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US Nuclear Regulatory Commission
Washington, DC 20555

Attention: Document Control Desk

Three Mile Island Nuclear Station, Unit 2 (TMI-2)
Operating License No. DPR-73
Docket No. 50-320
Results of Post-Lower Head Sampling Program Cleanup

Dear Sirs:

The NRC-sponsored Lower Head Sampling Program was successfully completed on March 2, 1990. Some residual fuel was removed by the sampling program and data gathered during the sampling enabled us to improve our knowledge of residual fuel in the incore nozzles. As discussed in the TMI-2 Defueling Completion Report (DCR), a final cleanup was to be conducted immediately following the sampling program. A video inspection of the Lower Core Support Assembly (LCSA) and bottom head regions followed the final cleanup to reassess the amount of core debris remaining. As part of this video inspection, an attempt was made to examine areas of the LCSA that were previously inaccessible.

The result of this work was that the residual fuel estimates have been revised. The total quantity of residual fuel (i.e., UO_2) in the TMI-2 facility is now estimated to be less than 850 kg (i.e., less than 1% of the original core inventory). In addition, analyses have been performed based on as-defueled Reactor Vessel conditions which indicate an increased margin of subcriticality in the TMI-2 Reactor Vessel.

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The attached report provides the results of the March 1990 video inspection, the updated criticality analyses, and clarification of several DCR items discussed with the NRC during the recent review of the DCR. As these changes increase the margin of safety for the TMI-2 facility beyond that described in the DCR, GPU Nuclear intends to transition TMI-2 to Facility Mode 2 on April 27, 1990, as planned.

Sincerely,

M B Roche

M. B. Roche
Director, TMI-2

EDS/mkk

Attachment

cc: T. T. Martin - Deputy Regional Administrator, Region I
J. F. Stolz - Director, Plant Directorate I-4
L. H. Thonus - Project Manager, TMI Site
F. I. Young - Senior Resident Inspector, TMI

Results of Post-Lower Head Sampling Program Cleanup

Following the NRC-sponsored Lower Head Sampling Program, a final cleanup was conducted, as discussed in the TMI-2 Defueling Completion Report (DCR). A video inspection of the Lower Core Support Assembly (LCSA) and bottom head regions was also performed in March 1990 to determine the amount of core debris remaining. This inspection included an examination of areas of the LCSA that were previously inaccessible due to equipment design. As a result, residual fuel estimates have been revised. In addition, the criticality analyses presented in the DCR were based on the September 1989 estimates of residual fuel quantities and locations. Revised analyses have been performed based on the January 1990 "as-defueled" Reactor Vessel (RV) inspection.

The following presents the results of the March 1990 video inspection, the criticality analyses, and clarification of several DCR items previously discussed with the NRC

Results of March 1990 Video Inspection

Based on the March 1990 video inspection, the total quantity of residual fuel (i.e., UO_2) in the LCSA and bottom head regions was reduced to 272.7 and 23.3 kg, respectively (See Table 1). Thus, the total quantity of residual fuel in the RV and the TMI-2 facility is now estimated to be 608.8 and 833.8 kg, respectively. The location and mass of the residual fuel deposits are detailed on a sub-region basis as follows:

Lower Core Support Assembly Region

Between Lower Grid Rib Section (LGRS) and Lower Grid Distributor Plate (LGDP)

The March 1990 video inspection verified that two small masses seen in the January 1990 video inspection, amounting to 1.7 kg of resolidified core debris (Type 3), remain in this area. In addition, there is a thin layer of fine debris (Type 1) uniformly distributed on the surface of the LGDP amounting to 0.9 kg. Therefore, the total quantity of core debris estimated to be in this area is 2.6 kg (2.0 kg UO_2).

LGDP Peripheral Flow Holes

In the January 1990 video inspection of this area, all but two holes were inspected and seen to contain no debris. To be conservative, these holes were assumed to be full of debris. However, the remaining two holes were examined during the March 1990 video inspection and were verified to be empty.

Between LGDP and Forging

During the March 1990 video inspection, it was observed that only one mass of core debris (Type 3) remains in the southeast quadrant rather than the three masses seen during the January 1990 inspection. Based on the estimated volume, a total of 0.3 kg of residual core debris remains. In addition, there is a thin layer of fine debris (Type 1) on the surface of the forging amounting to 1.2 kg. Therefore, the total quanity of core debris in this area is estimated to be 1.5 kg (1.1 kg UO_2).

Forging Peripheral Flow Holes

During the March 1990 video inspection, an attempt was made to insert a camera into each of the six remaining small diameter holes in the forging that were not examined during the January 1990 video inspection. Three of these holes were observed to be void of fuel, one hole was approximately 1/3 full of resolidified debris (Type 3), and one hole was approximately 2/3 full of resolidified debris (Type 3). The remaining hole was verified to be full of small stones, i.e., resolidified debris (Type 3). Of the large diameter flow holes, 21 were observed to contain varying amounts of resolidified debris (Type 3). Based on the estimated volume, there is 123.8 kg of residual core debris (89.9 kg UO_2) remaining in these holes.

Inside Support Post Stubs

The inside support posts were cut off 5.1 to 10.2 cm (2 to 4 inches) above the top of the forging. It was relatively easy to vacuum loose debris (Type 1) out of the stubs. During the cleanup following the Lower Head Sampling Program, the small rocks that were previously seen in the stubs were also vacuumed out. Therefore, no residual core debris remains in these stubs.

Between Forging and Incore Guide Support Plate (IGSP)

The space between the forging and the IGSP is 1.3-cm (1/2-inch) wide where the forging is the thickest. Because of the taper on the forging, the space increases to 20.3 cm (8 inches) at the periphery. This region was cleaned with a flushing tool inserted through a number of the holes in the forging and operated to flush both the hole and the space below the hole. Based on the March 1990 video inspection, it is estimated that there is 180.1 kg of core debris (Type 3) in this region. The bulk of that core debris is in the form of a single solidified mass of approximately 150 kg (110 kg UO_2) in the southeast quadrant of this region. This mass is inaccessible to defueling because of the pattern of cutting of the forging. In any event, the configuration and condition of this mass is such that criticality is not a concern [i.e., mass is less than the Safe Fuel Mass Limit (SFML)].

In addition, there is a thin layer of fine debris (Type 1) uniformly distributed on the surface of the IGSP. Also observed was a piece of fuel rod approximately 30.5-cm (12-inches) in length that was assumed to be filled with fuel pellets and which was located such that it could not be removed. The total amount of Type 1 material is 1.9 kg. Therefore, the total quantity of core debris estimated to be in this area is 182.0 kg of core debris (132.9 kg UO_2). This estimate includes debris observed in the flow holes in the IGSP.

Between IGSP and Flow Distributor

Based on the March 1990 video inspection, it is estimated that there is 6.5 kg of resolidified core debris (Type 3) in this area and 1.1 kg of loose, fine debris (Type 1) distributed on the surfaces of this area. Therefore, the total quantity of core debris estimated to be in this area is 7.6 kg (5.5 kg UO_2).

Bottom Head Region

Head Surface

The bottom head region was examined in the March 1990 video inspection. There appears to be a fine dusting of material (Type 1) distributed over the entire bottom head surface except for two patches where the granular material was somewhat deeper [an average of 0.3-cm (0.1-inch)]. Based on the estimated volume, 11.2 kg of core debris (8.1 kg UO_2) remains in this area.

Incore Instrument Nozzles

Nineteen incore instrument nozzles have partial guide tubes standing above them which could have prevented material from collecting in the nozzles if the instrument strings were still intact (including the spiral seal). Guide tubes around the remaining 33 nozzles have been removed and the instrument strings severed. A number of the nozzles were melted off, some to within 2.5 cm (1 inch) of the head surface. During the Lower Head Sampling Program, 14 of the incore nozzles were cut and removed. These nozzles were videotaped during and following removal. The results of that video examination provide the basis for estimating the remaining residual fuel . As a conservative upper limit, it is assumed that ten of the 33 incore nozzles have the annular space between the instrument string and the inside of the nozzle/guide pipe filled with loose debris (Type 1) to a depth of 2.4 meters (8 feet), ten contain no debris, and 13 contain a 2.5-cm (1-inch) long plug of resolidified fuel material in the annular space. Based on the estimated volumes, 12.5 kg of loose core debris (Type 1) and 0.3 kg of resolidified debris (Type 3) are estimated to reside in these locations. Therefore, the total quantity of core debris estimated to be in this area is 12.8 kg (9.2 kg UO_2).

Standing Incore Guide Tubes

The quantity of core debris reported in the DCR was in error. The correct value is 8.2 kg of core debris (6.0 kg UO_2) remaining in this area.

Reactor Vessel Residual Fuel Criticality Assessment

Criticality Safety Analysis

An updated criticality safety analysis was performed based on the January 1990 video inspection results. That analysis incorporated a more conservative approach than that reported in the DCR in that the fuel debris was modelled entirely as burned batch 3 fuel (i.e., 2.67 wt % U-235 enrichment). The analysis discussed here was developed for actual plant conditions (i.e., as existed in January 1990). The criticality calculations presented were performed by Oak Ridge National Laboratory (ORNL) and were reported in Reference 1.

The model, shown in Figure 1, represents the end state RV condition following the completion of in-vessel defueling (i.e., January 1990). The three major areas where core debris resides are the RV bottom head, the LCSA, and the core former area (i.e., between the core former baffle plates and the core barrel) in the Upper Core Support Assembly (UCSA). Fuel accumulations in other locations within the vessel were considered to be too small (i.e., much less than the SFML) and/or separated from these three areas by a far enough distance [i.e., the equivalent of approximately 30.5 cm (12 inches) of water, Reference 2] so as not to cause a reactivity increase due to neutronic interaction between these areas. Additionally, the conservative debris quantities that were modelled will more than compensate for the small quantity of debris not specifically modelled. Details of the modelling of each of the regions follow:

Core Former Region

To conservatively model remaining debris in the core former area, it was assumed that a 0.3-cm (0.1-inch) thick, 3-meter (10-foot) high surface debris layer remained attached to the core barrel. This conservative representation of the core former region also bounds the limited amount of core debris that remains in the regions above/outside the UCSA.

Lower Core Support Assembly

The major focus and detail of the geometrical model occurred in the modelling of this region. The LGRS and LGDP were assumed to be of the same radial thickness [i.e., 12.7 cm (5 inches), ΔR of Figure 1] and the lower grid forging and the IGSP were assumed to be of the same radial thickness [i.e., 50.8 cm (20 inches), ΔR of Figure 1].

The flow holes in both the LGRS and the LGDP are void of fuel. There is some debris on these plates but much less than is modelled (Figure 1). The flow holes in the forging were assumed to be filled such that 50% of the forging volume in the model is comprised of a debris/water mixture and 50% is stainless steel. To account for the small amount of core debris remaining in the IGSP flow holes, this plate was modelled as two regions. The inner region contained only water and steel (i.e., the plate holes are empty). The outer region (i.e., closer to the vessel wall) was modelled with the holes completely filled with an optimally moderated core debris/water mixture. The inner and outer regions of the IGSP were 35.6 cm (14 inches) and 15.2 cm (6 inches), respectively, in radial thickness. An additional conservative assumption included in the model was that the flow holes in the forging were filled with fuel and unborated water in an optimal mixture, even though, many of the holes were free of debris.

Although significant portions of the LCSA plates were free of debris, a debris layer was applied to each of the modelled LCSA plates to account for any debris that could not be removed from the plate surfaces. These debris layers were conservatively assumed to extend the entire 360° around the RV.

The thickness of the debris layer on top of the LGRS was assumed to be 0.3 cm (0.1 inch). Between the LGRS and the LGDP, two debris accumulations were modelled. The first was a 0.3-cm (0.1-inch) radial thickness accumulation located on the outer periphery of this region which extended axially the entire distance between the two plates. The second debris layer modelled in this region was a 0.3-cm (0.1-inch) thickness placed on top of the LGDP. The region between the LGDP and the lower grid forging was similarly modelled with these two debris layers.

Due to the small separation distance between the lower grid forging and the IGSP [i.e., 1.3-cm (1/2-inch)], there has been limited access to the area underneath the lower grid forging. However, to support the conservative approach, the amount of core debris modelled in this region was assumed to be much larger than that assumed for other areas of the LCSA. Based on the January 1990 video inspection, the core debris was assumed to fill the outer 20.3 cm (8 inches) from the vessel wall inward over the entire distance separating the lower grid forging from the IGSP. The remaining radial 17.8 cm (7 inches) of this region were free of debris accumulations and were modelled as unborated water only. Underneath the IGSP, a 3.8-cm (1.5-inch) layer of debris with a 5.1-cm (2-inch) radial thickness was modelled representing debris left in the "knuckle" of the flow distributor plate.

The actual vertical offsetting of the plates was conservatively neglected. Instead, the LCSA plates were assumed to have a constant outer radius corresponding to the lower grid forging. Similarly, the core former and the bottom head regions were conservatively assumed to connect directly to the LCSA. No consideration was given for the effect of offsetting of these regions. This approach modelled the various regions as being closer to each other than actual, implying neutron interaction between the modelled debris accumulations.

A 20.3-cm (8-inch) carbon steel region was placed on the outside of the annular ring to represent the RV wall. This approach essentially moved the water region between the core barrel and the vessel wall to outside the vessel. This was considered appropriate and conservative since only small accumulations of debris fines were found in this region and because analyses have shown steel to be a better neutron reflector than unborated water. Finally, an unborated water reflector of effectively infinite thickness was placed outside the carbon steel region.

Reactor Vessel Bottom Head

Using a conservative approach, a 0.4-cm (0.15-inch) layer of core debris covering the entire inside surface of the bottom head was assumed to exist in the model for this criticality assessment; this amount of material is greater than that observed in the bottom head region.

Conservative Approach Summary

As discussed above, significant conservative assumptions were built into the geometrical model for this analysis. These conservative assumptions are summarized below:

- Conservative values for the modelled layers of core debris on the LCSA plates.
- The entire inside surface of the RV bottom head was assumed to be covered with a 0.4-cm (0.15-inch) thick layer of core debris.
- A 0.3-cm (0.1-inch) thick layer of core debris, with a height of 3 meters (10 feet), was assumed to be attached to the core barrel in the core former region of the model.
- No credit was taken for the vertical offsetting of the LCSA plates or the other regions of the model, and the regions between the plates were conservatively modelled.
- Each of the LCSA plates was modelled with a radial thickness that bounded the presence of core debris on the plate.
- The modelled debris and vessel internals were assumed to extend 360° around the periphery of the RV.
- The flow holes, as modelled for the forging, were assumed to be filled with core debris and unborated water in an optimal mixture.
- Unborated water was assumed to fill all portions of the RV, excluding the modelled debris accumulations and vessel internals.
- No credit was taken for the plans to eventually drain the RCS, essentially leaving the RV without a moderating medium.
- Considerably more core debris was included in the analytical model than remains in the RV (see Table 2).

Considering the above approach and the condition of the RV following defueling, it was concluded that the geometrical model described above, including the postulated core debris locations, was conservative and appropriately bounds the RV configuration that exists.

Fuel Modelling

The original loading of the core included 56 assemblies of 1.98 wt% (batch 1), 61 assemblies of 2.64 wt% (batch 2), and 60 assemblies of 2.96 wt% (batch 3) U-235 enrichment. The enrichment of the fuel used in this evaluation was that corresponding to burned batch 3 fuel (i.e., 2.67 wt% U-235 enrichment). This extremely conservative assumption bounds the enrichment of fuel remaining in the RV. The fuel was represented as a homogeneous medium for which the neutronic data corresponded to a dodecahedral lattice of spherically shaped fuel pellets. The size of the spherical pellets was the equivalent of standard cylindrical fuel pellets. Another maximum reactivity assumption was the preservation of the pellet surface to mass ratio in the fuel pellet volume. This assumption enhanced the resonance shielding effect on the U-238 cross-sections. Conservatively, it was also assumed that there was nothing present in the fissile media except fuel pellets and unborated water. Thus, the negative reactivity effects due to the presence of cladding, absorber material and structural materials were ignored.

Unborated water was used for the moderating medium. The presence of residual boron which would remain in the RV following the draining process has been ignored. Furthermore, an optimum fuel volume fraction (i.e, resulting in a maximum k_{∞}) for fuel and unborated water (VF = 0.28) was determined and used in this evaluation.

The optimal fuel particle size for UO_2 particles moderated with unborated water was shown in previous analyses to be greater than a standard-size fuel pellet. However, any core debris particles larger than standard-size pellets were considered to contain impurities, as melting and subsequent resolidification was the only credible means by which the larger particles could have been formed. In such a process the other materials within the vessel (e.g., cladding, structural materials, and poisons) would have intermixed with the fuel, thus reducing the reactivity of the debris. Furthermore, particle sizes less than a standard-size pellet have been shown to be significantly less reactive than full pellets. Defueling experience has indicated that particle sizes much smaller than standard pellets are representative of the remaining core debris. Consequently, in accordance with the conservative method used, the spherical equivalent of standard full-size pellets was assumed for this evaluation.

As discussed above, a significantly conservative approach was included in the development of the analytical fuel model. This conservative approach is summarized below:

- No credit was taken for the structural or solid materials existing in the debris, though sample data has shown the presence of impurities in all samples evaluated to date.

- Unborated water, optimally mixed with the core debris, was assumed for the moderating material in all fuel bearing regions of the model.

- The fuel particle size was assumed to be the equivalent of standard full-size pellets.

- Actual fission product retention was considerably greater than that which was assumed in the analysis.

- The fuel enrichment was represented as 100% TMI-2 batch 3 burned fuel. Batch 3 fuel is the most highly enriched of the TMI-2 fuel.

Results

To evaluate the criticality safety consequences of the residual core debris in the RV, ORNL performed an analysis using the Monte Carlo computer program KENO V.a (Reference 3) and the model described above. The result of this analysis, provided in Reference 1, is a calculated neutron multiplication factor (k_{eff}) for this case of 0.945 which includes the addition of 0.025 Δk for computer code bias.

It is therefore concluded that the residual core debris in the RV will remain subcritical. Furthermore, because the core debris in the vessel is well separated from ex-vessel debris locations, the effect of neutronic coupling between in- and ex-vessel debris accumulations will be negligible during post-defueling plant conditions.

The analyses were performed assuming that the debris was optimally moderated with unborated water; therefore, the above conclusions would be applicable whether or not the RV is drained. A significant reactivity reduction would be expected with reduced moderation, which would be representative of the draining of the vessel.

Criticality Event Analysis

The analysis discussed above applies to the currently estimated residual core debris quantity, its configuration, and its distribution within the RV. The analysis demonstrated that there is no potential for a criticality event. This section evaluates the criticality safety of a potential relocation and accumulation of substantial residual core debris to the bottom head.

With approximately 609 kg of residual fuel (UO_2) in the RV, it can be postulated that the drying and spalling of surface films, a seismic event, aging and corrosion, or other unidentified events could cause the residual core debris to accumulate in one area resulting in a potentially critical mass. However, as evidenced by the extensive defueling effort, the residual core debris and contained fuel has consistently resisted multiple removal attempts by aggressive mechanical means. Nonetheless, because the total amount of residual fuel in the RV exceeds the SFML, it is necessary to evaluate the significance of a relocation and accumulation of a larger quantity of residual fuel. Therefore, the following evaluation bounds any credible fuel relocation.

The worst-case accumulation of core debris would occur if a substantial quantity of debris relocated to the bottom head. If this occurred, it is considered incredible for the debris to collect in an ideal spherical geometry. The vessel geometry would not facilitate collection in such a small and confined arrangement. Most likely, debris would collect on the bottom head in a pile or layer. The relatively large surface area of such a geometry would significantly enchance neutron leakage and, thus, reduce k_{eff}. This effect was seen in the results of an analysis performed by ORNL. The analysis assumed more than half of the remaining core debris in the RV (i.e., 350 kg) would collect in the bottom head. The 350 kg value conservatively bounds the total quantity of Type 1 debris (i.e., loose, fine, granular debris) and Type 2 debris (i.e., surface films) that could accumulate in the bottom head. The Type 3 debris (i.e., resolidified material) most likely will remain in place and accounts for approximately 339 kg of the 609 kg total in the RV. As a modelling conservative assumption, the relocation included the Type 1 material in the annular gap between the thermal shield and the core barrel, a quantity of approximately 119 kg, that most likely would not relocate due to the geometric configuration and confinement of that volume.

The assumed configuration of the debris is shown in Figure 2. Region L_1 contains an optimal mixture of 350 kg of core debris and unborated water. Region L_2 contains approximately 500 gallons of unborated water. The height of L_2 is large enough to consider it an effectively infinite water reflector. This 500 gallons is significantly more water than is expected to accumulate in the RV throughout PDMS. The core debris was assumed to be 2.67 wt% U-235 (i.e., burned batch 3 fuel), standard fuel pellets, and contained no impurities. The resultant neutron multiplication for this configuration was $k_{eff} = 0.913$ (Reference 1), including a 0.025 Δk computer code bias. Thus, there is no criticality safety concern associated with this unlikely occurrence and resultant configuration.

References:

1. Letter, C. V. Parks, Oak Ridge National Laboratory, to D. S. Williams, GPU Nuclear Corporation, April 9, 1990.

2. Nuclear Safety Guide, TID-7016, Thomas, J. T., Revision 2, June 1978.

3. NUREG/CR-0200, Petrie, L. M., et. al., KENO V.a: An Improved Monte Carlo Criticality Program with Super-Grouping, included as Section F11 in SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluations, Vols. 1-3, U.S. Nuclear Regulatory Commission, Revision 3, December 1984.

Clarification of DCR Items

AFHB Cubicle FH304

AFHB cubicle FH304 was inadvertently omitted from the DCR Table 5-1, i.e., AFHB Cubicles which Contains No Residual Fuel. FH304 is the annular area on the 347'-6" elevation between the Reactor Building and the Auxiliary Building. All pathways have been isolated since the accident; thus, this area is void of fuel.

Results of SRG Reviews

The TMI-2 Safety Review Group (SRG) performed a detailed review of the preparations and conduct of the residual fuel measurements and the derivation of the residual fuel values reported in the DCR. The elements of the fuel measurements program evaluated by the SRG included the video inspection plan, the sample data supporting DCR fuel mass assumptions, an independent review of the videotapes, a verification of the computer program, observations of videotape data collection, a review of post-inspection in-vessel work activities and the subsequent March 1990 video inspection. During the review of the computer program methodology for determining the volume of fuel in specific locations, a conservative worst case approach was used to ensure that there was no potential for the residual fuel quantities reported in the DCR to exceed those used in the criticality safety model.

The SRG concluded that the residual fuel measurements were adequately performed, provided a bounding estimate of the residual fuel mass and were sufficiently accurate to ensure that the residual fuel was properly identified by location and quantity. A comparison of the residual fuel measurement results to the DCR criticality safety analysis for the RV found that the analysis bounded the final residual fuel configuration. Therefore, the SRG concluded that the measurements were adequate and agreed with the DCR conclusion that criticality safety was assured.

DCR Table 5-10 Reference Errors

The correct references for the sample analyses detailed on the DCR Table 5-10 are as follows:

Sample	Reference
OTSG '8'	5.15
Core Debris	5.34
Bottom Head	5.37
Pressurizer	5.52
MUF-5B (B&W)	5.51
MUF-5B (0104)	5.51
MUF-5B (0105)	5.51
MUF-58 (0111)	5.51

TABLE 1

RESIDUAL FUEL QUANTIFICATION IN THE REACTOR VESSEL

LOCATION	DEBRIS TYPE *	CORE DEBRIS (kg)	RESIDUAL FUEL (kg UO2)
Work Platform Region and Suspended Equipment			
Westinghouse Vacuum Pump Module	1	1.3	0.9
In-Vessel Filtration System	1	22.7	16.3
Canister Positioning System	1	19.0	13.7
DWCS Inlet/Outlet Piping	N/A	0	0
Subtotal		43.0	30.9
Downcomer Region			
Cold Leg Flow Deflectors	1	16.5	11.9
Hot Leg Bosses in CSS	1	37.0	26.6
Outer Surface of CSS	N/A	0	0
Surface Deposits on RV Cylindrical Shell	N/A	0	0
Thermal Shield Outer Surface	N/A	0	0
Surveillance Specimen Capsule Holders	1	4.9	3.5
Thermal Shield Support Blocks (Top Surface)	1	21.2	15.2
Thermal Shield Inner Surface and Annular Gap	1	164.9	118.6
Drain Holes at Bottom of Thermal Shield	3	0.3	0.2
Core Catchers/Seismic Restraint Blocks	1	4.0	2.9
Subtotal		248.8	178.9
Internals Indexing Fixture Region			
RV Flange, IIF Flange, and CSS Flange	1	6.8	4.9
Internals Indexing Fixture Inside Surface	N/A	0	0
Subtotal		6.8	4.9

* Debris Type: 1 = Loose/Fine Debris
2 = Surface Film Material
3 = Resolidified Material

**Includes fuel rod piece assumed full of fuel pellets; the weight per length of rod segment is 1 kg/m and contains 80.3 % UO_2 (Reference 5.70).

TABLE 1 (Cont'd)

RESIDUAL FUEL QUANTIFICATION IN THE REACTOR VESSEL

LOCATION	DEBRIS TYPE	CORE DEBRIS (kg)	RESIDUAL FUEL (kg UO2)
CSS Region			
Vent Valve Seats (Inner Surfaces)	1	12.2	8.7
Hot Leg Openings	1	0.3	0.2
LOCA Bosses	1	1.1	0.8
Inner Surface of CSS	N/A	0	0
Top of Lower CSS Flange	1	1.4	1.0
Subtotal		15.0	10.7
UCSA Region			
Baffle Plate Inside Surface	3	23.3	17.0
Baffle Plate Outside Surface	3	23.3	17.0
Baffle Plate Flow Holes and Bolt Holes	1	14.6	10.5
Former Plates Top and Bottom Surfaces	1,3	54.8	39.9
Former Plates Edge Holes	N/A	0	0
Core Barrel Inner Surface	N/A	0	0
Orifice Holes to Thermal Shield Gap	3	1.3	0.9
Subtotal		117.3	85.3
LCSA Region			
LGRS Top Surface and Peripheral Flow Holes	1,3	56.6	41.3
Between LGRS and LGDP	1,3	2.6	2.0
LGDP Peripheral Flow Holes	N/A	0	0
Between LGDP and Forging	1,3	1.5	1.1
Forging Peripheral Flow Holes	3	123.8	89.9
Inside Support Post Stubs	N/A	0	0
Between Forging and IGSP (includes IGSP Flow Holes)	1,3	182.0**	132.9**
Between IGSP and Flow Distributor	1,3	7.6	5.5
Flow Distributor Flow Holes	N/A	0	0
Subtotal		374.1	272.7
Bottom Head Region			
Head Surface	1	11.2	8.1
Incore Instrument Nozzles	1,3	12.8	9.2
Standing Incore Guide Tubes	3	8.2	6.0
Subtotal		32.2	23.3
Surface Film Deposits (See Table 5-6)	2	N/A	2.1

TOTAL = 608.8 kg

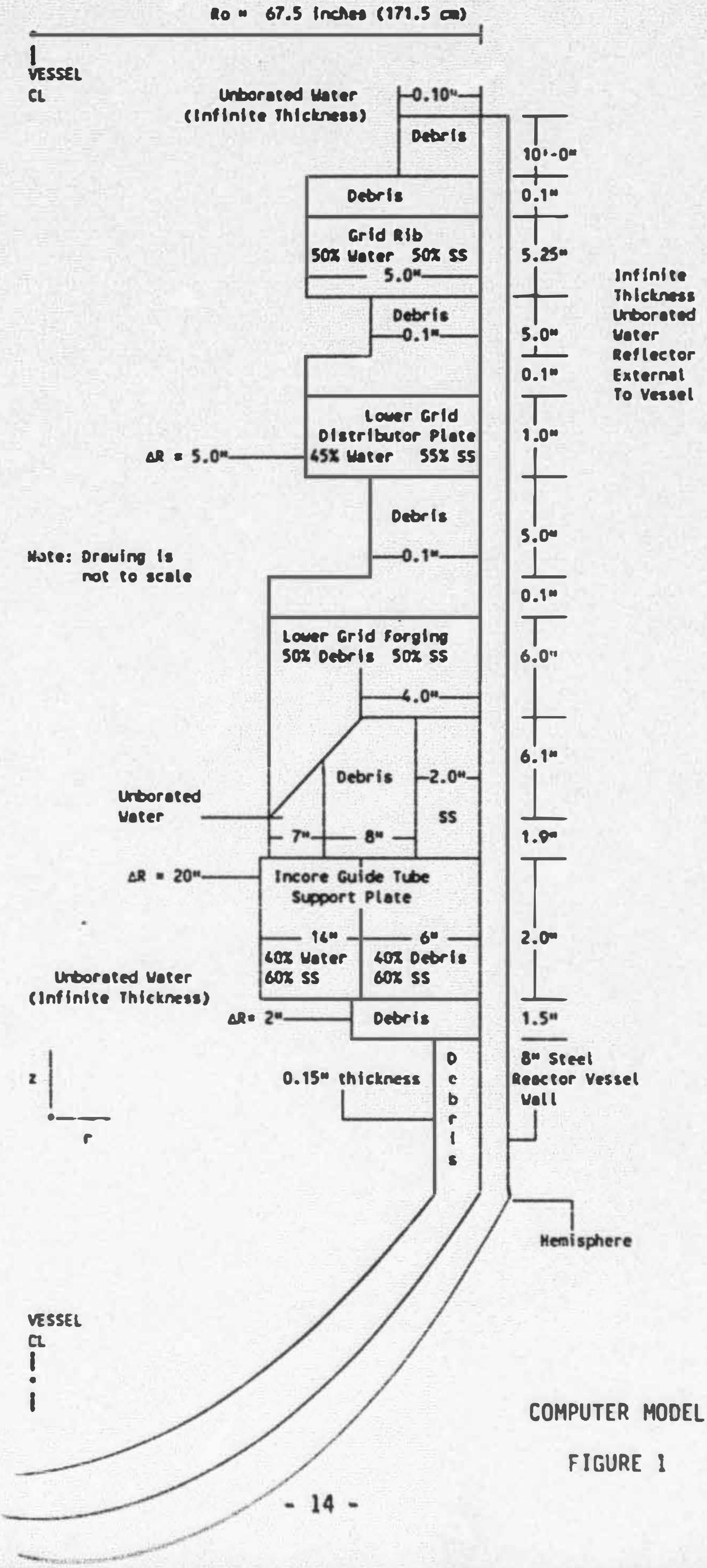
0531P

TABLE 2

COMPARISON OF MODEL TO ESTIMATED REMAINING FUEL MASSES

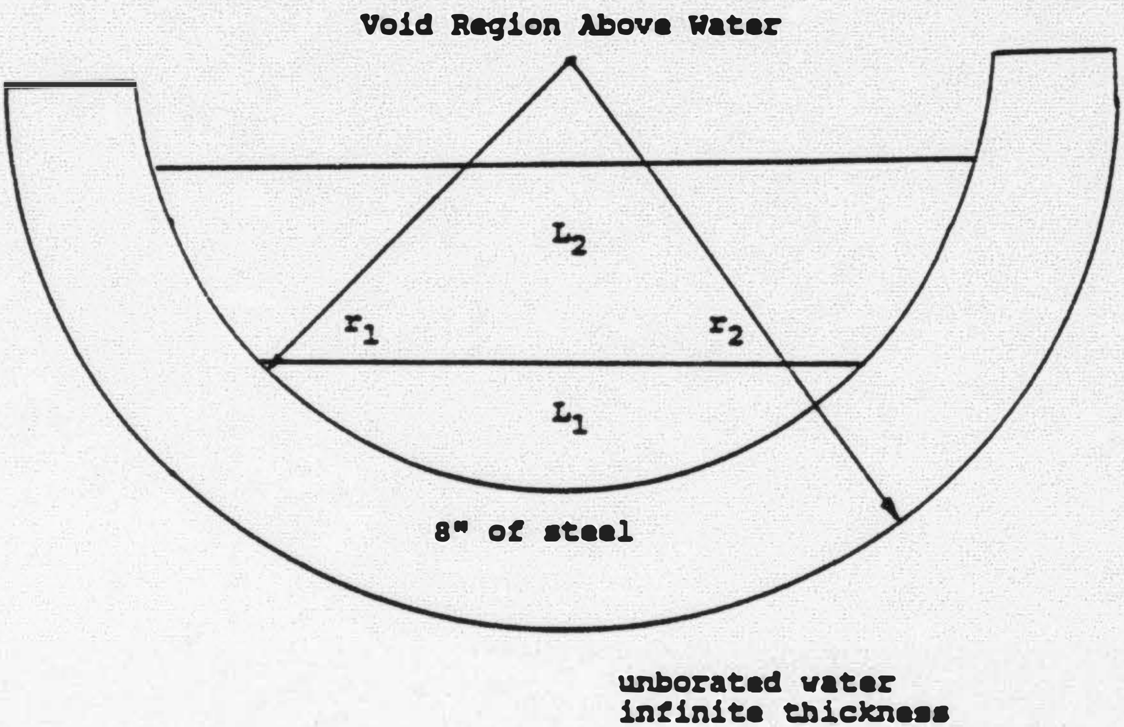
	MASS OF UO_2 (kg)	
LOCATION	ESTIMATED	MODEL
Bottom Head	23.3	200
UCSA	85.3	240
LCSA	272.7	2,470

NOTES:
1. Estimated quantities were taken from Table 1 of this document.
2. The other regions of the RV that contain debris were considered to be separated from the areas of interest by large distances [>30.5 cm (12 inches)] and/or to have smaller-than-SFML quantities.
3. The neutron multiplication of a fuel mass is not only influenced by mass; the configuration of the mass is also an important consideration.



COMPUTER MODEL

FIGURE 1



r_1 = 217.7 cm $\qquad$ r_2 = 238.0 cm

L_1 = region containing 350 kg of core debris and unborated water

L_2 = region containing ~500 gallons of unborated water

BOTTOM HEAD FUEL MODEL

Figure 2