria 54.

The review of the method for controlling material which leaks past the MSIVs covers the components being utilized, the analytical method used for the dose release calculations, and the offsite doses.

1. PSB reviews the components being used to assure their ability to function following a postulated LOCA. The system is reviewed to determine that:

   a. The capability of the system to perform its intended function is maintained assuming a single active failure of a main steam line isolation valve.

b. The compatibility of initiation means and control, as appropriate, of the system with respect to operator action times.

2. Reactor Systems Branch (RSB) reviews the acceptability of the meteorological conditions used for the dispersion calculations, the calculational methods and the results of the offsite dose releases.

Related review evaluations will be performed by other branches and the results will be coordinated by PSB to complete the overall evaluation of the system. The evaluations provided by other branches are as follows. The Engineering (EB) Branch determines that the components piping and structures are designed in accordance with applicable codes and standards as part of its primary review responsibility for SRP Sections 3.9.1 through 3.9.3. The EB also determines the acceptability of the seismic and quality group classifications for system components as part of its primary review responsibility for SRP Sections 3.2.1 and 3.2.2. The Engineering Branch verifies that inservice inspection requirements are met for system components as part of its primary review responsibility for SRP Section 6.6, and, upon request, verifies the compatibility of the materials of construction with service conditions. The EB also reviews the adequacy of the inservice testing program of pumps and valves as part of its primary review responsibility for SRP Section 3.9.6. The EB reviews the seismic qualification of Category I instrumentation and electrical equipment and the environmental qualification of mechanical and electrical equipment as part of its primary review responsibility for SRP Sections 3.10 and 3.11, respectively. The Electrical, Instrumentation and Control Systems Branch (EICSB) determine the adequacy of the design, installation, inspection, and testing of all electrical components (sensing, control, and power) required for proper operation as part of their primary review responsibility for SRP Sections 7.1 and 8.0, respectively. Licensing Guidance Branch, and Quality Assurance Branch as part of their primary review responsibility for SRP Sections 9.5.1, 16.0, and 17.0, respectively.

For those areas of review identified above as being the responsibility of other branches, the acceptance criteria and their methods of application are contained in the SRP sections corresponding to those branches.

II. ACCEPTANCE CRITERIA

Acceptability of a method, as described in the applicant's safety analysis report (SAR), is based on the offsite dose consequences predicted using the method when combined with the consequences from all other contributors, being within the exposure guidelines of 10 CFR Part 100, paragraph 11, for the design basis LOCA.

III. REVIEW PROCEDURES

The procedures below are used during the construction permit (CP) review to determine that the design criteria, design bases, and preliminary design meet the acceptance criteria given in subsection II of this SRP section. For the review of operation license (OL) applications, the procedures are utilized to verify that the initial design criteria and bases have been appropriately implemented in the final design. The OL review includes a determination that the content and intent of the technical specifications prepared by the applicant are in agreement with the requirements for system testing, minimum performance, and surveillance developed by the staff. The reviewer will select and emphasize material from this SRP section, as may be appropriate for a particular case.

Upon request from the primary reviewer, the secondary review branches will provide input for the areas of review stated in subsection I of this SRP section. The primary reviewer obtains and uses such input as required to assure that this review procedure is complete.

1. The information provided in the SAR pertaining to the design basis and design criteria, the system piping and instrumentation diagrams (P&IDs), and the system description are reviewed to determine that they clearly delineate the following:

   a. The method used to accomplish control of the main steam isolation valve leakage and the system components essential for operation following design basis LOCA conditions.

b. System drawings are reviewed to see that they show the method for accomplishing control of the leakage and the system description is reviewed to identify minimum performance requirements for the leakage control system isolation valves.

c. Design provisions have been made that permit appropriate inservice inspection and functional testing of system components. It is acceptable if the SAR information delineates a testing and inspection program and if the system drawings show the necessary design provisions to accomplish the testing program.

2. The method is reviewed to verify that any instrumentation, controls, and interlocks required for the method to perform its function are designed to appropriate standards. A statement in the SAR that such instrumentation, controls, and interlocks will be provided is acceptable for construction permit (CP) review.

3. The performance requirements, P&IDs, drawings, and the results of failure modes and effects analyses are reviewed to assure that the system can function following a design basis LOCA assuming a concurrent single active failure, including the failure of a single main steam isolation valve to close.

4. The reviewer evaluates the analyses presented in the SAR to assure the function of required components, traces the availability of these components on system drawings, and checks that the SAR contains verification that minimum requirements are met for each failure condition over the required time spans. For each case the design is acceptable if minimum system functional requirements are met. The reviewer upon request from RSB provides an estimate of the MSIV leakage rate, for use in calculating radiological consequences of a LOCA.

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided and his review supports conclusions of the following type, to be included in the staff's safety evaluation report.

The method of processing leakage past the MSIVs consists of the main steam lines, (and other components). The main steam lines up to (the turbine stop valves) and the main steam isolation valves as seismic Category I. The remaining portions of this method are non-seismic Category I. No power (electrical, hydraulic, phneumatic) is required to process the leakage. The steam line drain (turbine bypass) valves fail open on loss of power. The path for the leakage is through the MSIVs, down the steam line, (through the steam drain lines, through the condenser, past the turbine seals, and the to the environment).

The applicant's design also meets the requirements of General Design Criterion 54 as related to leak detection, isolation, and performance testing for system piping penetrating containment. The bases for acceptance is that the design meets positions C.1 through C.3 of Regulatory Guide 1.96.

The applicant has utilized the calculational methods described in NUREG-1169 and has demonstrated that the offsite doses for a LOCA, with the single active failure of an inboard MSIV, and with a leakage rate of ( ) scfh in addition to all other sources for offsite dose consequences following a design basis LOCA, the total offsite dose consequences is within the exposure guidelines of 10 CFR Part 100, paragraph 11. Therefore, using this method of controlling leakage past the MSIV is acceptable.

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plan for using this SRP section.

Except for those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of compliance with Commission regulations.

Implementation schedules for conformance to parts of the method discussed herein are contained in the referenced regulatory guide.

Those utilities with a safety grade leakage control system (LCS) may apply for removal of their LCS based upon using an alternate method as described in NUREG-1169.

VI. REFERENCES

1. 10 CFR Part 100, Reactor Site Criteria.

2. 10 CFR Part 50, Appendix A, General Design Criterion 54, "Piping Systems Penetrating Containment."

3. Regulatory Guide 1.96, "Design of Main Steam Isolation Valve Leakage Control Systems for Boiling Water Reactor Nuclear Power Plants."

4. NUREG-1169, "Resolution of Generic Issue C-8, An Evaluation of Boiling Water Reactor Main Steam Isolation Valve Leakage and the Effectiveness of Leakage Treatment Methods."

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1. REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)

NUREG-1169

2. TITLE AND SUBTITLE

Resolution of Generic Issue C-8
An Evaluation of Boiling Water Reactor Main Steam Isolation Valve Leakage and the Effectiveness of Leakage Treatment Methods

3. LEAVE BLANK

4. DATE REPORT COMPLETED

MONTH	YEAR
December	1985

5. AUTHOR(S)

J. N. Ridgely and M. L. Wohl

6. DATE REPORT ISSUED

MONTH	YEAR
January	1986

7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Division of Boiling Water Reactor Licensing
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Same as 7 above

11a. TYPE OF REPORT

Final

b. PERIOD COVERED (Inclusive dates)

12. SUPPLEMENTARY NOTES

Prepared with the assistance of Pacific Northwest Laboratory under FIN B2529, J. D. Jamison, Project Manager

13. ABSTRACT (200 words or less)

ABSTRACT

NUREG-1169 describes NRC staff and contractor efforts to resolve Generic Issue C-8, "Main Steam Isolation Valve Leakage and LCS Failure." This report describes efforts to determine the causes of excessive MSIV leakage and proposed solutions to the problems. A realistic fission product transport model was developed to assess the offsite dose consequences of alternate means of treating MSIV leakage using non-safety-grade systems that likely would be available for service following a design basis loss-of-coolant accident. The results of this assessment are presented in the report, together with conclusions regarding the prospects for reducing MSIV leakage, increasing the allowable MSIV leak rate, and the need to delete the requirement for a safety-grade leakage control system.

14. DOCUMENT ANALYSIS - a. KEYWORDS/DESCRIPTORS

Main Steam Isolation Valve, MSIV, MSIV Leakage, Boiling Water Reactors, Leakage Control System (LCS), MSIV Leakage Control

b. IDENTIFIERS/OPEN ENDED TERMS

Generic Issue C-8

15. AVAILABILITY STATEMENT

Unlimited

16. SECURITY CLASSIFICATION

(This page)
Unclassified
(This report)
Unclassified

17. NUMBER OF PAGES

18. PRICE