GPU Nuclear

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TMI-2
DIVISION
TECHNICAL EVALUATION REPORT
FOR

Defueling Canisters

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Title

TER for Defueling Canisters

Rev.	SUMMARY OF CHANGE
0	Issued for Initial Use
1	Update to incorporate design change from vibrapacked B_4C powder to sintered B_4C pellets, discussion of maximum particle size expected in filter canister, increase in load limit on fuel canister lower support plate from 350 to 550 lbs, addition of k_{eff} criteria for plant accident condition ($\leq$ 0.99), discussion of effects on criticality analyses caused by a) change to B_4C pellets, b) lower storage pool water temperature, and c) fuel particle size, addition of section regarding hydrogen controls within the canister.

SHEET	LATEST REV.	SHEET	LATEST REV.	SHEET	LATEST REV.	SHEET	LATEST REV.	SHEET	LATEST REV.	SHEET	LATEST REV.	SHEET	LATEST REV.
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REVISION STATUS SHEET

BECHTEL

DOCUMENT TITLE: Technical Evaluation Report for Defueling Canisters

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1.0 Introduction

Canisters are required during the defueling at TMI-2 to retain core debris ranging from very small fines to partial length fuel assemblies. These canisters provide effective long term storage of the TMI-2 core debris. Three types of canisters are required to support the defueling system to be used at TMI-2: filter, knockout, and fuel canisters.

1.1 Purpose

The purpose of this report is to show that the canisters are designed to remain safe under normal operation and handling conditions as well as postulated drop accidents and storage. Section 2.0 of this report describes the three types of canisters. Section 3.0 addresses the safety of the canister design considering design drop analyses and drop tests and criticality analyses. Requirements for spacing of the canisters in an array under normal conditions are also addressed. Section 4.0 outlines the radiological concerns associated with the handling and storage of the canisters. Section 5.0 draws conclusions about the safe operation and handling of the canisters.

1.2 Scope

This report addresses only those safety issues associated with the loading, handling and storage of the canisters as related to canister design. Analyses of the design drop considers only the effect of that drop on a canister; damage to other components is not considered. Actual handling of the canisters is not addressed in this report and neither are the shielding requirements for canister handling with the exception that the criticality concern associated with the use of lead shields around the canisters is addressed in Attachment 1. Also, the criticality concern associated with a drained spent fuel pool is addressed in Attachment 2. Canister performance during defueling is addressed here only as it impacts the safe use of the canister. Canister interfaces with the defueling equipment, canister handling equipment and the fuel transfer system are not covered in this report. The issues related to canister use (e.g. shielding requirements, load drops, etc.) are evaluated in the Safety Evaluation Report for Early Defueling of the TMI-2 Reactor Vessel (reference 3). The transportation requirements for the canisters will be separately addressed.

2.0 Canister Description

This section presents the designs of three canisters to be used in defueling TMI-2. Compatible with the RCS and spent fuel pool environment, these canisters provide long term storage of the TMI-2 core debris. In conjunction with the defueling system, the canisters will retain and encapsulate debris ranging from micron size particles to partial length fuel assemblies.

The canisters consist of a circular pressure vessel housing one of three types of internals, depending on the function of the canister. Except for the top closures, the outer shell is the same for all three types of canister design. It serves as a pressure vessel protecting against leakage of the canister contents as well as providing structural support for the neutron absorbing materials. It is designed to withstand the pressures associated with normal operating conditions. A reversed dish end is used for the lower closure head for all of the canisters while the upper closure head design varies according to the canister's function. The canisters are non-buoyant under all storage and operational conditions.

Each canister contains a recombiner catalyst package incorporated into the upper and lower heads. The catalyst recombines the hydrogen and oxygen gases formed by radiolytic decomposition of water in the canisters.

Each canister has two pressure relief valves which are connected to the canisters using Hansen quick disconnect couplings. The low pressure relief valve has a pressure setpoint of 25 psig. The high pressure ASME code relief valve has a 150 psig setpoint.

2.1 Codes and Standards

The defueling canisters have been classified as Nuclear Safety Related for criticality control purposes.

Th y are designed and designated for fabrication in accordance with the following codes and standards:

ANSI/ANS 8.1 (1983)	American National Standards Institute/ American National Standard, Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors
ANSI/ANS 8.17 (1984)	American National Standards Institute/ American National Standard, Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR Fuel Outside Reactors
ANSI N45.2 (1977)	American National Standards Institute, Quality Assurance Program Requirements for Nuclear Power Plants

ANSI N45.2.2 (1972)	American National Standards Institute, Packaging, Shipping, Receiving, Storage, and Handling of Items for Nuclear Power Plants
ANSI N45.2.11 (1974)	American National Standards Institute, Quality Assurance Requirements for the Design of Nuclear Power Plants
ANSI N45.2.13 (1976)	American National Standards Institute, Quality Assurance Requirements for Control of Procurement of Items and Services for Nuclear Power Plants
ANSI/ASME NQA-1 (1979) Appendix 17A-1 (including ANSI/ASME NQA-1a-1981 Addenda)	Quality Assurance Program Requirements for Nuclear Power Plants, Nonmandatory Guidance on Quality Assurance Records
ANSI/ASME NQA-1 (1979) Supplement 17S-1 (including ANSI/ASME NQA-1a-1981 Addenda)	Quality Assurance Program Requirements for Nuclear Power Plants, Supplementary Requirements for Quality Assurance Records
ASME Boiler and Pressure Vessel Code, Section VIII, Part UW (lethal) (1983)	American Society of Mechanical Engineers, Pressure Vessels
ASME Boiler and Pressure Vessel Code, Section IX (1980)	American Society of Mechanical Engineers, Welding and Brazing Qualifications
ASTM A 312 (1982)	American Society for Testing and Materials, Seamless and Welded Austenitic Stainless Steel Pipe
SNT-TC-1A (1980)	American Society for Nondestructive Testing, Recommended Practice for Nondestrutive Testing, Personnel Qualification and Certification
10 CFR 21	Reporting of Defects and Noncompliance
10 CFR 50, Appendix A	General Design Criteria for Nuclear Power Plants
10 CFR 50, Appendix B	Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants
10 CFR 72	Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation
NUREG-0612	Control of Heavy Loads at Nuclear Power Plants

2.2 Fuel Canister

The fuel canister is a receptacle for large pieces of core debris to be picked up and placed in the canister. The fuel canister consists of a cylindrical pressure vessel with a flat upper closure head. It uses the same outer shell as the other canisters. Within the shell, a full length square shroud forms the internal cavity (see Figure 2.2-1). This shroud is supported at the top by a bulkhead that mates with the upper closure head (see Figure 2.2-2). Both the shroud and core debris rest on a support plate that is welded to the shell. The support plate has impact plates attached to absorb canister drop loads and payload drop loads.

The shroud assembly consists of a pair of concentric square stainless steel plates seal welded to completely enclose four sheets of Boral, a neutron absorbing material (see Figure 2.2-1). The shroud internal dimensions are larger than the cross section of an undamaged fuel assembly. The shroud external dimensions are slightly smaller than the inner diameter of the canister, thus providing support at the shroud corners for lateral loads. The void area outside of the shroud is filled with a cement/glass bead mixture to the maximum extent practical to eliminate migration of the debris to an area outside of the shroud during a design basis accident.

The upper closure head is attached to the canister by eight equally spaced bolts. These bolts are designed for the design pressure loads, handling loads, and postulated impact force due to shifting of the canister contents during an in-plant load drop or a shipping accident.

2.3 Knockout Canister

Designed to separate debris ranging in size from 140 microns up to approximately the size of whole fuel pellets (whole fuel pellets included), the knockout canister, Figure 2.3-1, is part of the Fines/Debris Vacuum System. The influent comes directly from the defueling vacuum system inside the reactor while the outlet flow goes to a filter canister for further treatment. Flow fittings are 2" cam and groove type similar to the filter canister fittings and are capped or plugged after use. Externally, the knockout canister is similar to the other canisters, using the same outer shell design. It also incorporates the same handling tool interface.

The internals module for the knockout canister is supported from a lower header welded to the outer shell. An array of four outer neutron absorber rods around a central neutron absorber rod is located in the canister for criticality control. The four outer rods are 1.315" O.D. tubes filled with sintered B_4C pellets.

The central absorber rod is comprised of an outer strongback tube surrounding a 2.125" O.D. tube filled with sintered B_4C pellets. Lateral support for the neutron absorber rods and center assembly is provided by intermediate support plates.

The influent flow is directed tangentially along the inner diameter of the shell, setting up a swirling action of the water within the canister. The large particulates settle out and the water moves upwards, exiting the canister through a machined outlet in the head. A full flow screen ensures that particles larger than 850 microns will not escape from the knockout canister. This screen has been designed to withstand the maximum pressure differential across the screen that can be developed by the vacuum system equipment.

2.4 Filter Canister

As part of either the Defueling Water Cleanup System or the Fines/Debris Vacuum System, the filter canisters are designed to remove small debris particles from the water. Externally, it is similar to the other canister types. The filter assembly bundle that fits inside the canister shell was designed to remove particulates down to 0.5 (nominal) microns. Flow into and out of the filter canister is through 2 1/2" cam and groove quick disconnect fittings (Figure 2.4-1).

The internal filter assembly bundle consists of a circular cluster of 17 filter elements, a drain line and a neutron absorber assembly (Figure 2.4-2). The influent enters the upper plenum region, flows down past the support plate, through the filter media and down the filter element drain tube to the lower sump. The flow is from outside to inside with the particulate remaining around the outer perimeter of the filter elements. The filtered water exits the canister via the drain line.

A filter element consists of 11 modules. Each module consists of pleated filter media forming an annulus around a central, perforated drain tube (Figure 2.4-3). Fabricated from a porous stainless steel material, the media is pre-coated with a sintered metal powder to control pore size. Bands are placed around the outer perimeter of the pleated filter media to restrict the unfolding of the pleats.

The filter assembly bundle is held in place by an upper support plate and lower header. The lower header is welded to the outer shell of the canister to provide a boundary between the primary and secondary side of the filter system. The upper header is equipped with a series of openings to allow for the passage of the influent into the filter section of the canister and to protect the filter media from direct impingement of particles carried in the influent flow. Six tie rods position the upper plate axially relative to the lower support plate.

The filter canister has a central neutron absorber rod that is comprised of an outer strong back tube surrounding a 2.125" O.D. tube filled with sintered B_4C pellets.

The filter canisters are not expected to contain significant quantities of fuel particles larger than 850 microns. The filter canisters are used with the defueling water cleanup system (DWCS)

and the defueling vacuum system. The DWCS is used to process both spent fuel pool/fuel transfer canal water and reactor coolant system (RCS) water. In the RCS, the DWCS suction is located in the upper region of the reactor vessel, where large fuel debris (i.e., > 850μ) would not be expected to be suspended in solution. The spent fuel pool/fuel transfer canal is not expected to contain significant quantities of fuel particles larger than 850 microns. Consequently, the DWCS filter canisters are not expected to contain significant quantities of fuel particles larger than 850 microns.

When the filter canisters are used in conjunction with the defueling vacuum system, they are located downstream of the knockout canisters. Proof of principle testing (Reference 11) has shown that for the planned vacuum system flowrates, minimal quantities, if any, of 850 micron or larger sized particles would be carried out of the knockout canister. Additionally, the discharge of the knockout canisters are equipped with a 841 micron screen to prevent larger fuel particles from exiting the knockout canister. Thus the vacuum system filter canisters are not expected to contain significant quantities of fuel particles larger than 850 microns.

Figure 2.2-1

Fuel Canister

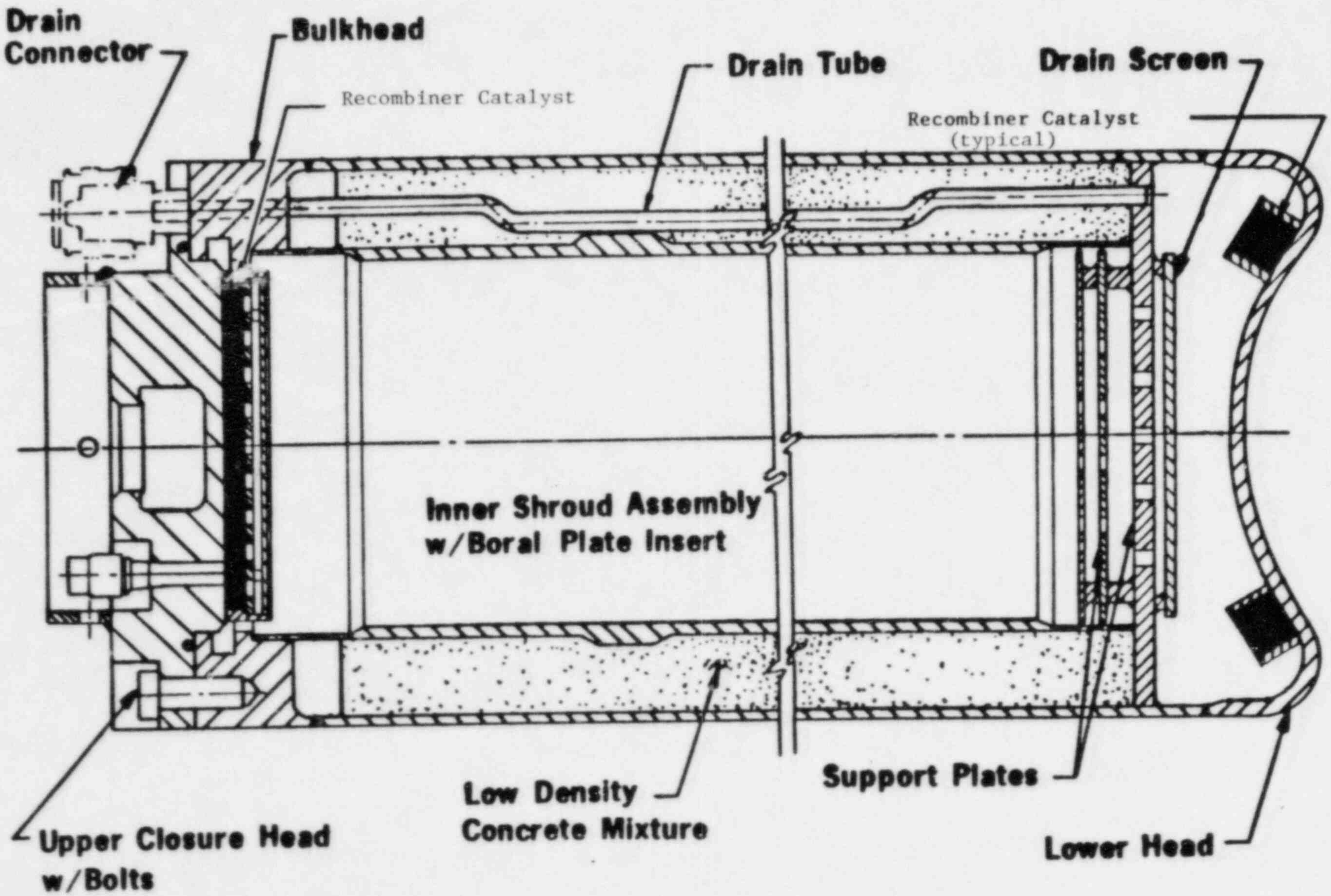

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Figure 2.2-2

Fuel Canister Bulkhead View

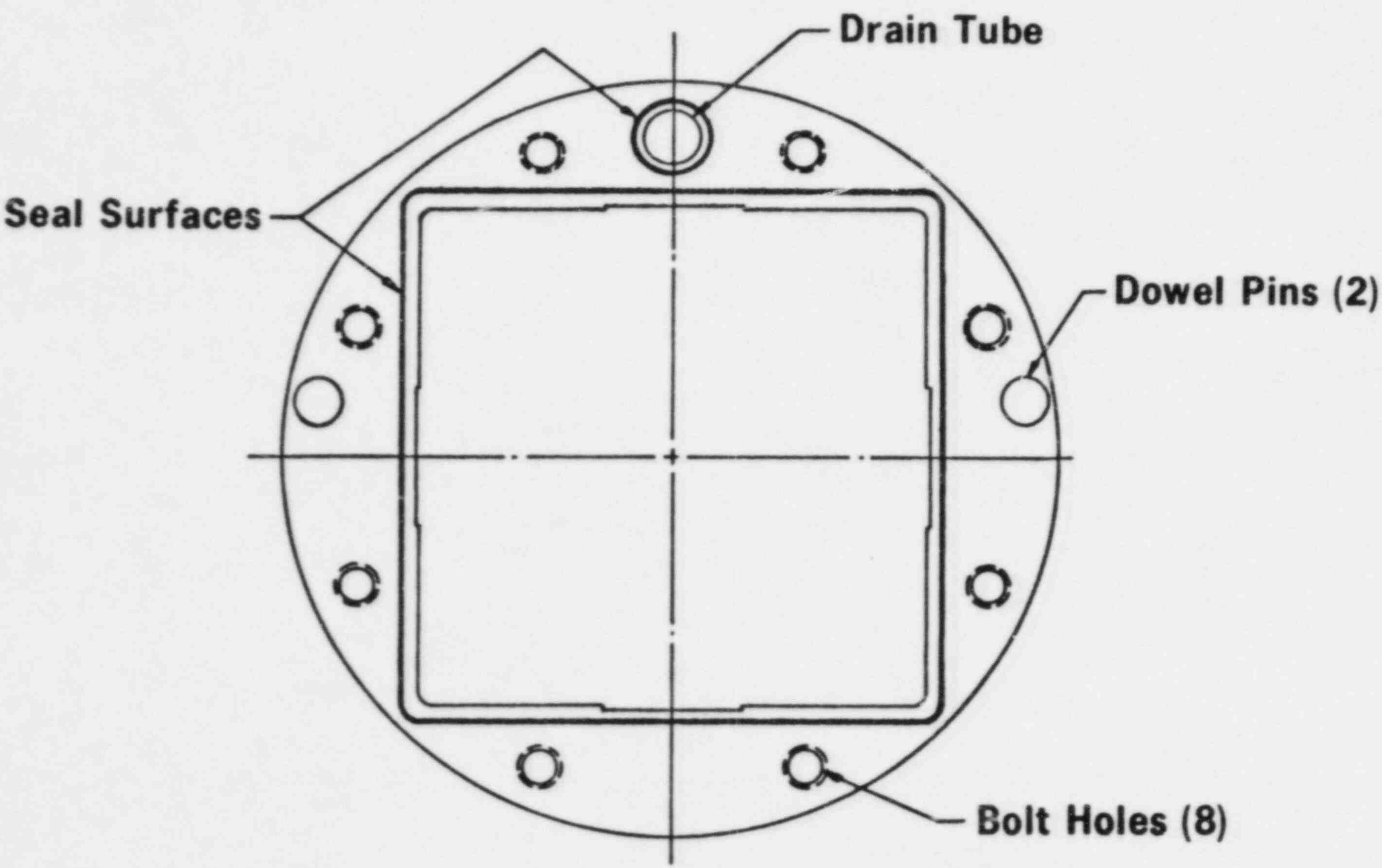
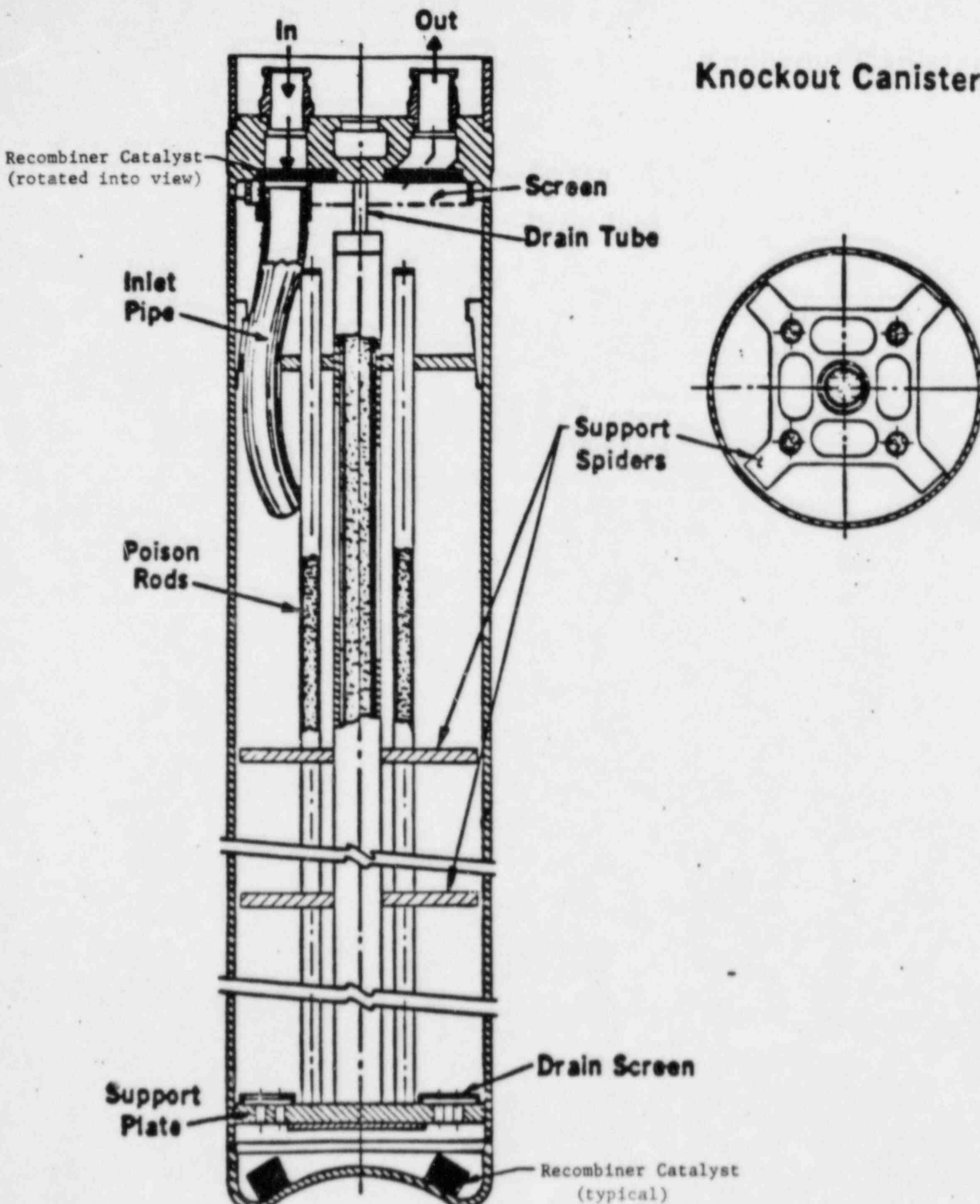


Figure 2.3-1



In
Out
Knockout Canister
Recombiner Catalyst (rotated into view)
Screen
Drain Tube
Inlet Pipe
Support Spiders
Poison Rods
Drain Screen
Support Plate
Recombiner Catalyst (typical)

Figure 2.4-1

Filter Canister

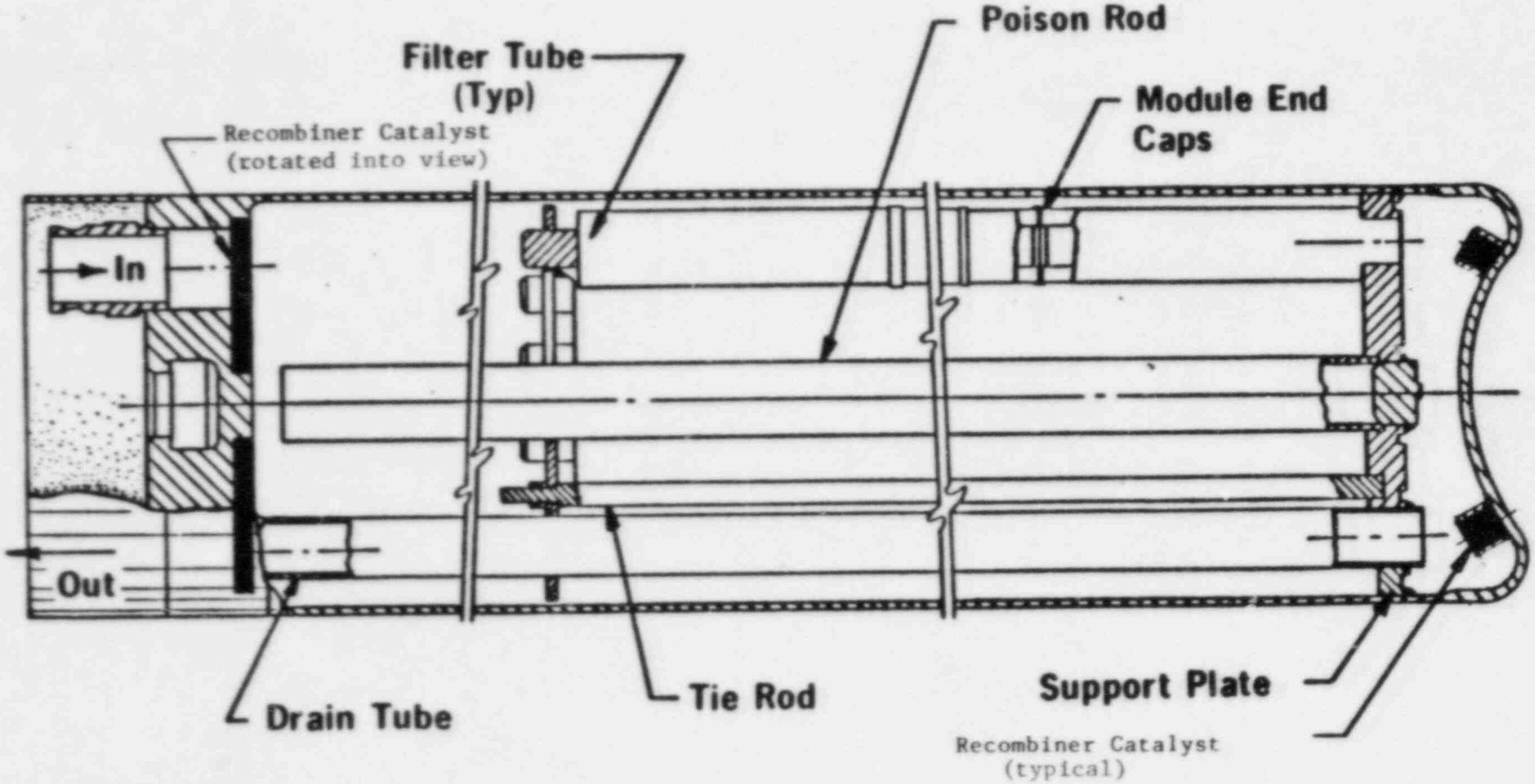


Figure 2.4-2

Filter Canister - Cross-Section at Mid-Plane

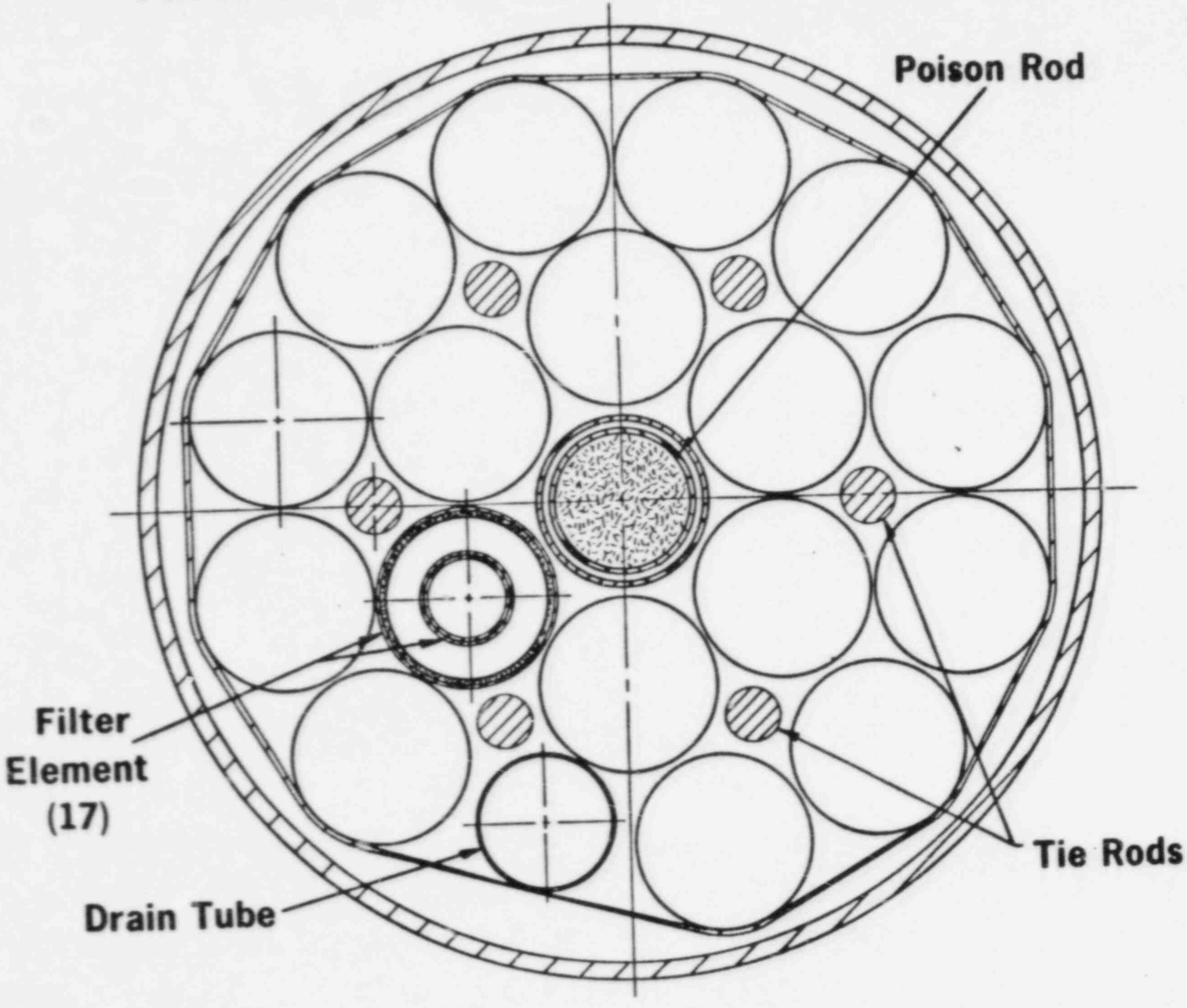
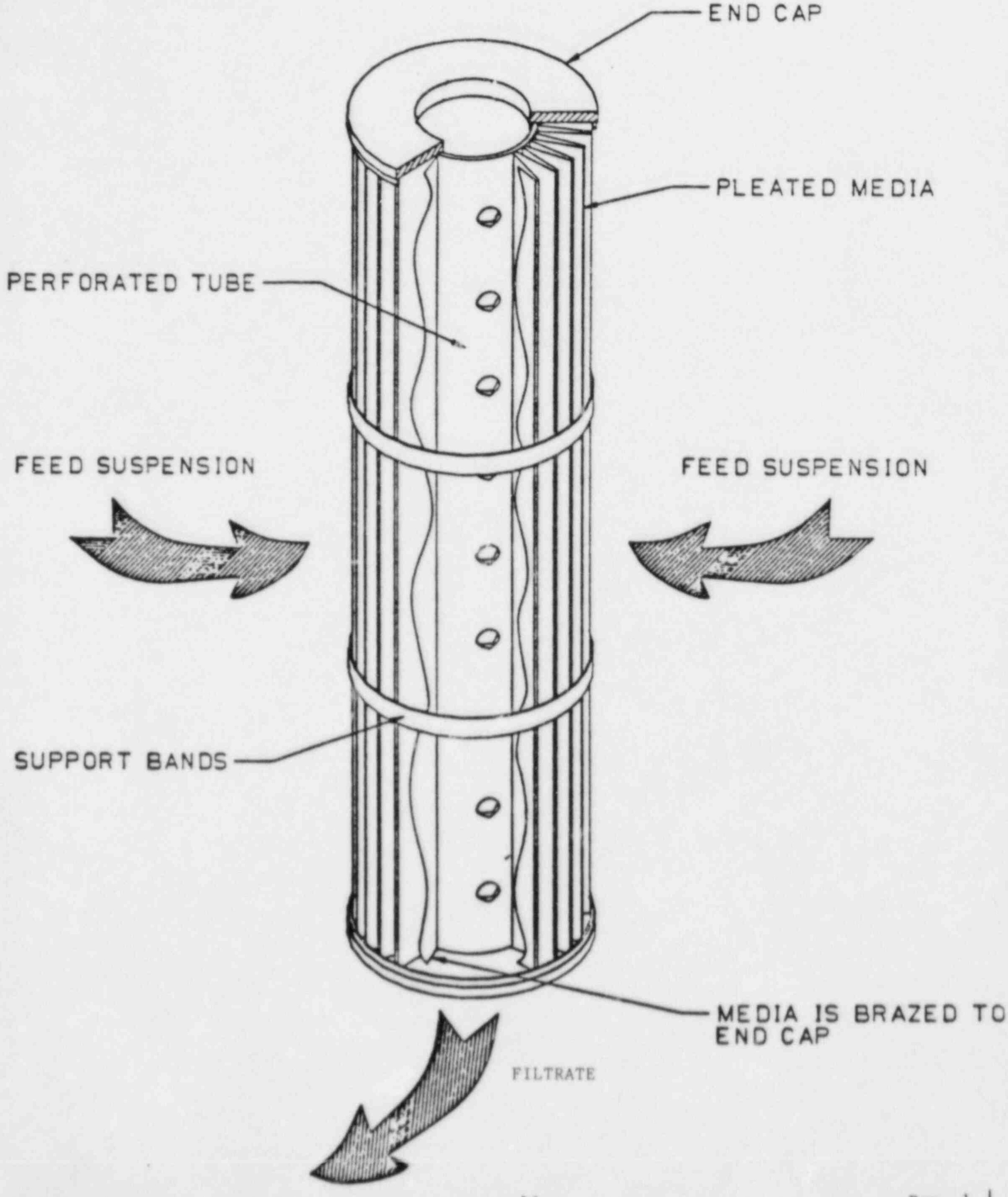


Figure 2.4-3

Filter Module



3.0 Technical Evaluation

This section summarizes the safety issues which were evaluated during the design of the canisters. These issues deal with the expected performance of the canisters during normal operations and various design basis events. Safety issues which were evaluated include structural forces on a canister as a result of a drop accident, criticality issues associated with both single canisters and canisters in the storage racks and the canister/storage rack interface, including any constraints on the storage rack design.

3.1 Canister Structural Evaluation

A structural evaluation has been performed (Reference 1) which addresses both the loads imposed on the canister during normal operations (loading and handling) as well as postulated drops.

A combination of analytical methods and component testing is used to verify the adequacy of the design. Acceptance criteria for normal operation is based on the ASME Pressure Vessel Code, Section VIII, Part UW (lethal).

Normal operation of the canister imposes very small loads on the canister internals. The largest load on the internals is the combined weight of the debris and internals. The configuration of the canisters is such that only the lower plate assembly that supports both the debris and internals experiences any significant loads. Results of the stress analysis shows a large margin of safety for the lower plate assembly and its weld to the outer shell for all canister types. The canister shell is subject to ASME Code, Section VIII standards. Verification of the canister shell structural design to the ASME requirements has been performed (Reference 1). The canisters are designed for a combined (canister, debris, and water) static weight of 3500 pounds.

During normal handling operations (lifting), the static plus dynamic loading considered in the design of the handling features of the canister is 1.15 times the static lifted weight. Results from the structural evaluation show an acceptable margin of safety considering the stress design factors specified in NUREG-0612 and ANSI N14.6.

Normal loading of the fuel canister presents two cases for evaluation. First is the capability of the lower support plate to absorb the impact of debris accidently dropped into the canister. Results of the dynamic impact evaluation show that the support plate can accommodate loads of up to 350 lbs (23% of a fuel assembly) dropped, in air, the full canister length without a failure of the lower plate to shell weld. This weight limit increases to 550 lbs. (in air weight) if credit is taken for the drag forces of the water in the canister. Second is the verification that placement of

debris within the canister will not rupture the shroud's inner wall. This would expose the Boral sheets to the RCS water which could cause corrosion of the boral. However, examination of the shrouds subjected to drop tests (reference 10) indicate that the inner wall is resistant to debris impacts and scrapes.

A dewatering system is used to remove water from all canisters prior to shipment. During this procedure, a pressure differential is developed across the debris screen, lower support plate and drain tube. The maximum pressure differential allowed, via a safety relief valve in the dewatering system, across canister internal components during dewatering is 55 psi. The canister internals are designed for a maximum differential pressure of 150 psi although filter media differential pressure is limited by design to 60 psid. Hence, an adequate margin of safety exists for the dewatering process.

The canisters are capable of withstanding enveloping accidents. Vertical drops of 6'-1 1/2" in air followed by 19'-6" in water, or 11'-7" in air are considered along with a combination of vertical and horizontal drops. These drops were analyzed to bound a drop in any orientation. For these cases, the structural integrity of the poison components must be maintained and the canister must remain subcritical. Deformation of the canister is acceptable. Although not expected based on the B&W drop test results, leakage of core material from the canister, up to its full contents, is allowed provided that the contents left in the canisters remain subcritical. An equivalent drop in air was calculated for the worst case and this equivalent air drop was used as the basis for the structural analysis. Structural analysis methods were used to determine the extent of the deformation of the shell and canister internals. Impact velocities were calculated for the specified canister drops. Based on these velocities, strain energy methods were used to compute the impact loads associated with the various postulated drops. Vector combinations of the horizontal and vertical components were used to determine the effect of a drop at any orientation.

In the vertical drop cases (reference 10), the same deformation will occur regardless of the canister type, since it is shell dependent. Test results from the actual canister drops have verified that for the bottom impact, all deformation occurs below the lower support plate in the lower head region. An upper bound shell deformation was computed using the ANSYS (Reference 5) computer code and the results are presented in Figure 3.1-1 along with the actual test results.

To determine the consequences of a vertical and horizontal drop on the filter and knockout canisters, their internals were analyzed with finite element methods using the ANSYS computer program. This analysis incorporated the actual non-linear properties of the material. Geometric constraints imposed by the shell were accounted for by limiting the displacement of the supports.

In the filter canister, criticality control is provided by the central B_4C poison rod coupled with the mass of steel in the filter element drain tubes and tie rods. Using the end caps of the filter modules as deflection limiters, the entire tube array deflection is limited to 1.6" under postulated accidents. This analysis is conservative because it does not take into account the 5 circumferential bands around the array or the viscosity of the filter cake bed, both of which would tend to maintain the standard spacing. Using the maximum calculated deformed geometry (before the array bounced back closer to its original position), the criticality criterion given in section 3.2 was met.

In the knockout canister, criticality control is provided by the central B_4C poison rod coupled with four absorber rods. Results from the structural analysis show that the poison rods remain essentially elastic during all postulated accidents and the maximum instantaneous displacements are less than 0.75 inch. As in the case of the filter canister, the resultant deformed geometry successfully met the criticality criterion given in section 3.2.

The fuel canisters, with their square-within-a circle geometry, exhibit different drop behavior than the other canisters. For both the vertical and side drops, the fuel canister internals will not experience significant deformations other than the shell deformations discussed above. Lightweight concrete filling the void between the square inner shroud and the circular outer shell provides continous lateral support to both the outer shell and the shroud. This results in a distributed loading function for horizontal drops resulting in no calculated deformation to the shroud shape. Testing has demonstrated that the lower support plate remains in place for design drops while supporting a mass equal to the shroud, payload and the concrete. The lack of significant deformation after a drop (reference 10) makes the criticality analysis for the standard design applicable to the drop cases as well.

3.2 Canister Criticality Evaluation

Criticality calculations were performed to ensure that individual canisters as well as an array of canisters will remain below the established k_{eff} criterion under normal and faulted conditions. The criticality safety criterion established is that no single canister or array of canisters shall have a k_{eff} greater than 0.95 during normal handling and storage at the TMI-2 site. For plant accidents (e.g., drained spent fuel pool), the criticality safety criterion established is a $k_{eff} \leq 0.99$. These criteria are satisfied for all canister configurations.

The computer codes used in this work were NULIF, NITAWL, XSDRNPM and KENOIV (References 6, 7, 8 and 9). The NULIF code was used primarily for fuel optimization studies in a 111 energy group representation. NITAWL and XSDRNPM were used for processing cross sections from the 123 group AMPX master cross section library.

NITAWL provides the resonance treatment and formats the cross section for use by either XSDRNPM or KENOIV. In most cases, XSDRNPM cell weighted cross sections were used in the KENOIV calculations but for some comparative fuel optimization runs the NITAWL output library was used directly by KENOIV.

The calculational models assume the following conditions for the canister contents:

1. Batch 3 fresh fuel only
2. Enrichment: batch 3 average + 2σ (highest core enrichment)
3. No cladding or core structural material
4. No soluble poison or control material from the core
5. Credible fuel size and optimal volume fraction and moderator density
6. Canister fuel regions are completely filled without weight restrictions
7. Uniform 50°F temperature
8. B-10 surface density was assumed to be 0.040 gm/cm^2 in the Boral used for the fuel canister. (Actual B-10 surface density will be 0.040 gm/cm^2 with a 95/95% confidence level in the testing to provide at least a 2σ margin.)
9. B_4C density used is the poison tubes for the filter and knockout canister was assumed to be 1.35 gm/cm^3 with the boron weight percent assumed to be 70%. (Actual B_4C density will be at least 1.38 gm/cm^3 with a boron weight percent meeting requirements for ASTM-C-750 Type 2 B_4C powder, minimum boron weight percent 73%.)

Optimization studies were performed to determine the value of these parameters. These optimization studies are presented in Reference 1 along with other parametric studies performed for special cases.

The KENO analysis employs a fuel model that bounds all debris loading configurations. Three basic configurations were analyzed for each canister: a single canister surrounded by water, an array of canisters in the storage pool and a disrupted canister model resulting from an enveloping drop. The standard canister configuration assumed that some minimum degree of damage could have occurred in the canisters during normal loading operations. All the canisters analyzed in an array were assumed to have this minimum damage. A 17.3" center-to-center spacing was analyzed for the array cases. The 17.3" center-to-center spacing accounts for all storage rack tolerances and is the minimum center-to-center spacing possible

for any two canisters. The canisters are assumed to be loaded with debris consisting of whole fuel pellets enriched to 2.98 w/o, optimally moderated with 50°F unborated water. This provides the most reactive fuel configuration possible for the canisters. Thus, the analysis will provide conservative results and bound any actual configuration including draining of the canisters during the dewatering operation. For accident conditions, it is assumed that optimized fuel is present in both normal fuel locations and in all void regions internal to the canister. Filling all void regions with fuel has the effect of adding fuel to the canister after a drop.

The canister shell, including the lower head, is identical for all three canisters. The cylindrical shell is modelled using the maximum shell OD of 14.093" and the nominal 0.25" wall thickness. The model explicitly describes the concave inner surface but squares off the rounded corners. This increases the volume of the lower head.

All three canisters contain catalytic material for hydrogen recombination in both the lower and upper head. This material and its structural supports are not included in the models. The volume occupied by these materials is replaced with fuel. In addition, the protective skirt and nozzles on the upper canister head are not modelled.

The storage rack cases assume the canisters are stored in unborated water with a 17.3" minimum center-to-center spacing. Sensitivity studies were performed on the nominal 18" center to center spacing to determine the effect of a canister dropped outside of the rack. These analysis show that $k_{eff} < 0.95$ for canisters dropped outside the rack as long as the side of the dropped canister does not come within 2" of the side of the nearest canister in the rack. This requirement is met by the storage rack design (Reference 2).

Three cases are examined for a dropped canister: a vertical drop, a horizontal drop and a combined vertical and horizontal drop. The shell deformation is essentially the same for all cases. For these drops, the cylindrical shell is assumed not to deform. Any deviation from the cylindrical shape would increase the surface to volume ratio and increase the neutron leakage from the system. In the lower head region of the shell, a tear drop shape expansion is assumed to occur. The bottom head is modelled as a flat plate with the internal components resting on it. To bound all drop cases, the canister was assumed to rotate during a drop and land on its head. A similar tear drop shape will result. Both of these cases were merged into a single model that assumes the tear drop deformation at both the top and bottom with the internals displaced to the flattened lower head surface. For the combined vertical-horizontal drop, the radial displacement of the internal components is combined with the double tear drop model. This drop model bounds any conceivable drop configuration by exceeding conservative stress estimates of deformation.

Results

The results of KENO, using basic three dimensional canister models are presented in Table 3-1. These results represent bounding values for any configuration of the canisters at TMI-2.

Basically, they show that for any configuration, the effective multiplication factor, with uncertainties included, will be less than 0.95. Due to the conservatism built into the models, the k_{eff} of any actual configuration will be less than these bounding values.

Three assumptions used in the analyses reported in Table 3-1 have been reevaluated. The affected assumptions are:

1. type of poison used in the filter and knockout canisters,

2. storage pool water temperature, and

3. fuel particle size.

The values reported in Table 3-1 for the filter and knockout canisters are based on the assumption that the poison tubes for the canisters are filled with vibrapacked B_4C powder. Actual fabricated filter and knockout canisters contain compressed sintered B_4C pellets. This change resulted in a small reduction to the diameter of the poison in the canisters which results in a small increase in the multiplication value (k_{eff}) of the two canister types. Based on analyses the increase in multiplication will not exceed 0.4% Δk.

The values reported in Table 3-1 assume a minimum temperature of 50°F for all canister types. For canisters stored in the spent fuel pool the temperature could be as low as 32°F. Explicit criticality array calculations were not performed at this lower temperature. Rather, an evaluation was performed to determine the maximum increase in multiplication due to cooling from 50°F to 32°F. The maximum change in multiplication was determined to be an increase of 0.1% Δk.

The results reported in Table 3-1 are also based on the assumption that no single fuel mass greater than a whole fuel pellet exists in the TMI-2 core. Examinations of the core have indicated that fuel melting may have occurred. To assess the impact of this possibility an evaluation was performed to determine the k_∞ for the most reactive batch 3 fuel particle size. The k_∞ for the large particle was only 0.07% Δk higher than the k_∞ for the standard whole pellet.

In conclusion, the changes in k_{eff} resulting from the three modified assumptions will not result in exceeding the k_{eff} criteria of 0.95 for the cases reported in Table 3-1.

3.3 Canister Hydrogen Control Evaluation

A generic feature of the canisters is the recombiner catalyst package incorporated into the upper and lower heads of all the canisters. The catalyst recombines the hydrogen and oxygen gases formed by radiolytic decomposition of the water trapped in the damp debris. This reduces the buildup of internal pressure in the canister and keeps the gases below the flammability limit. The redundant locations ensure that an adequate amount of catalyst is available for any canister orientation in which hydrogen might be generated (e.g., an accident which leaves a canister upside down). Test results (Reference 4) have shown that the catalyst will perform effectively when dripping wet, but not when submerged.

A total of 200 grams of catalyst is initially installed in each canister. Then extra catalyst is installed in the beds to fill remaining voids. The 200 gram quantity was determined from the catalyst tests run by RHO (Reference 4) which used 100 grams and a H_2/O_2 generator which simulated the maximum gas generation stated in the report of 0.076 liter/hr hydrogen. Additionally, the beds were designed to meet the shape and volume requirements established by the tested catalyst beds. A total of at least 200 grams of catalyst is installed in the canister in order to be assured that at least 100 grams is above the maximum water level for all canister orientations. At least 100 grams of catalyst is at either end of the canister and the bed arrangement at each end is symmetrical.

The maximum predicted gas generation rate in a canister has been determined by two separate models; (1) the maximum theoretical gas generation rate and (2) the maximum realistic gas generation rate. The maximum theoretical gas generation rate was determined by Rockwell Hanford Operations (RHO) in their document RHO-WM-EV-7 (GEND-051) for purpose of developing the catalytic recombiner bed design. The maximum realistic gas generation rates were determined by GPU for purposes of predicting canister internal pressures during periods when the canisters are water solid.

Both models are based on the Turner paper, "Radiolytic Decomposition of Water in Water-Moderated Reactors Under Accident Conditions", referenced in the RHO report. The basic relationship is:

$H_2 = (W)(F)(G)(r)\ 8.4 \times 10^{-3}$ liters/hour

where:
F = fraction of γ and β energy absorbed in water
G = H_2 generation value in moles/100 eV
r = ratio of peak to average decay heat energy in the fuel debris
W = ionizing radiation per canister (watts)
8.4×10^{-3} = unit conversions (L•ev/W.hr)

For the maximum theoretical generation, the above factors are maximized as follows:

- o W - the maximum quantity of fuel debris in any canister, not including residual water weight or weighing accuracy, is assumed. (W = 54.2)
- o F - The fraction of γ and β energy absorbed is conservatively high and large amounts of water are also assumed to be available for absorbtion which is in excess of what is possible in the canisters. (F = 0.2)
- o G - The hydrogen gas generation value is based on a) completely turbulent/boiling conditions when the radiolytic gases are instantly removed from the generation site and b) no build up of hydrogen overpressure which tends to retard radiolysis. (G = 0.44)
- o r - The ratio of peak-to-average decay heat energy in the fuel is based on the most active region of an undamaged core. This assumes the fuel is intact and not scattered to other regions. (r = 1.9)

For the maximum realistic generation of hydrogen and oxygen, the worst case realistic factors for the damaged TMI core are used as follows:

- o W - The maximum quantity of fuel debris expected in any canister is used which includes allowances for residual water and weighing accuracy. (W = 50)
- o F - The fraction of γ and β energy absorbed is based on the maximum amount of water possible in an actual canister. (F = 0.07)
- o G - The hydrogen gas generation value is based on the actual worst case core debris conditions expected in a canister which includes lower temperature, quiescent conditions. (G = 0.12)
- o r - The ratio of peak to average decay heat energy in the fuel debris is based on the worst case conditions in the damaged TMI core. (r = 1.4)

The resulting hydrogen/oxygen generation rates for the two models are:

	Max. Theoretical liter/hour	Max. Realistic liter/hour
H_2	7.6×10^{-2}	5.0×10^{-3}
O_2	3.8×10^{-2}	2.5×10^{-3}
Total	1.14×10^{-1}	7.5×10^{-3}

The generation of other gases was not considered. Since the amount of contaminants in the RCS is small, the generation of other gases from the radiolytic decomposition of these contaminants is not expected to be significant.

Using the maximum realistic gas generation rate of 0.0075 liters/hour and assuming no recombination or scavenging of oxygen, the 25 psig relief valve is estimated to first open in approximately 25 days for the worst case canister. Released gas will be vented through the pool water directly to the containment or fuel handling building and is such a small quantity that it will cause no combustion concerns in the atmosphere of these buildings.

To address the issue of canister pressurization resulting from failure of the 25 psig relief valve a second relief valve is installed on the canisters. This relief valve will ensure that canister pressure does not exceed the design limit of 150 psig. The additional relief valve will make the canister single failure proof with regards to pressurization. This second valve will also be installed in such a manner to eliminate common mode failure of the two pressure relief valves.

The recombiner catalyst is ineffective when it is under water. An evaluation has been performed to determine how long it takes an undewatered canister to reach 150 psig if the 25 psig relief valve fails closed. This time for the worst case canister is 139 days. A similar concern exists for the dewatered canister should a signficiant amount of oxygen scavenging occur and the 25 psig relief valve fails closed. Assuming no recombination, (i.e. complete oxygen scavenging) the canister will reach the design pressure in 4286 days for the worst case canister.

If the relief valve should fail open while the canisters are being stored there is the possibility that fuel debris can be released into the pool water. If contaminants are released into the pool the defueling water cleanup system (DWCS) can be used as necessary to limit the contamination level of the water. Hence, a failed open relief valve does not pose a safety concern. Additionally, given that it is planned, although not required, to dewater the canisters shortly after they are loaded, pressurization of the canisters caused by hydrogen/oxygen generation will be minimal and the relief valve is not expected to open.

Although not considered a credible event, the consequences of a hydrogen ignition inside a canister has been evaluated. The maximum pressure that can be reached inside a canister under normal conditions, because of the 25 psig relief valve, is approximately 42 psia. This pressure includes the 25 psig set pressure and 5 feet of water submergence. Under the assumption that the recombiner catalyst does not function properly, a flammable mixture of hydrogen and oxygen can accumulate within a canister. If an ignition of this mixture is postulated, an overpressurization of the canister could occur. The ultimate stresses will be reached for various canister components at the estimated pressures:

- o canister shell - 2160 psi
- o fuel canister bolts - 2900 psi
- o threaded connections - 2500 psi

Considering the large margin that exists between these pressures and the maximum, normal condition canister pressure (i.e., approximately a factor of 50), the overpressurization resulting from an ignition of hydrogen within the canister is not expected to affect the overall canister integrity.

Table 3-1 Results of 3D KENO Criticality Calculation

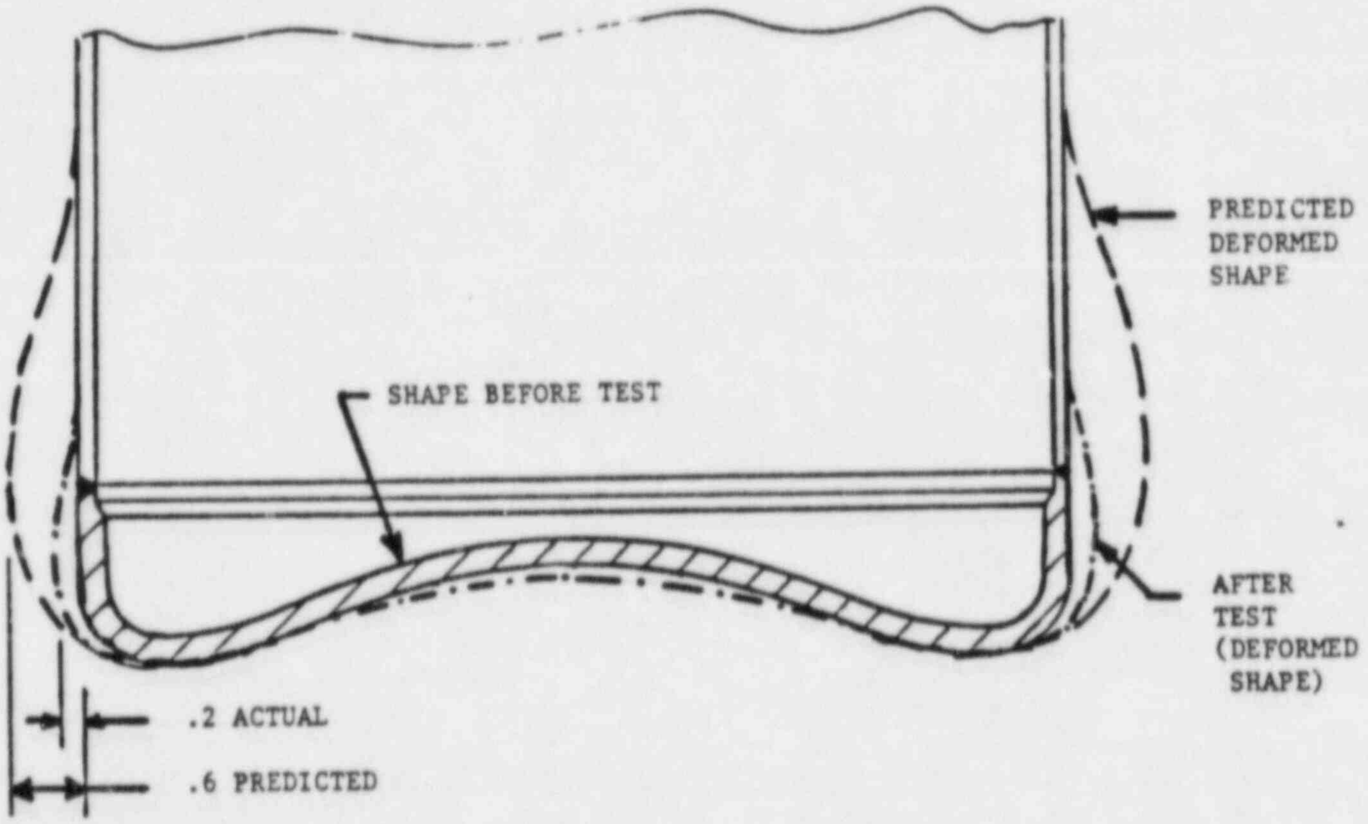
Description	$k_{eff}+2\sigma$	Histories	Maximum k_{eff}*
Filter Canister**			
Single, Ruptured Filters	0.795 ± 0.024	9331	0.839
17.3" Array, Ruptured Filters	0.823 ± 0.021	52374	0.867
Vertical Drop, Ruptured, without filter screens	0.798 ± 0.025	8127	0.843
Horizontal Drop, Ruptured, without screens	0.843 ± 0.010	15050	0.873
Combined Horizontal/Vertical Drop, Ruptured, without screens	0.851 ± 0.021	44849	0.892
Fuel Canister			
Single, Standard Configuration	0.825 ± 0.012	15050	0.857
17.3" Array, Standard Configuration	0.829 ± 0.025	6321	0.877
Knockout Canister**			
Single, Standard Configuration	0.835 ± 0.018	10535	0.873
17.3" Array, Standard Configuration	0.877 ± 0.015	11438	0.915
Vertical Drop, Single	0.843 ± 0.019	9933	0.882
Horizontal Drop, Single	0.853 ± 0.008	26488	0.881
Combined Horizontal/Veritical Drop, Single	0.851 ± 0.016	12943	0.887

*k_{eff} + 2σ + calculational bias (see Reference 1)

**results are based on vibrapacked B_4C powder in the poison tubes

Figure 3.1-1

SHELL DEFORMATIONS - VERTICAL DROP (ALL CANISTERS)



4.0 Radiological Considerations

The canisters are designed to be loaded with core debris from the TMI-2 RCS. These canisters do not contain internal shielding and must be shielded during all handling and storage operations.

The shielding requirements for the various canister operations (e.g. loading, handling, and storage) are discussed in reference 3.

Personnel exposure from the loaded canisters will be addressed in Reference 3 as part of the canister handling sequence.

5.0 10CFR 50.59 Evaluation

Changes, Tests and Experiments, 10CFR 50, paragraph 50.59, permits the holder of an operating license to make changes to the facility or perform a test or experiment, provided the change, test or experiment is determined not to be an unreviewed safety question and does not involve a modification of the plant technical specifications. A proposed change involves an unreviewed safety question if:

a) The probability of occurrence or the consequences of an accident or malfunction of equipment important to safety previously evaluated in the safety analysis report may be increased; or

b) the possibility for an accident or malfunction of a different type than any evaluated previously in the safety analysis report may be created; or

c) the margin of safety, as defined in the basis for any technical specification, is reduced.

The defueling canisters replace the fuel cladding lost during the accident as the barrier for containing the fuel. As discussed in Section 1.1 of this TER, the purpose of this evaluation is to show that the canisters are designed to remain safe under normal operation and handling conditions as well as postulated drop accidents and storage. The scope of the evaluation relates only to design aspects and not in field canister use which is addressed in the Safety Evaluation Report for Early Defueling of the TMI-2 Reactor Vessel (Reference 3). On this basis the scope of this 10 CFR 50.59 Evaluation is limited to design aspects of the canister.

The issues of concern with canister design are criticality control and overpressurization protection. With respect to criticality control, this evaluation shows that the canister will remain subcritical under any configuration or following structural deformation due to a load drop. With respect to overpressurization protection, two relief valves will be installed on each canister to prevent the possibility of a single failure or common mode failure from overpressurizing the canister. Thus, it can be concluded that the design of the defueling canisters neither increases the probability of any accident previously evaluated nor creates the possibility of a different type of accident. Additionally, as the current TMI-2 Technical Specifications do not specifically address containment of the fuel debris, the margin of safety as defined in the basis of the Technical Specifications is not reduced.

As discussed above, these canisters are critically safe by design. Additionally, activities associated with canister closure and handling, including installation of the relief devices, will be performed in accordance with procedures prepared, reviewed and approved in accordance with TMI-2 Technical Specifications Section 6.8, which requires NRC approval of certain types of procedures. Therefore, as no further engineering controls are needed to ensure criticality safety and activities associated with canister closure and handling will be controlled in accordance with procedures subject to Technical Specification Section 6.8, it is GPU Nuclear's belief that no changes to the Technical Specifications are required.

In conclusion, within the bounds described in this report, the design and use of the defueling canisters do not result in an unreviewed safety question, nor require changes to the TMI-2 Technical Specifications.

6.0 Conclusions

Canisters are needed to provide effective long term storage for the TMI-2 core debris. Three types of canisters are required to support the defueling system: fuel, filter and knockout canisters. These canisters have been evaluated to determine if they could safely perform their function under normal and accident conditions. The results of this evaluation snow that the canisters will remain subcritical under normal operations, handling and accident conditions. A structural evaluation of the canisters has shown that they maintain their integrity and will function as designed under normal operating conditions. Drop analyses and drop tests were used to determine the effect of a design basis drop on the canister shell and internals. The results from these analyses were used in determining the reactivity of the canisters under accident conditions. Therefore, based on structural and criticality considerations, it can be concluded that these canisters can safely function under normal and accident conditions at TMI-2.

7.0 References

1. TMI-2 Defueling Canisters Final Design Technical Report, Babcock and Wilcox, Document No. 77-1153937-04, May 24, 1985.

2. Technical Evaluation Report for Fuel Canister Storage Racks, 15737-2-G03-113, Rev. 0.

3. Safety Evaluation Report for Early Defueling of the TMI-2 Reactor Vessel, 15737-2-G07-107.

4. Evaluation of Special Safety Issues Associated with Handling the TMI-2 Core Debris, RHO-WM-EV-7, Rockwell Hanford Operations, February 1985.

5. Computer Code "ANSYS" Revision 4.1, March 1, 1983, Swanson Analysis System Inc., Houston, PA.

6. "NULIF-Neutron Spectrum Generator, Few Group Constant Calculator and Fuel Depletion Code", BAW-426, Rev. 5.

7. "NITAWL, Nordheim Integral Treatment and Working Library Production," NPGD-TM-505.

8. "XSDRNPM AMPX Module with One Dimensional S_n Capability for Spatial Weighting," AMPX-II, RSIC-RSP-63, ORNL.

9. "KENO4, An Improved Monte Carlo Criticality Program," NPGD-TM-503, Rev. B.

10. TMI-2 Drop Testing of Defueling Canisters Final Report, Babcock and Wilcox, Document No. 77-1156372-00, February 1985.

11. TMI-2 Early Defueling Fines/Debris Vacuum System Proof-of-Principle Test Report, TMI-AD-84-018, Westinghouse Electric Corporation, Advanced Energy Systems Division, October 1984.

Attachment 1

TMI-2 Transfer System Criticality Technical Report