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November 5, 1985
NRC/TMI 85-083

Docket No. 50-320

Mr. F. R. Standerfer
Vice President/Director, TMI-2
GPU Nuclear Corporation
P. O. Box 480
Middletown, PA 17057

Dear Mr. Standerfer:

Subject: Defueling Canister Technical Evaluation Report

Your letter dated April 9, 1985 (reference 1) was the initial submittal of the Technical Evaluation Report (TER) for the proposed design of the defueling canisters. NRC staff review of the TER resulted in several questions which were sent to you via our letter of June 10, 1985 (reference 2). These questions were discussed at a meeting between our technical staffs on July 25, 1985. Your letters of August 15 and September 10, 1985 (references 3 and 4) forwarded your responses to the questions and a subsequent revision to the TER.

The TER addressed the general structural design of the canisters, their operational interface with other systems, flammable gas control considerations, and a criticality evaluation. This letter transmits our safety evaluation and approval of the design of the defueling canisters. This approval is based on a review of the submitted TER and additional information presented in references 5 through 8. This review provided reasonable assurance that the canisters, if fabricated in accordance with the design specifications, are capable of performing their intended function without posing a significant risk to the health and safety of the occupational work force or the public. Additionally, we have determined that the proposed use of the canisters is within the scope of activities and associated environmental impacts which were considered in the staff's Programmatic Environmental Impact Statement.

As you are aware, NRC inspections of one of your canister fabricators as well as your own audits and surveillances of the vendor have identified significant deficiencies in the implementation of the vendor's quality assurance program. These noted deficiencies have cast doubt on whether equipment provided by this vendor meets required design specifications and, accordingly, whether the equipment is suitable for use during defueling. We understand that your staff and others have implemented a program involving an extraordinary level of quality assurance oversight to attempt to correct the deficiencies and to

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verify the canisters conformance to the design specifications. We are currently reviewing the results of that program. When we have completed our review and have determined that there is reasonable assurance that the canisters meet all design specifications we will forward our approval for the use of the canisters. It should also be noted that use of the canisters for defueling is contingent upon NRC approval of the Early Defueling Safety Evaluation Report and the associated procedures subject to Technical Specification 6.8.2.

Sincerely,

ORIGINAL SIGNED BY:
William D. Travers

William D. Travers
Acting Director
TMI Program Office

Enclosures: As stated

cc: T. F. Demmitt
R. E. Rogan
S. Levin
W. H. Linton
J. J. Byrne
A. W. Miller
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REFERENCES

1. Letter 4410-85-L-0067, F. Standerfer to B. Snyder, Technical Evaluation Report for Defueling Canisters, dated April 9, 1985

2. Letter NRC/TMI 85-042, W. Travers to F. Standerfer, Technical Evaluation Report for Defueling Canisters, dated June 10, 1985

3. Letter 4410-85-L-0167, F. Standerfer to B. Snyder, Technical Evaluation Report for Defueling Canisters, dated August 15, 1985

4. Letter 4410-85-L-01183, F. Standerfer to B. Snyder, Defueling Canister Technical Evaluation Report, dated September 10, 1985

5. TMI-2 Defueling Canisters Final Design Technical Report, Document No. 77-1153937-03, April 11, 1985

6. Canister Structural Analysis Report for Cask Transportation Accidents, Document No. 77-1156615-02, May 24, 1985

7. GEND-051, Evaluation of Special Safety Issues Associated with Handling the Three Mile Island Unit 2 Core Debris, June 1985

8. Memorandum from J. Byrne to W. Travers, Filter Canister Accident Criticality Analysis, September 19, 1985

NRC STAFF SAFETY EVALUATION OF DEFUELING

CANISTER DESIGN

DESCRIPTION OF CANISTERS

The defueling canisters are designed to accept and confine the TMI-2 core debris ranging in size from fines of about 0.5 microns in diameter up to partial length fuel assemblies of full cross section. The canisters are to be an integral part of the defueling systems and are intended to provide effective confinement for transport and long term storage of the damaged core debris. They are designed to ensure their contents remain subcritical under all postulated on-site conditions and also, when in combination with a shipping cask, to remain subcritical under both normal and accident conditions during transport. The three types of canisters (i.e., fuel, knockout, and filter canisters) are equipped with fixed neutron absorber material for criticality control, with catalytic recombiners to control the concentration of combustible gas mixtures generated from radiolytic decomposition of water, and with appropriate process connections for filling, closing, dewatering, inerting, and monitoring. All three types of canisters have a nominal overall length of 150 inches with the outer shell being fabricated of 14 inch OD 304L stainless steel pipe with a nominal 1/4 inch wall thickness. A reversed dished tank end is welded to the shell to form the lower closure head.

The fuel canister is designed as a receptacle for large pieces of core material which will be picked up and placed either directly into the canister or into other containers which will be inserted into the canister. Within the cylindrical shell is a full length approximately 9 inch square cross section shroud forming an inner cavity. The shroud is formed of stainless steel plates with Boral sheets sandwiched between them to serve as neutron absorbers. The plates are seal welded to encapsulate the boral and protect it from corrosion. The thickness of the inner plates protects the boral sheets from impacts from the canister contents. The inner cavity is sized to accept the full cross section of an intact fuel assembly. The void space outside of the shroud is filled with a light weight cement/glass bead mixture to prevent migration of fuel material to this area. The shroud assembly is welded to and supported by a bottom support plate which is welded to the inside diameter of the shell. The bottom support plate is designed to withstand the impact of a 550 pound piece of debris dropped the full length of the canister in water. If the drop is in air, the weight is reduced to 350 pounds. The upper end of the shroud is fitted into a recess and supported by an upper bulkhead which is welded to the shell and forms the mating surface for the upper closure head. The removable closure head is bolted to the bulkhead and sealed with gaskets. It has a machined socket in the center of its exterior to mate with the single point grapple on the canister lifting tool. The empty dry fuel canister weighs about 1230 pounds.

The knockout canister is designed for use in the fuel debris vacuum system. It will separate debris particles ranging from about 140 microns up to full fuel pellet size or larger. The process inlet line enters the top of the canister and bends to direct the flow tangentially along the inner circumference of the shell creating a swirling action that causes the

entrained debris to settle out in the canister vessel. The water then exits through an 850 micron screen to a process connection in the top of the canister. The canister internal assembly is supported from a bottom support plate that is welded to the inside diameter of the canister shell. The assembly is positioned at the top by welded chock blocks. The internals consist of an array of four outer poison rods and one central poison rod. The outer rods are 1.3 inch OD stainless steel tubes that are filled with neutron absorbing B_4C pellets and sealed at both ends. The center rod is a 2.875 inch OD guard pipe surrounding a 2.125 inch OD tube filled with B_4C pellets. The rod array is supported laterally by seven intermediate support plates along its length. The guard pipe around the center poison rod forms a 1/16 inch annular gap, open to the bottom head of the canister and connected to a process fitting at the top, to provide a canister dewatering pathway. The empty knockout canister weighs 1046 pounds in air.

The filter canister is designed for use in the fuel debris vacuum system, the defueling water cleanup system, and the canister dewatering system. It will remove fuel fines larger than 0.5 microns from the process streams. The canister internals are attached to a bottom support plate which is welded to inner diameter of the canister shell. The internals are comprised of a bundle of 17 filter modules, a drain line, and a centrally located poison rod containing B_4C pellets. The central poison rod is similar to that in the knockout canister. The filter modules consist of elements which are a pleated sintered stainless steel media around a center support tube. The media and support tube are induction brazed to stainless steel end caps. Eleven elements are stacked end to end around a perforated drain tube and seal welded at the end caps to form a module. The drain tube is plugged at the top and open at the bottom. The process flow enters the top of the filter canister and flows around the filter bundle. The process liquid flows through the filter elements depositing the entrained particles larger than 0.5 microns on the outside of the media. The liquid enters the perforated tube and flows downward into the bottom plenum of the canister. The effluent exits through the top of the canister via an effluent fitting connected by the internal drain tube to the bottom plenum. The empty filter canister weighs about 1440 pounds in air.

All types of canisters are designed with suitable process connections for their intended use. The top head of each type is provided with a 1/4 inch inert gas purge connection and a 3/8 inch drain fitting which is connected to the internal dewatering pipe. Each of these connections is fitted with a Hansen quick disconnect coupling. The filter canister head has 2½ inch inlet and outlet process connections, and the knockout canister has 2 inch inlet and outlet process connections. The process connections are provided with cam and groove type fittings which will be closed with expanding mandrel plugs after the canisters are filled. Welded to the top of each canister is a cylindrical skirt to protect the penetration fittings during normal handling and postulated handling accidents. All types of canisters have a machined recess in the outside surface of the upper head to accommodate the single point lifting grapple used for normal handling operations. The bottom support plates in all three types of canisters forms a fuel free "sump" in the bottom head. This is connected to the drain fitting at the top head for canister dewatering. In the fuel canister, the dewatering path is a 3/8 inch tube running from the lower head through the area outside the boral shroud. In the knockout canister, the annular gap between the center poison rod and its

strongback pipe forms the dewatering pathway. In the filter canister, the process effluent pipe runs from the lower head region to the upper head penetration. A dewatering pathway is machined internally in the upper head from the effluent pipe to the drain fitting. All three types of canisters are designed with catalytic recombiner cartridges in the lower and upper heads. These are described in more detail in the gas management section of this report.

STRUCTURAL EVALUATION

The defueling canisters are designed to the requirements of the 1983 edition of the ASME Pressure Vessel Code, Section VIII, Division 1, Part UW (lethal). They have design pressures of 150 psig internal and 30 psig external. Fabrication, inspection, and testing of the canisters is performed to the standards of the ASME Code. The canisters are Nuclear Safety Related and the licensee's procurement specifications require that they be manufactured under the controls of a Quality Assurance program meeting the requirements of 10 CFR 50 Appendix B and ANSI N45.2. Structural analysis by the canister designers included evaluations of the loads imposed on the canisters during normal operations as well as postulated load drops and shipping accidents. Acceptance criteria for normal operations was based on the ASME Pressure Vessel Code. In addition, analysis was performed to show acceptable safety margins when applying the specified stress factors of NUREG-0612 and ANSI N14.6 for the normal handling condition. The design criteria for postulated accident conditions is that for the predicted deformed geometry following an accident, the canisters and their contents must remain subcritical,although leakage of material is permissible.

Canister structural analysis for the normal operation and handling condition was performed using standard analytic techniques. This analysis demonstrated acceptable design margins and met the requirements of the ASME Code and other applicable regulatory requirements and industry codes and standards.

The approach used in demonstrating that the canister design met the specification for the postulated accident conditions used a combination of analytical methods and component testing. The design specifications for the shipping cask intended for use in transporting the filled defueling canisters is that it shall limit the loads imposed on the canisters to no more than 40 g's axial and 100 g's lateral during hypothetical transportation accidents per 10 CFR 71. A detailed evaluation of the proposed cask's conformance to this specification has been performed and included both analysis and impact testing of a scale model. This evaluation is presently under review by the NRC Transportation Certification Branch as part of the licensing process for the cask. Analysis and supporting drop tests of the canister was performed to demonstrate that the fixed poisons installed in the canister remain intact and capable of performing their intended criticality control function when subjected to these loads, or that subcriticality could be maintained by other geometrical constraints.

For onsite handling accidents, canister drops of 6 feet-1½ inches in air followed by 19 feet-6 inches in water, or 11 feet-7 inches in air were considered to be credible. This does not include a potential drop in the Fuel Handling Building Truck Bay during cask loading. This potential canister drop will be evaluated in the fuel shipping Safety Evaluation Report. Combinations

of vertical and horizontal drops were considered. These drops were determined to impart loads on the canisters in excess of those for the transportation accident. Structural analyses were performed to determine the extent of the canister shell and internals deformation resulting from these loads.

Deformation of the canisters due to a vertical drop was determined by analysis of data from a drop test program and was found to be shell dependent. The predicted deformation in this case was a bulging of the canister shell below the lower support plate. No significant deformation of the canister internals, significant to the criticality analysis, is expected to occur from a pure vertical drop. This was demonstrated during actual drop tests for a bottom end impact. This also bounds the top end impact and for purposes of criticality analysis the deformed shape was assumed to exist at both ends of the canister.

For the horizontal drop case, the filter and knockout canister's internals were analyzed with finite element methods using the ANSYS computer code. It incorporated the actual non-linear properties of the material and accounted for geometric constraints imposed by the canister shells. The deformations predicted by these analyses with additional conservatisms on poison structure locations were used in the criticality calculations. The deformed geometry for the fuel canister was determined by a 30 foot drop of a simulated partial length unit. The testing showed insignificant deformation of the boral shroud from the lateral loads imposed.

Vector combinations of the vertical and horizontal load components were used to predict the effect of a drop in any orientation, and the conservatively modeled worst case deformed geometry for each type of canister was factored into the criticality analysis.

The NRC staff review of the licensee's structural analysis has determined that proper codes and standards were employed in the design of the defueling canisters. The structural analysis shows sufficient margins of safety when applying the maximum predicted loads expected during normal onsite operations and handling and subsequent transportation. The structural analysis for accident conditions used industry standard and NRC accepted analytic techniques and provides reasonable assurance that the maximum expected deformation has been predicted for factoring into the criticality analysis.

CRITICALITY EVALUATION

The defueling canisters are designed to ensure their contents remain subcritical under all normal operational conditions and during all postulated accident conditions. The conditions analyzed included both a single canister configuration and an array of canisters on a 17.3 inch center to center spacing, which is the minimum spacing for all onsite storage rack locations. Both an intact canister and a canister deformed by the worst case drop accident were modeled. The deformed geometry used in the calculations was that predicted by the structural analysis with additional conservatism for poison structure location. The canisters were modeled using computer codes generally recognized as acceptable by the NRC staff. The calculational model used the following conservative assumptions:

1. The canister's contents consist of batch 3 fuel only with the average batch 3 enrichment plus 2 standard deviations. Batch 3 fuel is in the highest enriched region of the core and has an average enrichment of 2.93 percent. It assumed no fissile burnup or fission product inventory that would contribute negative reactivity.

2. The canisters contents are assumed to contain no cladding or core structural material and no soluble poison or control material (i.e., control rod debris or burnable poison) from the core.

3. The contents are assumed to be fuel in the optimal lump size and to contain the optimal fuel to moderator ratio with no boration of the entrained water.

4. All void regions of the canister are assumed to be filled with fuel without regard to the weight restrictions on a loaded container. All three types of canisters contain catalytic recombiners in the upper and lower heads. The criticality analysis assumed that the regions occupied by the recombiners was filled with fuel.

5. The analysis assumed the lowest possible loading of fixed poison material.

The canister geometry was conservatively modeled to account for the internal configuration and the structural members of canister internals and closure heads.

The fuel canisters were analyzed for a single canister infinitely reflected by water, an infinite array of canisters in unborated water, and a canister deformed by the bounding drop case. The deformed case assumed fuel had migrated into the bulged lower and upper heads. All cases yielded a maximum Keff of 0.877.

Two knockout canister configurations were considered. These included the standard undamaged configuration and the damaged configuration in which the worst deformed geometry was used. The damaged configuration for the knockout canister did not assume that fuel had migrated into the upper and lower head regions as in the other types of canisters, and did not assume loss of the B_4C pellets as in the filter canister. A drop test of an as-built knockout canister was performed by Oak Ridge National Laboratory and demonstrated that the bottom support plate and the poison rods remained intact following the maximum predicted impact loads from a drop accident. These configurations were analyzed as a single canister infinitely reflected by water, an infinite array of undamaged canisters in unborated water, and a single dropped canister. The maximum calculated Keff was 0.915.

Two filter canister configurations were also considered. They assumed fuel above the lower support plate and a second configuration with fuel in the lower head plus fuel filling the filter element drain tubes (i.e., ruptured filters). The maximum calculated Keff when considering the single canister, the array of canisters, and the single dropped canister was 0.892.

The NRC staff performed independent calculations to verify the licensee's criticality analysis. These included computer code analysis of several test

cases as well as an evaluation of the assumptions and the computer codes used by the licensee. The NRC results were in agreement with the licensee's. Summaries of the NRC's analyses are included as appendices 1 and 2 to this SER.

The licensee presented additional analysis to determine the effects on criticality by the canister transfer shielding. The staff determined that the analysis used acceptable analytic techniques with appropriate levels of conservatism. This analysis showed that handling a filled undamaged canister in the proposed transfer shield will not result in a Keff of greater than 0.95. Analysis of a damaged canister will be performed on a case by case basis as needed.

CANISTER GAS MANAGEMENT

After filling a canister with fuel debris, water will remain in the canister. Prior to dewatering, the canister will be completely flooded with RCS water. Following dewatering, the canister will contain residual water entrained in the fuel debris as well as a certain amount of free "slosh" water not removed by the dewatering system. Since this water will be in direct contact with fuel and fission product containing debris without benefit of the fuel cladding to provide shielding from alpha and beta radiation, there could be significant amounts of hydrogen and oxygen generation from radiolytic decomposition of the water. Gas generation could result in internal pressure build up and production of combustible gas mixtures inside the canisters. Studies were performed by Rockwell Hanford Operations (RHO) to predict the rate of gas generation and to develop suitable catalytic recombiners to control the gas concentrations.

The rate of gas generation has been shown to be a function of 1) the amount of ionizing radiation emitted by debris in a canister, 2) the fraction of the energy absorbed in the water, 3) the ratio of peak to average decay heat energy in the fuel debris, and 4) the amount of gas produced per unit of energy. Using the empirical relationship which has been confirmed experimentally, the maximum theoretical gas generation rate has been predicted as 0.114 liters per hour of hydrogen plus oxygen in stoichiometric proportions. The licensee's evaluation states that there is significant conservatism in this calculation and provided what was considered a "maximum realistic generation" rate based on what is considered a more probable condition in the core debris. The licensee's predicted maximum realistic gas generation rate is 0.0075 liters per hour. The conservatisms used in the theoretical predictions are as follows: 1) the maximum quantity of fuel in a canister used in the calculations (800kg) did not include allowances for residual water or for weighing accuracy. This quantity was reduced in the "realistic" prediction, 2) the fraction of energy absorbed in the water conservatively assumed that large amounts of water were present for absorption rather than using the maximum amount of water that could possibly be present in a filled canister, 3) the amount of gas produced per unit of absorbed energy assumed no oxygen scavenging (i.e., chemical removal) that would produce excess hydrogen and resultant back-reactions, 4) the ratio of peak to average decay heat energy is based on the most active region of an undamaged core and does not account for possible dispersal of the material from this core region during the accident. The NRC staff reviewed the basis for the gas generation rates and concurs that there is significant conservatism in the

theoretical generation rate. However, there is insufficient data presented in the Technical Evaluation Report to justify the staff's use of the licensee's lower predicted "realistic" rate or to accurately quantify the conservatisms in the theoretical calculations. Therefore, the staff's safety evaluation is based on the 0.114 liter per hour maximum theoretical gas generation rate.

Following a series of tests by RHO, the catalyst chosen for use in the defueling canisters was a mixture of 80 percent Engelhard Deoxo-D nuclear grade catalyst and 20 percent AECL silicone-coated catalyst. Details of the catalyst test program are documented in GEND-051, "Evaluation of Special Safety Issues Associated with Handling the Three Mile Island Unit 2 Core Debris", dated June 1985. The test program involved a catalyst bed similar to that in the canisters. It was installed in a test chamber into which hydrogen and oxygen were admitted at a controlled rate. The test chamber's pressure and temperatures were monitored and its internal atmosphere was sampled and analyzed. The tests demonstrated that the designed catalyst beds containing 100 grams of catalyst in the required proportions were capable of maintaining the chamber atmosphere below 1.2 percent hydrogen and 0.6 percent oxygen while recombining the gases at a rate of 0.3 liters per hour of hydrogen plus oxygen in stoichiometric proportions. This shows significant margins of safety from the lower flammability limits of 5 percent oxygen and 4 percent hydrogen, and from the maximum theoretical gas generation rate of 0.114 liters per hour. The testing demonstrated, though that the catalysts do not function when immersed in water. After immersion and being "drip dried" in a 100 percent relative humidity atmosphere, they will begin recombination at a reduced rate. The rate increases and reaches full capacity within a short period of time as the heat generated by the recombination reaction causes further drying of the catalyst. Further testing was performed to demonstrate that the chemical species expected to come in contact with the catalyst from the RCS or during canister fabrication will have no deleterious effects on the catalyst performance. Additionally, tests were performed to demonstrate that freezing conditions during transportation will not stop the recombination reaction once started.

The catalyst beds installed in the defueling canisters are designed so that as long as the canister is no more than half full of free water, at least 100 grams of the catalyst will not be immersed in water regardless of canister orientation. Four recombiner packages, each containing 25 grams of catalyst, are attached symmetrically about the axis of the inner surface of the lower canister head in all types of canisters. The upper head of the fuel canister has one large diameter flat catalyst bed containing 100 grams of catalyst on the inner surface. The knockout and filter canisters have two symmetrically located beds containing 50 grams each of catalyst in the upper heads. All catalyst cartridges are welded in place and structurally designed to remain intact and functional, provided they are not immersed, during any postulated drop accident. The catalyst material is covered by a retainer screen that holds it in place but allows free diffusion of gas to the catalyst surface and diffusion of water vapor away from the catalyst.

Based on a review of the licensee's evaluation and available literature on radiolytic decomposition, the NRC staff has determined that the maximum theoretical gas generation rate has been predicted with considerable conservatism. The staff has further determined that the designed catalytic recombiners have acceptable margins of safety and provide reasonable assurance

that combustible gas mixtures will not develop in the filled canisters after dewatering.

CANISTER OPERATIONS

The fuel canisters are designed to be inserted into the reactor vessel where they are supported by either the canister positioning system or the single canister support bracket. Pieces of fuel debris are picked up by various types of defueling tools and placed into the canisters. Methods of debris placement will be controlled by procedures approved by the NRC staff and will ensure that dropped debris will not impose impact loads on the bottom support plate in excess of those designed. The knockout canisters are inserted in the canister positioning system where they are connected to the fuel debris vacuuming system. The filter canisters are installed in either the defueling water cleanup system where they are supported by the storage racks in the fuel transfer canal and spent fuel pool, or they are installed in the fuel debris vacuuming system in the reactor vessel. They can also be used in the final canister dewatering system in the spent fuel pool. The canisters will be filled with core debris in their respective processing systems. They are designed to be filled to a maximum dewatered weight of 2800 pounds with an allowance of 5 percent of the canisters to be 5 percent overweight or 2940 pounds. The worst case loaded and flooded canister could weigh 3500 pounds. The canisters will be weighed during processing to ensure they are maintained within the design weight limits. When filling is complete, the upper head is bolted onto the fuel canister. The process connections are plugged on the filter and knockout canisters. They may then be partially dewatered in the reactor vessel to expose sufficient catalyst to control the gas buildup. Two relief valves will then be installed. A 25 psig relief is installed on the inert gas purge connection and a 150 psig ASME code relief valve is installed on the dewatering connection. These relief valves are to protect the canisters from overpressurization in the unlikely event of catalyst failure or in the event of canister storage prior to dewatering. The canisters will then be transferred to the 'A' spent fuel pool for storage, final dewatering, and preparation for shipment. Both initial dewatering in the reactor vessel and final dewatering in the spent fuel pool will involve water removal by purging the canisters with argon, an inert cover gas. They will be left pressurized to about 13 psig with the inert gas. After final dewatering and purging, the canisters will be monitored for a sufficient period of time to verify that the catalytic recombiners are functioning.

The staff has evaluated the consequences of several situations in which gas generation may occur in a canister.

If a canister is filled solid with debris and water, the recombiners will be ineffective. This will result in pressure buildup and periodic lifting of the relief valves. This will occur in a short period of time (about 40 hours) with the maximum theoretical gas generation rate. If the 25 psig relief valve fails to operate, the internal pressure will reach the setpoint of the 150 psig relief valve in about nine days. Lifting of the relief valves is considered to be acceptable since the canisters are stored underwater. The quantity of flammable gas mixtures vented by relief valve actuation will be small and readily dispersed by venting into the water and diluted by the surrounding atmosphere. Thus, no fire hazard should exist. Activity released to the water by relief valve lifting is readily removed by the defueling water

cleanup system. Failure of both relief valves is considered very unlikely since they are independent of one another and installed in such a manner that they are not subject to a common mode failure. If, however, both were to fail, it would take nearly one year for canister internal pressures to reach the yield stress on the canister shell. This is not considered credible since canister dewatering should take place before this time has elapsed.

Following dewatering and inerting of a canister, its internal pressure should remain stable. If, however, the recombiners fail to operate, the pressure will increase. Assuming failure of the recombiners, it will take about one week to achieve a flammable mixture in the canister. Ignition of this mixture is unlikely, but if it were to occur the canister yield stresses would not be exceeded. It will take about one month to reach the set point of the 25 psig relief valve and about one year to reach 150 psig relief valve setpoint. This is assuming the minimum canister void space of 96 liters and a gas generation rate of 0.114 liters per hour. Lifting of the relief valves in these cases is of no safety consequence as previously discussed above.

The licensee's evaluation presented an analysis of the consequences of ignition of the vented gases if relief valve actuation were to occur while a canister is in the transfer shield. The staff review of that evaluation concurs that the consequences of such an event pose no significant risk.

The staff has determined that the canister design is compatible with the scope of operations discussed in the licensee's Technical Evaluation Report.

CONCLUSION

The NRC staff has performed a safety review of the design of the proposed defueling canisters. This review consisted of evaluation of the canister structural design, evaluation of the licensee's criticality analysis, evaluation of the canister's combustible gas control features, and evaluation of the affects of postulated accidents and abnormal conditions. Based on the review, the canister design and their proposed operations do not pose a significant risk to the occupational work force or the public. The defueling canisters, which are necessary to support planned defueling activities, do not present the possibility of any accident not previously analyzed nor do they change the consequences of, or likelihood of any previously analyzed accident. Margins of safety as previously analyzed are not reduced. The staff concludes that the canister design does not necessitate additional changes to the plant Technical Specifications and does not constitute an unreviewed safety question. The scope of activities and the associated environmental impact of the defueling canisters as discussed in Defueling Canister Technical Evaluation Report are within those previously considered in the PEIS. We therefore approve the design of the defueling canisters. Use of the canisters is contingent upon our approval of those procedures subject to Technical Specification 6.8.2. Operations to fill the canisters with core debris will also be contingent upon our approval of the Early Defueling Safety Evaluation Report.

APPENDIX I

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

AUG 1 9 1985

MEMORANDUM FOR: Richard A. Weller, Leader
Safety and Environmental Review Section
Three Mile Island Program Office
Office of Nuclear Reactor Regulation

THRU: Charles E. MacDonald, Chief
Transportation Certification Branch
Division of Fuel Cycle and Material Safety
Office of Nuclear Material Safety and Safeguards

FROM: Charles R. Marotta, Senior Criticality
and Shielding Engineer
Transportation Certification Branch
Division of Fuel Cycle and Material Safety
Office of Nuclear Material Safety and Safeguards

SUBJECT: CRITICALITY REVIEW OF TECHNICAL EVALUATION REPORT (TER) FOR THE TMI-2 DEFUELING CANISTERS AS DOCUMENTED IN REFERENCE A (BELOW)

REFERENCES:

A. TER (15737-2-G03-114, Rev. 0) dtd 03/22/85 TMI-2 Division Technical Evaluation Report for Defueling Canisters

B. Three (3) IBM Computer Listings (B&W property to be returned to B&W):
   1. KENO-IV, 123 Gps, Gen. Geom: Damaged Fuel Canister
   2. KENO-IV, 123 Gps, Gen. Geom: Damaged Filter Canister
   3. KENO-IV, 123 Gps, Gen. Geom: Damaged Knock-out Canister

   (delivered to NRC on May 23, 1985)

C. Three (3) B&W fiche copies of the above listings giving nuclear data and geometric details (NRC property; delivered to NRC on May 23, 1985)

I. Introduction and Conclusions

As requested in your memorandum to C. E. MacDonald dated April 24, 1985, a detailed review has been performed of the submitted GPU (Refs. A and B, B&W analyses) criticality Safety Analysis for the loading of canisters in the defueling of the TMI-2 core. Based on this review, we find that the criticality calculational method, physical and geometric assumptions, atomic number densities (giving mass loadings of nuclides per region) and description of canisters analyzed to be accurate and represent the cases intended.

In addition to this detailed review and verification, independent KENO-IV Monte Carlo calculations of the knock-out and fuel canisters were performed. The independent calculations agree with the results obtained by B&W as given in Ref. A. A comparison of NRC and B&W's keff's under various conditions is given in Table 1. Since the filter canister contains a similar 2" diameter B_4C central poison rod as in the knock-out canister and in addition contains about ten times the amount of internal steel of that in the knock-out canister, the filter canister was considered less reactive than the knock-out canister and hence not analyzed by NRC.

We, therefore, recommend acceptance of the criticality analysis portion of Ref. A and concur with the subject submittal that there exists at least a 5% shutdown margin for all three canisters under normal and assumed accident modes.

In Table 1, below, and in Ref. A, we note that B&W did not report any keff's for B_4C replaced by water or replaced by a void. NRC calculated a single knock-out canister to have a 4.3% shutdown when the B_4C is replaced by water; a 3.8% shutdown when the B_4C is replaced by water and the remaining steel tubes are deflected off-center by 1.2 inches. We note that these latter two cases are supercritical for the infinite array calculation as given in Table 1. Thus, if the above scenarios can be realized in the postulated accident modes, the 5% margin shutdown is compromised. Further, if a void replaces the B_4C, the shutdown margin is further reduced from 4.3% to 3.4%.

In summary then, we find:

1. The B&W calculational methodology (KENO IV-123 Group GamThermos cross-sections) represents one of the best state-of-the-art approaches which has successfully calculated many appropriate benchmark criticals. In particular, we note that the B&W fuel-water homogenization procedure - fundamental to the B&W approach and results - has been done correctly.

2. The B&W criticality analyses used the most (neutronically) reactive fuel/water mixture in representing the core debris in each canister.

3. Some conservatisms used by B&W were:

   (a) Each canister was loaded up to a height of 14 feet ($\sim$ an extra 3 feet of reactive material).

   (b) The density of B_4C was taken as 1.35 gm/cc; areal density of B-10 for boral was taken as 0.04 gm/cm^2.

(c) The minimum amount of steel has been credited to the knock-out canister ($\sim$ 1-1/2 volume percent) and the filter-canister ($\sim$ 14 volume percent).

4. NRC independent calculations agree very well with the B&W results for the cases considered.

A brief discussion of the criticality methods used to establish the conservative acceptable parameters fundamental to both B&W's and NRC's follows.

II. Basic Assumptions and Methods Used in Criticality Calculations

Both B&W and NRC assumed the TMI-2 debris contents for all three canisters to be $U(3)O_2$ unclad pellets moderated by unborated H_2O with a volume fraction of 0.30 of fuel and 0.70 of water. This has been established via many independent calculations to constitute the most reactive mixture. For a borated water system over the range of 3000 to 5000 ppm boron in water, the most reactive mixture turns out to be a volume fraction of 0.60 of fuel and 0.40 of water. However, for these borated systems, the keff is of the order of 30% less than any corresponding system moderated by unborated water. Thus, the Δ k is of the order of 0.3 and completely controls selection of the most reactive mixture to be fuel moderated by unborated water. All criticality calculations thus use unborated water as moderator.

Both B&W and NRC assume a very conservative density for B_4C viz 1.35 gm/cc versus 2.43 gm/cc given in the handbooks. In addition, an areal density of 0.04 g/cm^2 for B-10 is assumed for boral.

Both B&W and NRC use the KENO-IV Monte Carlo computer program with the 123 group Gam Thermos neutron cross-section set adjusting the resonance nuclide (U-238) with the NITAWL program. B&W then homogenizes the $U(3)O_2$ and the associated water (30/70 mixture) via an XSDRN cell group-spatial weighting into a debris mixture. Using generalized geometry, this homogenized water-fuel mixture occupied all space within the boral plates of the fuel canister, all space inside the knock-out canister not occupied by the 5 B_4C-SS clad rods and all space inside the 17 filter elements of the filter canister.

As a check on the above homogenization procedure, NRC's model required that the $U(3)O_2$ pellet be described as a discrete cylinder surrounded by the cell (30/70) water. This restricted NRC's canister's geometry to a square-cylinder. The pellet-water constituted a box-type in the KENO-IV geometry, and since the fuel canister possesses a square internal region (surrounded by boral) which will contain the debris, it represents the ideal case to check the homogenization process fundamental to B&W's calculated procedure. Results of Table 1, under Fuel Canister show that the homogenization procedure of B&W and the discrete procedure of NRC to be equivalent - they calculate the same keff for the single fuel canister and for an array.

For the knock-out canister, the square cylinder geometry of NRC maintained the exact masses of UO_2, H_2O, steel and B_4C that exist in B&W's cylindrical geometry. Table 1 for the undamaged single knock-out canister, B_4C in place shows excellent agreement; for the infinite array, the NRC value of k_∞ is higher by $\sim$ 4-1/2% since in this geometry the square box ends come much closer to neighboring boxes whereas the cylinders remain effectively further apart from one another.

The damaged cases for NRC were calculated by assuming the B_4C being replaced by water whereas B&W assumed only a displacement of the B_4C-SS rod. Although NRC's condition is more severe, the single damaged knock-out canister is still subcritical, but the infinite array of such damaged canisters is supercritical.

NRC's worth of the B_4C can be estimated from Table 1:

For Single Canister	For the Array
$\frac{\Delta k}{k} = \frac{0.957-0.887}{.922} = 7.6\%$	$\frac{1.033-0.961}{.997} = 7.2\%$

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TABLE 1

COMPARISON OF B&W AND NRC CALCULATED MAXIMUM* Keff's
FOR
KNOCK-OUT AND FUEL CANISTERS
CONTAINING TMI-2 DEBRIS
Using KENO IV with 123 Group GamThermos Neutron Cross-Sections when each canister is loaded with most reactive $U(3)O_2/H_2O$ mixture**

STATUS OF CANISTER CALCULATED	KNOCK-OUT CANISTER						FUEL CANISTER	
	UNDAMAGED				DAMAGED		UNDAMAGED	
	(B_4C in Place)		(B_4C repl by H_2O)		(B_4C repl by H_2O & SS displ 1.2")	(B_4C & SS displ 0.75")	(Boral in Place)	
	NRC	B&W	NRC	B&W	NRC	B&W	NRC	B&W
SINGLE CANISTER (H_2O flooded and reflected)	0.887[a]	0.873	0.957[b] 0.966[d]	---	0.962	0.882	0.866	0.857
INF. ARRAY OF CANISTERS (17.3" c to c spacing in H_2O pool)	0.961[c]	0.915	1.033	---	1.041	---	0.872	0.877

*Maximum value for B&W is keff + 2σ + calc. bias; for NRC, it is keff + 3σ.
**Assumed fuel vol/water vol = 30/70, fuel as pellet in unborated water.

All cases used $\rho(B_4C)$ as 1.35 gms/cc; BORAL assumed 0.04 gm B-10/cm^2

(a) NRC Calc. for this case with 3000 ppm boron in H_2O; keff = 0.582 - no steel in canister.
(b) NRC Calc. for this case with 3000 ppm boron in H_2O; keff = 0.646 - no steel in canister.
(c) NRC calc. for this case with 3000 ppm boron in H_2O; keff = 0.618 - no steel in canister.
(d) B_4C replaced by a void.

APPENDIX II

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

OCT 30 1985

MEMORANDUM FOR: Richard A. Weller, Leader
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THRU: Charles E. MacDonald, Chief
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FROM: Charles R. Marotta, Senior Criticality
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SUBJECT: CRITICALITY SAFETY EVALUATION OF A LOADED CANISTER DROPPING ITS CONTENTS ONTO A SIMILAR LOADED CANISTER IN A MAXIMUM VOLUME STORAGE UNIT

1. Introduction and Summary

As agreed in our conference phone call with Phil Grant and John Thomas on Friday, October 18, 1985, I have analyzed the criticality aspects of the accidental dropping of the contents of a loaded canister onto a similar loaded stored canister. The analysis indicates that for the loading limitations per canister, maximum storage volume per canister available and 4350 ppm boron in water, such an accident poses no criticality hazard and under very conservative assumptions (discussed below), the keff shutdown range is between 32% (max) to 13% (min). A total of six KENO Monte Carlo (123 gps) cases were analyzed and form the basis of the above conclusion. Results are given in Table 2. The computer input-output for these cases are on file in Transportation Certification Branch, NMSS.

2. Problem Definition

The concern of the subject accident scenario is the criticality state of a stored loaded canister when surrounded by the dropped contents of a similar canister. The stored canister resides in a parallelipiped borated (4350 ppm) water region of dimensions 18 inches by 18 inches by 14 feet - a volume of 892,000 cc.

3. Problem Solution: Assumptions and Methods

The approach in solving the above problem was to assume all canister contents to have a maximum payload of dry 900 kg $U(3)O_2$ pellets - this nominal value is 4-1/2% higher than the greatest payload (861 kg - total) for a knock-out canister.

To understand the detailed approach taken (described below) in solving the problem, the following criticality observations are reviewed. They were established in previous studies.

a. The as-built pellet is the form and geometry of the fuel to affect the optimum Vol fuel to Vol water ratio (V_F/V_W) both for unborated water and borated water.

b. Unborated water; maximum reactivity exists for fuel as pellet for V_F/V_W = 30/70, water is more important than fuel.

c. Borated water; maximum reactivity for fuel pellet shifts to V_F/V_W = 60/40 over the boration of 2500 ppm to 4500 ppm boron. Fuel is more important than the borated water. But the ratio goes from 58/42 to 62/38 over the boration range showing the small dependence on ppm; we have thus assumed an average value of 60/40.

d. Since the above ratios (30/70 and 60/40) represent optimum values and further increase of fuel into the system would decrease reactivity, small uranium slurry volume and/or uranium fines in the moderator region give a crude-first approximation of reactivity reduction. This is not exactly correct since introducing fuel in the moderator region shifts the optimum value. This has been neglected and is considered a second order effect on the assumption the system spectrum remains constant and the shift is small.

With the above as background, Table 1 can be constructed showing how many canister-full contents can be accommodated in the water storage paralleliped of 892,000 cc total volume. The canister contents are assumed to be 900 kg UO_2 at density 10 grams/cc. No canister structural material or canister poison material is considered present in the storage volume.

TABLE 1

Number of Canister Contents in Storage Volume	$\frac{\text{Volume } UO_2}{\text{Volume } H_2O}$	V_F/V_W
1	90,000 cc UO_2 802,000 cc H_2O	.112
2	180,000 cc UO_2 712,000 cc H_2O	.253
3	270,000 cc UO_2 622,000 cc H_2O	$.434 \approx \frac{30}{70} (=.428)$
4	360,000 cc UO_2 532,000 cc H_2O	.678
5	450,000 cc UO_2 442,000 cc H_2O	1.020
6	540,000 cc UO_2 352,000 cc H_2O	$1.538 \approx \frac{60}{40} (=1.500)$

This Table 1 shows that it will take about six canister contents to approach the optimum 60/40 ratio for borated systems and about only three canister contents to approach the optimum 30/70 for unborated systems.

The criticality analysis of the cases specified in Table 2 were modeled as cells as a discrete pellet region surrounded by its associated moderator close-fitting into the 18" x 18" cross-sectional area. This gave a UO_2 mass loading of 2764 kg (vs 2700 = 3 x 900) for the 30/70 ratio and 5678 kg UO_2 (vs 5400 = 6 x 900) for the 60/40 ratio due to the arithmetical discrepencies of fitting prescribed volume fractions into a fixed region. The 30/70 case is very slightly non-conservative, whereas, the 60/40 is quite conservative since more fuel is a more reactive situation here.

4. Discussion of Results and Conservatisms

Comparison of Cases 1 and 4 show that keff will decrease by 0.14 for the unborated case by increasing the fuel by a factor of 2 in line with maximum reactivity for the 30/70 mixture. For the borated cases, a comparison of Cases 2 and 5 and Cases 3 and 6, an increase in keff of 0.14 and 0.19 results respectively by increasing the fuel by a factor of 2 in line with maximum reactivity for the 60/40 mixture.

Case 6 represents approximately six canister-fulls filling the storage volume at the most reactive mixture 60/40 for 4350 ppm boron in the storage water. If one considers the canister poisons and structural materials as well as the core (canister contents) material to contain control-rod poisons, fixed poisons, core structure material, fission products and lower average core enrichment, all the tabulated keffs of Table 2 can be decreased by at least 0.10. Since only 2 canister contents represent the accident conditions, subcriticality is assured by a large margin.

In addition, Case 7 represents a 14 foot deep infinite slab of Case 6 contents with a resulting keff of 1.085.

Case 3 of Table 2 rerun as an infinite system in the X-Y-Z direction, gave a k_{∞} of 0.8021.

Case 7 of Table 2 rerun as an infinite system in the X-Y-Z direction, gave a k_{∞} of 1.095.

TABLE 2

KENO K_{eff}'s for an 18 inch x 18 inch x 14 feet Parallelepiped Canister Storage Volume Containing Most Reactive $U(3)O_2$-H_2O Mixture
(for boron concentrations of zero, 3000 ppm and 4350 ppm in water)

KENO Case No.	PPM Boron	Vfuel / Vwater	keff[a][b]	Contents of Storage Volume[c] (18"x18"x168"=31.5ft^3=8.92x10^{5}cm^3)
				2764 kg $U(3)O_2$; 618 kg H_2O
1	0	30/70	1.239	zero gms boron
2	3000	30/70	0.775	1893 gms boron
3	4350	30/70	0.677	2746 gms boron
				5678 kg $U(3)O_2$; 362 kg H_2O
4	0	60/40	1.099	zero gms boron
5	3000	60/40	0.918	1113 gms boron
6	4350	60/40	0.871	1614 gms boron
			K-INF(X-Y)	5678 kg $U(3)O_2$; 362 kg H_2O
7	4350	60/40	1.085 [d]	1614 gms boron

[a] to within ±0.003 for 1 std. dev.

[b] all cases (except No. 7) reflected by 1 foot all around appropriate borated-water reflector.

[c] storage volume does not contain any structural (internal and external) canister materials or canister poisons.

[d] reflected top and bottom, Z direction by 1 foot of borated water.

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