UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 2, 1997

Science and Engineering Associates, Inc.
Attn: Ilene R. Colina
Contract Administrator
6100 Upton Blvd., NE
Albuquerque, New Mexico 87110

Dear Ms. Colina:

Subject: Task Order No. 1, Entitled "Reprioritization of GSI-107, Main Transformer Failures," Under Contract No. NRC-04-97-036

In accordance with Section G.4(c), of the subject contract, this letter definitizes the subject task order. This effort shall be performed in accordance with the enclosed Statement of Work and the contractor's technical proposal dated December 3, 1996, which is hereby incorporated by reference and made a part of the subject task order.

Task Order No. 1 shall be in effect from January 2, 1997 through February 12, 1997, with a ceiling amount of $20,091.00. The amount of $18,608.00 represents the total estimated reimbursable costs and the amount of $1,483.00 represents the fixed fee.

The obligated amount of this task order shall at no time exceed the task order ceiling. When and if the amount(s) paid and payable to the Contractor hereunder shall equal the obligated amount, the contractor shall not be obligated to continue performance of the work unless and until the Contracting Officer shall increase the amount obligated with respect to this task order. Any work undertaken by the Contractor in excess of the obligated amount specified below is done so at the Contractor's sole risk.

The amount currently obligated by the Government with respect to this task order is $15,000.00, of which the sum of $13,889.00 represents the estimated reimbursable costs, and of which $1,111.00 represents the fixed fee. It is estimated that the amount currently allotted will cover performance through February 3, 1997.

Accounting Data for Task Order No. 1 is as follows:

Commitment No:	RES-C97-317
APPN No:	31X0200.760
B&R No:	76015115050
JOB CODE:	W6650
BOC No:	252A
Obligated Amount:	$15,000.00

DF02 1/1

The following individual is considered to be essential to the successful performance of work hereunder:

230008

Dr. Willard Thomas

The Contractor agrees that key personnel shall not be removed from the task order effort without compliance with Contract Clause H.3, "Key Personnel."

Your contacts during the course of this task order are:

Technical Matters: Joram Hopenfeld
(301) 415-5897

Contractual Matters: Sharon Mearse
(301) 415-6591

The issuance of this task order does not amend any terms or conditions of the subject contract.

Please indicate your acceptance of Task Order No. 1 by having an official, authorized to bind your organization, execute three copies of this document in the space provided and return two copies to the Contracting Officer. You should retain the third copy for your records.

If you have any questions regarding this matter, please contact me on 301/415-6591.

Sincerely,

Sharon D. Mearse

Sharon D. Mearse, Contracting Officer
Technical Acquisition Branch No. 1
Division of Contracts
Office of Administration

Enclosure:
As stated

ACCEPTED:

Ilene R Colina
NAME

Contract Administrator
TITLE

1/8/97
DATE

Task Order 001
"Reprioritization of GSI-107, Main Transformer Failures"

of NRC Contract NRC-04-97-036
"Technical Assistance for Prioritizing and Resolving Generic Safety Issues"

(FIN No. W6650)

Background

The subject generic safety issue (GSI) was assigned a LOW priority in NUREG-0933 dated 06/30/91. The issue was on the low/medium border line but was classified low because of potential benefits from the station blackout (SBO) rule. In a memo (Att. 4) the Electrical Engineering Branch summarized transformer failures through 3/1/96 showing an increase in transformer failures and related reactor trips.

Objectives

The objective of this task is to reassess the present status of GSI and recommend whether a prioritization change is warranted.

Scope of Work

The contractor will review the Attachments 1 - 3 and reevaluate the priority of GSI-107 in accordance with standard evaluation procedures (Ref. 1 and 2). The contractor should include in his evaluation all transformer related events with emphasis on those involving transformer explosions.

Reporting Requirements

No additional reporting requirement beyond those already agreed to in NRC contract NRC-04-97-036.

Deliverables and Delivery Schedule

A draft report shall be submitted to the NRC Project Officer and NRC Technical Monitor two weeks following the initiation of work. The final report shall be submitted to the NRC Project Officer and NRC Technical Monitor at the end of the period of performance. The draft and final report shall follow the guidance in Reference 1 and 2 for report preparation and content. The format of the final report shall meet the design specifications for NUREG/CR reports.

Travel

None.

Period of performance

The period of performance is 6 weeks from task award.

Technical Direction

Technical direction will be provided by J. Hopenfeld, NRC 301- 415-5897.

References

1. Emrit, R., et. al., A Prioritization of Generic Safety Issues, NUREG-0933, U.S. Nuclear Regulatory Commission, Washington, D.C., July 1991.

2. Andrews, W., et. al., Guidelines for Nuclear Power Plant Safety Issue Prioritization Information Development, NUREG/CR-2800 (PNL-4297), U.S. Nuclear Regulatory Commission, Washington, D.C., February 1983, (Supplement 1) May 1983, (Supplement 2) December 1983, (Supplement 3) September 1985, (Supplement 4) July 1986, (Supplement 5) July 1996.

3. Regulatory Analysis Technical Evaluation Handbook, NUREG/BR-0184, U.S. Nuclear Regulatory Commission, Washington, D.C., August 1993. (DRAFT)

Attachments

1. Issue 107 : Main Transformer Failures, NUREG-0933 (06/30/91)

2. Memo, Beckjord to Jordan 4/7/1995 " Periodic Review of Low Priority Generic Safety Issue"

3. Memo, Russel to Morrison 4/11/1996 Same Subject

4. Memo, Calvo to Thadani 3/7/96 "Transformer Failures"

ISSUE SUMMARY WORK SHEET

ISSUE NO./TITLE: 107, Main Transformer Failures

SUMMARY OF PROBLEM AND PROPOSED RESOLUTION:

The concern of this issue is the generic safety implications associated with main transformer failures at U.S. light water reactors (LWRs). Safety issue resolution involves licensee reviews and evaluations of main transformer problems and enhancement of fire protection capabilities where necessary.

AFFECTED PLANTS

BWR:	Operating = 24	Planned = 20
PWR:	Operating = 47	Planned = 43

RISK/DOSE RESULTS (man-rem)

PUBLIC RISK REDUCTION =	2.6E+03
OCCUPATIONAL DOSES:	
SIR Implementation =	0
SIR Operation/Maintenance =	0
Total of Above =	0
Accident Avoidance =	17

COST RESULTS ($$10^6$)

INDUSTRY COSTS:	
SIR Implementation =	4.3
SIR Operation/Maintenance =	- 0.4
Total of Above =	3.9
Accident Avoidance =	0.9
NRC COSTS:	
SIR Development =	0.08
SIR Implementation =	0.74
SIR Operation/Maintenance Review =	3.4
Total of Above =	4.2

MAIN TRANSFORMER FAILURES

ISSUE 107

1.0 SAFETY ISSUE DESCRIPTION

The principal concern of this issue is the potential safety implications associated with main transformer failures at U.S. light water reactors (LWRs). Concern for this issue arose when the North Anna Power Stations had seven main transformer failures in 26-months. Five of these resulted in reactor trips. Of the seven failures, three included rupture of the transformer tank with two fires occurring. One of the fires spread beyond the transformer bay to the turbine bay.

Safety-related loads are supplied from buses that can be supplied from any one of the following at the licensees choice: 1) auxiliary transformer, 2) startup transformer (or reserve auxiliary transformer), or 3) backup power supply (e.g. diesel generators). A main transformer failure will result in a loss of load or unbalanced load on the generator. A generator/turbine trip would result and power would not be available to the auxiliary transformer for station power. Station power would be obtained from the grid through the startup transformer or from backup power sources. Switchyards have redundant and duplicate systems to provide sufficient relaying and circuit breakers so that a failure would not be expected to cause a loss of offsite power. In the event of a failure in the switchyard to provide power to the startup transformer, power can be backfed through the main transformer to the auxiliary transformer.

An assessment of the main transformer failures at North Anna concluded that there was a possibility of generic implications arising out of plant specific characteristics (Dalton, Kresser, Savage and Selan 1982). ANO-1 also experienced main transformer failures that resulted in three oil spills from tank ruptures and one fire. Some of the generic issues addressed were transformer fires, transformer maintenance and operational procedures, excessive shipping and handling, cascading effects, electrical/mechanical damage and explosions. Generic issues regarding transformer fires included addressing the fire protection system, overhead conductors and buses, cable trays, storage of flammable material near potential fire hazards, and oil filled transformers in general. Some of the issues that were identified included that the oil from a ruptured transformer will float on the water used by fire protection system such that the fire will move in the direction of drainage, the fire may propagate to overhead cables and buses, and the need for access to adjacent locations (such as building roofs) when fighting the fire.

PROPOSED RESOLUTION

For purposes of this analysis, this proposed safety issue resolution (SIR) is assumed to involve the following actions:

1. Licensees should evaluate their main transformer to ensure that the offsite power is protected. Design requirements should be established for routing and separation of offsite power source feeds to protect against loss from a transformer fire.

2. Fire protection system for the main transformer should be reviewed for adequacy and revised as necessary to assure that potential fire is prevent from spreading to other plant areas. The review should address the deluge system, drainage system, fire barriers, and fire fighting equipment and procedures.

3. Maintenance and operating procedures for the main transformer should be reviewed for adequacy and revised as necessary.

4. Modify, if necessary, the drainage system to provide drains for each transformer so that liquids flow away from the turbine building, power lines and safety related cables to or within the reactor and related safety equipment. Modifications could include adding drains, building dikes and sloping transformer yard away from buildings and other transformers.

5. Modify, if necessary, the fire fighting equipment and procedures. This may include longer hoses, increased ease of access to building roofs, mobility of fire fighting equipment, and training for personnel.

6. Move, if necessary, the power lines to the safety related buses so that they would not be affected by a fire in the transformer bays.

AFFECTED PLANTS

The resolution of this safety issue is assumed to affect all operating and planned LWRs as listed in NUREG/CR-2800 (Andrews et al. 1983).

2.0 SAFETY ISSUE RISK AND DOSE

The public risk reduction and occupational dose associated with the issue resolution are estimated in this section. Results are summarized in Tables 1 and 2, respectively. The analyses are conducted for a representative PWR and a representative BWR. The Oconee-3 PRA (Andrews et al. 1983, Appendix A) risk equations have been assumed to be representative of all PWRs for this analysis. The Grand Gulf-1 PRA (see Andrews et al. 1983, Appendix B) was used to derive estimates of core-melt frequency reduction and occupational dose increase for BWRs.

TABLE 1. Public Risk Reduction Work Sheet

1. Title and Identification Number of Safety Issue:

   Main Transformer Failures, Issue 107

2. Affected Plants (N) and Average Remaining Lives ($\bar{T}$):

	N	$\bar{T}$ (yr)
All PWRs	90	28.8
All BWRs	44	27.4
All plants	134	28.3

3. Plants Selected for Analysis:

   A PWR and a BWR are assumed to be representative of each type of reactor. The safety analyses are conducted for Oconee-3 for PWRs and Grand Gulf 1 for BWRs.

4. Parameters affected by SIR:

   For the representative PWR, the primary affected parameter is:

   T_2 Loss of power conversion system transient caused by other than loss of offsite power

   For the representative BWR, the primary affected parameter is:

   T_{23} Any transient other than loss of offsite power which requires an emergency reactor shutdown.

5. <u>Base-Case Values for Affected Parameters</u>:

For the representative PWR, the base-case frequency is:
$T_2 = 3/py$

For the representative BWR, the base-case frequency is:
$T_{23} = 7.0$

6. <u>Affected Accident Sequences and Base-Case Frequencies</u>:

<u>Oconee-3</u>:

T2MLU	τ (PWR-3) =	6.0E-7
	ß (PWR-5) =	8.8E-9
	ϵ (PWR-7) =	6.0E-7
T_2MQH	τ (PWR-3) =	5.5E-6
	ß (PWR-5) =	8.0E-8
	ϵ (PWR-7) =	5.5E-6
T_2MQFH	τ (PWR-2) =	2.5E-6
	ß (PWR-4) =	3.7E-8
	ϵ (PWR-6) =	2.5E-6
T_2MLUO	τ (PWR-3) =	4.1E-6
	ß (PWR-5) =	5.9E-8
	ϵ (PWR-7) =	4.1E-6
T_2KMU	τ (PWR-3) =	3.9E-6
	ß (PWR-5) =	5.7E-8
	ϵ (PWR-7) =	3.9E-6
T_2MQD	τ (PWR-3) =	7.5E-7
	ß (PWR-5) =	1.1E-8
	ϵ (PWR-7) =	7.5E-7

<u>Grand Gulf</u>:

$T_{23}PQI$	α (BWR-1) =	3.7E-8
	δ (BWR-2) =	3.7E-6
$T_{23}PQE$	τ (BWR-3) =	2.7E-7
	δ (BWR-4) =	2.7E-7
$T_{23}QW$	δ (BWR-2) =	1.2E-5
$T_{23}C$	δ (BWR-2) =	5.4E-6

7. <u>Affected Release Categories and Base-Case Frequencies</u>:

<u>Oconee</u>:

<u>Grand Gulf</u>:

Category	Frequency, py^{-1}	Category	Frequency, py^{-1}
PWR-2	2.5E-6	BWR-1	3.7E-8
PWR-3	1.5E-5	BWR-2	2.1E-5
PWR-4	3.7E-8	BWR-3	2.7E-7
PWR-5	2.2E-7	BWR-4	2.7E-7
PWR-6	2.5E-6		
PWR-7	1.5E-5		

8. Base-Case, Affected Core-Melt Frequency ($\bar{F}$):

$\bar{F}_{PWR}$ = 3.776E-5/py $\bar{F}_{BWR}$ = 2.206E-5/py

Note: These values were calculated using the Grand Gulf-1 and Oconee-3 PRA mini-computer codes. The values contain excess significant figures in order to compute the difference between the base-case and adjusted-case.

9. Base-Case, Affected Public Risk (W):

W_{PWR} = 98.830 man-rem/py W_{BWR} = 153.909 man-rem/py

10. Adjusted-Case, Affected Values and Affected Parameters:

As discussed in Attachment 1, SIR is assumed to reduce the frequency of transients at PWRs and BWRs by enhancing the reliability of main transformers and preventing potential fires that may result from main transformer failures from spreading to other vital areas of the plant. To model the effects of SIR on plant risk, the transient frequencies given in NUREG/CR-2800 (Andrews et al. 1983) were modified to reduce the transient frequencies by the amount equivalent to the frequency of outages caused by main transformer failures.

For PWRs, the adjusted case value is:

T_2 = 3/py - 0.023/py = 2.977/py

For BWRs, the adjusted case value is:

T_{23} = 7/py - 0.023/py = 6.977/py

11,12. Steps Leading to Calculation of Adjusted-Case Affected Accident Sequence Frequencies and Adjusted-Case Frequencies for Affected Release Categories.:

The Oconee-3 and Grand Gulf-1 mini-computer codes were used to calculate the adjusted-case affected core-melt frequencies and public risk values and the changes in core-melt frequency and public risk associated with SIR.

13. Adjusted-Case Affected Core-Melt Frequency ($\bar{F}^*$):

$\bar{F}^*_{PWR}$ = 3.747E-05/py $\bar{F}^*_{BWR}$ = 2.199E-05/py

14. Adjusted-Case, Affected Public Risk (W^*):

W^*_{PWR} = 98.072 man-rem/py W^*_{BWR} = 153.404 man-rem/py

15. Reduction in Core-Melt Frequency ($\Delta\bar{F}$):

$\Delta\bar{F}_{PWR}$ = 2.89E-7/py $\Delta\bar{F}_{BWR}$ = 7.25E-8/py

16. Per-Plant Reduction in Public Risk (ΔW):

ΔW_{PWR} = 0.76 man-rem/py ΔW_{BWR} = 0.51 man-rem/py

17. Total Public Risk Reduction, ΔW (Total):

Best Estimate (man-rem)	Error Bounds (man-rem) Upper	Lower
2.6E+03	9.6E+6	0

ATTACHMENT 1 (to Table 1)

Resolution of Issue 107 uses the Oconee-3 and Grand Gulf-1 PRAs as described by Andrews et al. (1983) as the basis for evaluation of this issue. Several PRAs were reviewed to determine whether main transformer failures were addressed in any of the dominant cut sets. Because failure rates for transformers are relatively low (on the order of 10^{-6} per hour), their failures are not a significant cause of transients. As a result, main transformer failures are integrated into a category of transients that result from loss of network load. The affected parameters, T_2 for Oconee and T_{23} for Grand Gulf, were then adjusted to determine the public risk and core-melt frequency reductions associated with Safety Issue Resolution (SIR).

It is postulated that SIR will enhance the reliability of the main transformers and thus reduce the frequency of transients associated with main transformer failures. The frequency of occurrence of reactor transients provided in NUREG/CR-3862 (Mackowiak et al. 1985) was used to estimate the reduction in transient frequencies associated with SIR. This document categorizes reactor transients into 41 categories for PWRs and 37 categories for BWRs. One of the BWR categories is for transients caused by loss of auxiliary power, characterized as a loss of incoming power to a plant as a result of onsite failures (such as failure of an auxiliary transformer). This category closely resembles failure of the main transformer. The transient frequency associated with this category is given as 0.02 events/py.

Licensee Event Reports (LERs) reviewed contained three of the seven main transformer failures at the North Anna Power Station. No other failures of main transformers were identified in the LERs. The IEEE reliability data for liquid filled transformers (347 to 550 kVA) at nuclear power generating stations are shown below. The sum of the failure rate for all failure modes as given by IEEE is 2.67 per 10^6 hours. The corresponds to an annual frequency of 0.023 failures per year for main power generators or unit transformers. This value is not significantly different than the transient frequency given above and will be used as the basis for reductions in main transformer failures that are postulated to result from SIR.

	Failure Rate/10^6 Hours		
Failure Modes	Low	Recommended	High
Single Phase Liquid Filled			
All Modes	0.74	1.62	2.67
- Catastrophic	0.53	1.16	1.91
- Degraded	0.094	0.21	0.34
- Incipient	0.12	0.25	0.42

Failure Modes	Failure Rate/10^6 Hours		
	Low	Recommended	High
Three Phase Liquid Filled			
All Modes	0.78	1.35	2.61
- Catastrophic	0.43	0.74	1.44
- Degraded	0.17	0.29	0.56
- Incipient	0.18	0.32	0.61

A second aspect of main transformer failures addressed here is the potential for fires. Fires are of concern because of their potential to damage or otherwise degrade the performance of one or more safety systems. For example, fires could result in spurious actuation of valves, generate false instrument readings in the control room, and produce mechanical and thermal damage to safety-related components. Main transformer fires could potentially spread to overhead electric power cables that supply AC power to safety buses and, depending upon their proximity to the main transformer, could damage the reactor or turbine buildings. As a result, a single fire could cause malfunctions of various components that receive electric power from the fire-damaged cables. The proposed SIR attempts to prevent a main transformer fire from spreading to other vital areas of the plant, including electric power and control cables.

The effects of transformer fires on public risk are difficult to quantify because of the limited treatment of fires given to date in PRA studies. The detailed Oconee-3 PRA (Sugnet et al. 1984) was reviewed to develop insights on the potential risks associated with main transformer fires. The analysis of fires at Oconee-3 included an attempt to identify critical locations where fires could result in an initiating event and, at the same time, cause failure of redundant safety-related components. The main transformers were not among the critical locations and thus analysis of main transformer fires was not performed. Presumably, this was for the following reasons:

- Main transformer fires that spread to power cables would result in a loss of AC power to safety-related systems. These systems are provided with backup DC power supplies and emergency diesel generators that would likely be unaffected by the fire and thus the plant would be capable of recovering from the loss of normal AC power. Offsite power could also be switched to the auxiliary transformers in the event of a fire involving the main transformers. Thus, three separate sources of AC power would be available in the event that a fire disables the main transformer and damages power cables. Combining the probabilities of failure for these backup power sources and the probability of occurrence of a fire provides evidence that a fire-induced common mode failure of all electric power is extremely low.

- Main transformers are typically provided with fire detection and extinguishment systems so it is expected that a fire in this area would

be of relatively short duration. The purpose of the SIR proposed here is to improve the fire extinguishment system and emergency procedures such that all plants are capable of providing a rapid and effective response to fires.

- Fires in other areas of the plant, such as the cable spreading room, control room, and electrical equipment room, appear to create situations in which a plant is more vulnerable to common cause failures than fires involving the main transformer.

For these reasons, the risks associated with main-transformer-fire-induced common cause failures of electric power supply systems is anticipated to be very low. Further, the risk reduction associated with the portions of the proposed SIR involving enhanced fire protection systems is not quantified here.

In order to evaluate the adjusted case core-melt frequency as a result of the SIR implementation, it was assumed that the transient initiating event frequencies would be reduced, at maximum, by the annual frequency of the transformer failures. The annual frequency of transformer failures was computed previously as 0.023 events/yr, based on IEEE reliability data.

Affected accident sequences for Oconee-3 include all sequences involving initiating event T_2 and those for Grand Gulf-1 include all sequences involving the initiating event T_{23}. These accident sequences and their base-case frequencies are presented in Table 1.

The adjusted-case, affected core-melt frequency for Oconee-3 is calculated by replacing the base-case frequency for initiating event T_2 of 3/py by the adjusted-case T event frequency of (3/py - 0.023/py) = 2.977 /py. The adjusted-case transient frequency was input to the Oconee-3 minicomputer code to calculate the adjusted-case core melt frequency and public risk. The adjusted-case, affected core-melt frequency for the representative BWR is calculated by replacing the base-case frequency for initiator T_{23} of 7/py by the adjusted-case T event frequency of 6.977/py. The Grand Gulf mini-computer code was used to calculate the reductions in core-melt frequency and public risk. The results of these calculations are presented in Table 1.

TABLE 2. Occupational Dose Work Sheet

1. Title and Identification Number of Safety Issue:

Main Transformer Failures, Issue 107

2. Affected Plants (N):

All 134 plants (71 operating and 63 planned) are assumed to be affected. This includes 90 PWRs and 44 BWRs.

3. Average Remaining Lives of Affected Plants ($\bar{T}$):

	$\bar{T}$ (yr)
All PWRs	28.8
All BWRs	27.4
All plants	28.3

4. Per-Plant Occupational Dose Reduction Due to Accident Avoidance, $\Delta(FD_R)$:

Using 19,860 man-rem for D_R, then

PWR: $\Delta(FD_R)$ = (19,860 man-rem)(2.89E-7/py) = 5.7E-3 man-rem/py
BWR: $\Delta(FD_R)$ = (19,860 man-rem)(7.25E-8/py) = 1.4E-3 man-rem/py

5. Total Occupational Dose Reduction Due to Accident Avoidance (ΔU):

Best Estimate (man-rem)	Error Bounds (man-rem) Upper	Lower
1.7E+1	1.5E+4	0

6 to 12. Steps Leading to Total Occupational Exposures for SIR Implementation, Operation, and Maintenance.

SIR is assumed to not involve any labor in radiation zones. This is because the main transformers are not located in a building in which radioactive materials are used or stored and thus the radiation dose rates would be zero. SIR does not require any entries into containment or into the reactor building. As a result, total occupational exposures for SIR implementation, operation, and maintenance are 0.

3.0 SAFETY ISSUE COSTS

The industry and NRC costs associated with resolution of this safety issue are estimated in this section. The results are summarized in Table 3.

TABLE 3. Safety Issue Cost Work Sheet

1. Title and Identification Number of Safety Issue:

   Main Transformer Failures, Issue 107

2. Affected Plants (N):

   All 134 plants (71 operating and 63 planned) are assumed to be affected.

3. Average Remaining Lives of Affected Plants ($\bar{T}$):

	$\bar{T}$ (yr)
Operating:	23.1
Planned:	30
All plants:	28.3

Industry Costs (Steps 4 through 12):

4. Per-Plant Industry Cost Savings Due to Accident Avoidance, $\Delta(FA)$:

   PWR: $\Delta(\bar{F}A)$ = (8.0E-07/py)($1.65E+09) = $287/py
   BWR: $\Delta(FA)$ = (8.0E-07/py)($1.65E+09) = $ 88/py

5. Total Industry Cost Savings Due to Accident Avoidance (ΔH):

Best Estimate	Upper Bound	Lower Bound
$8.5E+05	$5.0E+08	0

6. Per-Plant Industry Resources for SIR Implementation:

   For all operating plants, it is assumed that the NRC would issue a generic letter or bulletin requiring all plants to review the design and installation of main transformers and associated fire protection systems, control circuits, and operating and maintenance procedures. The assumed resource requirements for this review are:

Labor =	2	man-weeks/plant to evaluate fire protection system(s)
	1	man-weeks/plant to review protective circuitry
	4	man-weeks/plant to review operating and maintenance procedures
	2	man-weeks/plant to revise operating and maintenance procedures
	2	man-weeks/plant to revise staff training
	11	man-weeks/plant for SIR Implementation

As a result of the reviews conducted at all plants, it is assumed that 10% of the plants would require modifications to the fire protection system and rerouting of cables around the main transformer areas. The assumed resource requirements for the plants requiring modifications are:

Labor =	3	man-weeks/plant to design modifications
	2	man-weeks/plant to plan installation and testing
	2	man-weeks/plant to revise procedures
	2	man-weeks/plant for acceptance testing
	9	man-weeks/plant for SIR Implementation

Additional hardware requirements for those plants requiring modifications include: an additional drain, gravel and concrete to slope the area around the transformers and construct dikes; additional power lines to route power to the buildings; additional breakers to protect equipment connected to the auxiliary transformer; and longer fire hoses. The hardware and installation labor costs for the plants requiring modifications are itemized below:

Dike (250-ft long, 4-ft high)	$ 3,750
Concrete and gravel	15,820
Power lines (1,000 ft)	5,000
Poles (10 at $,1085 each)	11,000
Breakers (2 at $2,500 each)	5,000
Fire hose/storage cabinet (100-ft)	500
Subtotal	41,000
Escalation (1982 to 1988)	1.18
Total (1988 dollars)	$48,000

7. Per-Plant Industry Cost for SIR Implementation (I):

All plants (review and evaluation)		
Labor = (11 man-wks)($2270/man-wk)	=	$25,000
10% of plants (hardware modifications)		
Labor = (9 man-wks)($2270/man-wk)	=	$20,400
Hardware	=	48,000
Total	=	$68,400

8. Total Industry Cost for SIR Implementation (NI):

NI = (134 plants)($25,000/plant) + (14 plants)($68,400/plant)

= $4.3E+6

9. Per-Plant Industry Labor for SIR Operation and Maintenance:

All plants:
Labor = 0.2 man-wk/py for periodic review of main transformer procedures, operations, and maintenance

Plants requiring hardware modifications:
Labor = 1.0 man-wk/py for periodic maintenance/inspection of drains and new diked areas; removal of trash from drains; etc.

Improvements to the reliability of main transformers and improvements to the fire protection systems could potentially result in avoided costs of replacing a transformer damaged by a fire. This avoided cost was estimated as follows. First, SIR improves the reliability of main transformers an amount equivalent to 0.023 failures per reactor-year. A review of LER data indicated that 14 main transformer failures (7 at ANO-1 and 7 at North Anna) resulted in 3 fires for a conditional probability of 0.2 that a main transformer failure results in a fire. Thus, the potential exists for avoidance of 0.005 main transformer fires/py. These avoided costs apply only to the 10% of the plants that were assumed to identify deficiencies in their fire protection systems. The remaining 90% of the plants are assumed to be adequately prepared to prevent serious damage to the transformers that would result from a fire. The estimated replacement costs for a large transformer is $14,000, including installation.

Avoided replacement power costs associated with reducing the number of reactor trips per year caused by main transformer failures were also addressed. As above, SIR is postulated to reduce the frequency of transformer failures by 0.023 failures/py. A review of the LER data showed that of the 14 main transformer failures at ANO-1 and North Anna, 5 resulted in reactor trips. This is a conditional probability of 0.36 that a main transformer failure results in a reactor trip. Assuming each shutdown lasts three days, the avoided replacement power days are equal to 0.025 days/py. Using an average replacement power cost of $3E+5/day (Andrews et al. 1983), the avoided annual costs are about $7.5E+3/py.

= $4.3E+6

9. Per-Plant Industry Labor for SIR Operation and Maintenance:

All plants:
Labor = 0.2 man-wk/py   for periodic review of main transformer procedures, operations, and maintenance

Plants requiring hardware modifications:
Labor = 1.0 man-wk/py   for periodic maintenance/inspection of drains and new diked areas; removal of trash from drains; etc.

Improvements to the reliability of main transformers and improvements to the fire protection systems could potentially result in avoided costs of replacing a transformer damaged by a fire. This avoided cost was estimated as follows. First, SIR improves the reliability of main transformers an amount equivalent to 0.023 failures per reactor-year. A review of LER data indicated that 14 main transformer failures (7 at ANO-1 and 7 at North Anna) resulted in 3 fires for a conditional probability of 0.2 that a main transformer failure results in a fire. Thus, the potential exists for avoidance of 0.005 main transformer fires/py. These avoided costs apply only to the 10% of the plants that were assumed to identify deficiencies in their fire protection systems. The remaining 90% of the plants are assumed to be adequately prepared to prevent serious damage to the transformers that would result from a fire. The estimated replacement costs for a large transformer is $14,000, including installation.

Avoided replacement power costs associated with reducing the number of reactor trips per year caused by main transformer failures were also addressed. As above, SIR is postulated to reduce the frequency of transformer failures by 0.023 failures/py. A review of the LER data showed that of the 14 main transformer failures at ANO-1 and North Anna, 5 resulted in reactor trips. This is a conditional probability of 0.36 that a main transformer failure results in a reactor trip. Assuming each shutdown lasts three days, the avoided replacement power days are equal to 0.025 days/py. Using an average replacement power cost of $3E+5/day (Andrews et al. 1983), the avoided annual costs are about $7.5E+3/py.

10. Per-Plant Industry Cost for Operation and Maintenance (I_o):

For all plants:
I_o = (0.2 man-wk/py)($2270/man-wk) = $450/py

For plants requiring hardware modifications:
I_o = (1.0 man-wk/py)($2270/man-wk) = $2270/py

Avoided costs for transformer replacement:
I_o = -(0.005 transformer fires/py)($14,000/transformer)
= -$70/py

Avoided replacement power costs:
I_o = -$7,500/py

Note: Negative sign (-) indicates avoided costs.

11. Total Industry Cost for SIR Operation and Maintenance (NTI_o):

NTI_o = (134 plants)($450/py)(28.3 py) + (14 plants)($2270/py)(28.3 py)
- (14 plants)(28.3 yr)($70/py) - (14 plants)(28.3 yr)($7,500/py)
= -$3.7E+5

12. Total Industry Cost (S_I):

Best Estimate	Upper Bound	Lower Bound
$3.9E+06	$6.1E+06	$1.7E+06

NRC Costs (Steps 13 through 21)

13. NRC Resources for SIR Development

The NRC costs for developing the SIR include four man-weeks to issue a generic letter or bulletin to the licensees (includes technical, legal, and administrative staff support) 6 man-months to review licensee responses to the letter, assess the differences between plant designs, and research potential implementation measures (assumed to be provided by a contractor), and 4 man-wks of NRC technical staff labor to monitor the contractor. SIR development also includes issuance of revised design guidance to the licensees related to adequate main transformer designs and procedures. It is estimated that an additional 6 man-wks of NRC technical, legal, and administrative staff labor are needed to develop, approve, and issue the revised guidance.

14. Total NRC Cost for SIR Development (C_D):

Labor	(14 man-weeks)($2,270/man-week)	= $ 3.2E+04
Contract Support		+ 5.0E+04
C_D		= $ 8.2E+04

15. Per-Plant NRC Labor for Support of SIR Implementation:

NRC labor to support SIR implementation consists of reviewing utility plans to comply with the revised guidance plus an onsite inspection by resident inspectors to review the plans. The labor requirements are:

Review and approval of license's plans . .	. 2 man-wks/plant
Onsite inspection	. 0.4 man-wks/plant
Total .	. 2.4 man-wks/plant

16. Per-Plant NRC Cost for Support of SIR Implementation (C):

C = (2.4 man-wk/plant)($2270/man-wk) = $5.5E+03/plant

17. Total NRC Cost for Support of SIR Implementation (NC):

NC = (134 plants)($5.5E+03/plant) = $7.4E+05

18. Per-Plant NRC Labor for Review of SIR Operation and Maintenance:

NRC labor to review SIR operation and maintenance is assumed to be primarily integrated with other NRC inspection activities. However, additional labor is assumed to be needed for enhanced reviews of main transformer testing/maintenance programs, operability of the fire protection system, and the effectiveness of revised hardware configurations. The NRC labor requirements for these enhanced reviews are estimated at about 2 man-days per plant per year.

19. Per-Plant NRC Cost for Review of SIR Operation and Maintenance:

C_o = (0.4 man-wk/py)($2270/man-wk) = $908/py

20. Total NRC Cost for Review of SIR Operation and Maintenance ($N\bar{T}C_o$):

$N\bar{T}C_o$ = (134 plants)(28.3 yr)($908/py) = $3.4E+06

21. Total NRC Cost (S_N):

Best Estimate	Upper Bound	Lower Bound
$4.2E+06	$5.9E+06	$2.5E+06

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ISSUE 107: MAIN TRANSFORMER FAILURES

DESCRIPTION

Historical Background

This issue was identified in a DL memorandum[1183] which called for an assessment of the high failure frequency of main transformers and the resultant safety implications. Concern for this issue arose when the North Anna Power Station had seven main transformer failures in 26 months; five of these resulted in reactor trips. Of the seven failures, three included rupture of a transformer tank with two fires occurring. One of the fires spread beyond the transformer bay to the turbine bay. In a report[1184] prepared for the NRC by LLNL, it was concluded that there was a possibility of generic implications arising out of the plant-specific failures reported for the North Anna units.

The potential generic concerns identified in the LLNL report include the fire protection system, overhead conductor/buses, cable trays, storage of flammable materials, and oil-filled transformers in general. In addition, certain secondry aspects of the transformer failures were identified which include cascading effects, extensive electrical/mechanical damage, and missiles/explosions, although the LLNL report noted that these latter items appear to be either indirectly or remotely related to specific safety-significant concerns.

Current NRC regulations and guidance pertaining to fire protection and some of the generic concerns raised in the LLNL report[1184] are embodied in 10 CFR 50 Appendix R, the SRP,[11] and Regulatory Guide 1.120.[1185] This analysis evaluated the need for additional actions by the licensees to prevent main transformer failures and to reduce the resultant risk.

Safety Significance

Safety-related loads in nuclear power plants are supplied from buses that can be supplied from any one of the following sources: (1) the unit auxiliary (main) transformer; (2) the startup transformer (or reserve auxiliary transformer); or (3) the emergency onsite power supply (i.e., diesel generators). A main transformer failure will result in a loss of load or unbalanced load on the main generator. This would lead to turbine/generator trip and power would not be available to the unit transformers for the station power; however, station power can be obtained from the grid through the startup transformer or from emergency onsite power sources. Switchyards have redundant systems to provide sufficient relaying and circuit breakers so a transformer failure is not expected to cause a loss of offsite power.

Other generic concerns associated with this issue include: (1) oil from a ruptured transformer will float on the water delivered to extinguish the fire by the fire protection system such that the fire will move in the direction of drainage; (2) the fire may propagate to overhead cables and buses and create the need for access to adjacent locations (such as building roofs) by fire-fighting crews.

Possible Solutions

Resolution of this issue could involve the following actions:

(1) Evaluation of main transformer design and arrangements by licensees to ensure that the supply of offsite power is protected against transformer fires and smoke. Design requirements should be established for routing and separation of offsite power source feeds to protect against power loss due to a transformer fire.

(2) Review of fire protection system features for the main transformers for adequacy and revision, as necessary, to ensure that a potential fire is prevented from spreading to other plant areas. The review should address the deluge system, drainage system, fire barriers, and fire fighting equipment and procedures.

(3) Review of maintenance and operating procedures for the main transformers for adequacy and revision, as necessary.

(4) Modification of drainage systems, if necessary, to provide drains for each transformer so that liquids flow away from the turbine building, power lines, and safety-related cables to the reactor and related safety equipment. Modifications could include adding drains, building dikes and sloping the transformer yard away from buildings and other transformers.

(5) Modification of fire-fighting equipment and procedures, if necessary. This may include longer hoses, increased ease of access to building roofs, mobility of fire-fighting equipment, and training for personnel.

(6) Relocation of power lines to the safety-related buses, if necessary, so that they would not be affected by a fire in the transformer bay.

PRIORITY DETERMINATION

To establish the priority of this issue, the potential reduction in the plant core-melt frequency as the result of improved main transformer reliability due to implementation of the proposed resolutions was quantified. It was believed that improved reliability of main transformers will reduce the frequency of transients induced due to the main transformer failures, thus leading to enhanced plant safety.

Frequency Estimate

In the representative plant PRAs (Oconee 3 for PWRs and Grand Gulf 1 for BWRs), main transformer failures are integrated into a category of transients that result from loss of network load. The affected PRA parameters are transients other than loss of offsite power requiring or resulting in a reactor shutdown, i.e. T_2 (frequency of 3/RY) and T_{23} (frequency of 7/RY) for Oconee and Grand Gulf, respectively. It was assumed that implementation of the possible solutions will enhance the reliability of main transformers and thus reduce the frequency of the resultant transients.

Data in NUREG/CR-3862[1186] on a specific transient category, characterized as a loss of incoming power to a plant as a result of onsite failure (such as main

transformer failure), suggest that the transient frequency associated with this category is 0.02 event/RY. In addition, the IEEE reliability data for liquid-filled transformers (347 to 550 KVA) at nuclear power plants indicate that the main transformer failure rate due to all causes was 2.67/million-hours. This corresponded to an annual frequency of 0.023 failure/year for main power generator or unit transformers. This value was used as the base case for the failure frequency of main transformers. The second aspect of the main transformer failure, the risk from resulting fire, was determined to be insignificant and was not analyzed further. This conclusion was based on the findings of the Oconee 3 PRA which included the analysis of fires and their potential for causing failures of redundant safety-related components. Also, no particular sensitivity to main transformer fires was identified in NUREG/CR-5088.[1211]

It was assumed that implementation of the possible solutions (i.e., no design improvements to the transformer but improved maintenance and mitigative designs/procedures) would increase the reliability of main transformers by 50%. Therefore, the adjusted case main transformer failure frequency was estimated to be 0.01 event/RY. In addition, the adjusted case frequencies of the resultant transients (T_2 and T_{23}) were estimated as follows:

$$T_2 = (3 - 0.01)/RY$$
$$= 2.99/RY$$

$$T_{23} = (7 - 0.01)/RY$$
$$= 6.99/RY$$

Incorporating these values in the Oconee 3 and Grand Gulf 1 PRAs provide reductions in core-melt frequency estimates of 1.4×10^{-7}/RY for PWRs and 3.6×10^{-8}/RY for BWRs.

Consequence Estimate

This issue was assumed to be pertinent to all LWRs and thus had an affected population of 90 PWRs and 44 BWRs with average remaining lifetimes of 28.8 years and 27.4 years, respectively. Based on the Oconee and Grand Gulf PRAs, the associated public risk reduction was estimated to be 0.38 man-rem/RY and 0.25 man-rem/RY for PWRs and BWRs, respectively. Thus, the average public risk reduction associated with this issue was 9.6 man-rem/plant.

Cost Estimate

Industry Cost: Implementation of the possible solutions at the affected plants would require review of existing systems and procedures and hardware changes. It was estimated that the review of the existing systems and procedures will require 15 man-weeks/plant at $2,270/man-week. These efforts include evaluation of the fire protection systems, review of protective circuitry, review of operating and maintenance procedures, revision of operating and maintenance procedures, and revision of staff training. It was also assumed that, as a result of these reviews, about 10% of all affected plants will require hardware changes, modifications to fire protection systems, and rerouting of cables around the main transformer areas. It was estimated that it will require 9 man-weeks to prepare the design modifications and acceptance testing plan, install and test hardware changes, and revise procedures. Hardware and labor were estimated to

cost $48,000/plant to provide the following: additional drains, gravel, and concrete to slope the area around the transformers and construct dikes; additional power lines to route power to the buildings; additional breakers to protect equipment connected to the auxiliary transformers; and longer fire hoses. The cost was itemized as follows:

Dike (250 ft. long, 4 ft. high)	=	$ 3,750
Concrete and Gravel	=	$15,800
Power lines (1,000 ft)	=	$ 5,000
Breakers (2 at $2500 each)	=	$ 5,000
Fire Hose/Storage Cabinet (110 ft)	=	$ 500

Note: An escalation factor of 1.8 was used by PNL to convert 1982 dollar values to 1988. Therefore, the cost to implement the possible solutions at 90% of the plants was about $30,000/plant; for the remaining 10%, the cost was estimated to be $100,000/plant. The average cost for the affected population was approximately $40,800/plant.

For the affected plants, periodic review of main transformer procedures, operations, and maintenance was estimated to require 0.2 man-week/RY. At a cost of $2270/man-week, this amounted to $450/RY. In addition, those plants requiring hardware modifications (10% of affected plants as discussed above) require 1 man-week/RY (or $2270/RY) for periodic maintenance/inspection of drains and new diked areas, removal of trash from drains, etc. Plant maintenance and operation costs are recurring costs and were adjusted for present worth at a 5% discount rate over the 28.3-year average remaining plant life for the 134 affected plants. This resulted in an average plant cost (present worth) of $11,200/plant.

It was believed that improvements to the reliability of main transformers and improvements to fire protection systems could potentially result in: (1) avoided costs of replacing a transformer damaged by fire (3 out of 14 transformer failures resulted in fire, or 0.002 main transformer failure/RY); and (2) avoided replacement power costs associated with reducing the number of reactor trips caused by main transformer failures.

<u>NRC Cost</u>: NRC costs consisted of initial regulatory development and the resources required in support of the regulatory implementation. The initial regulatory development cost could involve the issuance of a generic letter or bulletin to the licensees, review of licensee responses, other related activities (i.e., revised design guidance, assessment of differences in plant design related to transformers, development of potential implementation measures), and the required technical, legal, and administrative staff labor. This portion of resource requirements was estimated to require 40 man-weeks ($90,000) in addition to potential outside contractor support (estimated to cost $50,000) for a total of approximately $140,000. Averaging this over the 134 affected plants resulted in an approximate NRC cost of $1,000/plant.

The implementation resource requirements consist of NRC labor to review utility plans to comply with revised guidance and additional inspection and monitoring of transformer maintenance/testing programs during the routine NRC plant inspections. This was estimated to require $4.1M over the life of all affected

plants. These costs are also recurring costs and when adjusted for present worth, as indicated above, resulted in an average NRC cost (present worth) of $17,000/plant.

Total Cost: Summing the average costs per plant for licensee implementation, maintenance, and operation and the NRC costs for regulatory development and implementation resulted in a total cost of $70,000/plant to implement the possible solution to this issue.

Value/Impact Assessment

Based on an average public risk reduction of 9.6 man-rem/reactor and a cost of $70,000/reactor to implement the possible solutions, the value/impact score is given by:

$$S = \frac{9.6 \text{ man-rem/reactor}}{\$0.07\text{M/reactor}}$$

$$= 137 \text{ man-rem/\$M}$$

Other Considerations

(1) Implementation of the possible solutions was assumed not to involve any labor in radiation zones because the main transformers are not located in a building in which radioactive materials are used or stored and thus the radiation dose rates are zero.

(2) The core-melt frequency reductions of 1.4×10^{-7}/RY for PWRs and 3.6×10^{-8}/RY for BWRs results in ORE avoidance associated with core-melt cleanup operations of 20,000 man-rem/core-melt.[64] The accident avoidance over the remaining plant life is $[(28.8)(90)(1.4 \times 10^{-7}/RY) + (27.4)(44)(3.6 \times 10^{-8}/RY)]$ (20,000)/134 or 0.06 man-rem/plant. The present worth cost of a core-melt accident is estimated at $1.65 billion considering cleanup and replacement power cost over a ten-year period.[64] The present worth of accident avoidance at each plant is estimated to be $[(28.8)(1.4 \times 10^{-7}/RY)(90) + (27.4)(3.6 \times 10^{-8}/RY)(44)]$ ($1,650M)/134 or $5,000.

(3) Current designs of operating nuclear power plants incorporate various independent means of supplying loads so that main transformer failures will not cause a total loss of offsite power. In addition, the promulgation of the station blackout rule (10 CFR 50.63) should further reduce the risk from loss of AC power from that considered in the Oconee 3 and Grand Gulf 1 PRAs.

(4) It was believed that implementation of the possible solutions could be accomplished during normal plant outages and would not require design modifications or work in radiation zones. The relatively high failure frequency of the main transformers at the North Anna plant highlighted a possible need for plant-specific evaluations by some licensees to review their main transformers and to implement an appropriate combination of the alternatives proposed in order to enhance safety.

CONCLUSION

Based on the above value/impact score, this issue was on the borderline between a low and medium priority for existing plants. However, it was believed that the risk estimates were high (because the effect of the station blackout rule was not included in the Oconee 3 and Grand Gulf 1 PRAs). Therefore, this issue was given a LOW priority ranking for existing plants.

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