5.2 Reactor Building

During the accident, fuel was transported to the RB as a result of the core degradation event and coolant flow from the RV through the PORV and RCS MU&P System. Table 2-1 reported that approximately 11 kg of fuel was transported to the RB during the accident sequence. Subsequent to the accident, fuel was relocated to the RB as a result of several cleanup operations including: transfer to and storage of structural RV components in the "A" CFT and "A" D-ring; storage of upper end fittings; flushing of defueling tools; and transfer of the defueling canisters into the FTC. Even though fuel was relocated to the RB during cleanup operations, RB residual fuel conditions were maintained significantly below the SFML. Further, a significant cleanup effort was undertaken (as described in Section 4.2) with the primary purpose of reducing exposure rates but which also resulted in the removal of additional core debris.

The following sections provide the current estimates of residual fuel remaining within the RB, not including the RCS and RV. These estimates are based on fuel measurements, visual inspections, and extensive evaluations of RB structures, systems, and components. The basis for each estimate is provided. As noted in Section 3.6, some of the reported residual fuel quantities are referred to as MDL indicating that the actual quantity of residual fuel is less than or equal to the reported value.

5.2.1 Reactor Vessel Head Assembly (Reference 5.7)

The RV head assembly was removed from the RV and placed on its storage stand on the 347' elevation in July 1984. Portions of the head structure that were exposed to reactor coolant include the dome, flange, leadscrews, leadscrew support tubes, and leadscrew motor housing. Only these components were considered when calculating fuel content in the head assembly. During and after the core degradation portion of the accident, the control rod assemblies were fully inserted into the core region. The leadscrews were, therefore, extended into the plenum area inside their support tubes. Because of the close proximity of the leadscrews to the head surfaces, leadscrew fuel deposition data is taken as an analog for fuel deposition on head surfaces.

In November 1982, three (3) leadscrews were removed for analysis. Fuel analyses were performed on two (2) of the samples by Battelle Columbus Laboratories, Science Applications, International Corporation, and Babcock and Wilcox. Also, a sample of a leadscrew support tube was analyzed for radionuclide activity on both internal and external surfaces.

The fuel content of the leadscrews was extrapolated from direct fuel assay of the leadscrew samples. The fuel content of the other RV head assembly components was calculated by:

- determining the Ce-144 activity on leadscrew surfaces by gamma spectroscopy and the fuel activity on the leadscrew surfaces by direct assay;

- adjusting the activity distribution as evidenced by the internal/external contamination ratio on the leadscrew support tube sample;

- dividing by the average Ce-144/fuel ratio determined for the leadscrews to get a fuel to surface area value;

- multiplying the fuel/area ratio by the corresponding surface area for the RV head assembly component in question.

Visual inspection was done of the RV head assembly and no desposits were observed in the structure. Considering the force of gravity and the RV head assembly geometry, gravel-like material is not expected to be on the RV head.

Summing the component fuel values produced the total fuel estimate for the RV head assembly. The preliminary estimate of fuel in the RV head assembly is 1.4 kg, primarily in the form of surface films.

5.2.2 Reactor Vessel Upper Plenum Assembly (Reference 5.8)

During reactor operation, the plenum is located directly above the reactor core and below the RV head assembly. It consists of a cover, CRA guide tube assemblies (guide tubes), upper grid (at the bottom of the plenum), and the flanged plenum cylinder with openings for reactor coolant flow (see Figures 5-5 and 5-6). CRA guide tube assemblies provide CRA alignment, protect CRAs from coolant cross-flow, and provide structural attachment of the grid assembly to the plenum cover. The leadscrews, which move the CRAs in and out of the core, were inside the guide tubes during the accident. The 69 guide tubes are vertical cylinders that constitute the majority of the surface area in the plenum assembly.

During the accident, fuel particles were transported to the plenum when large amounts of reactor coolant flow, steam, and hydrogen passed through it. Fuel was deposited in sediment and surface films on the plenum surfaces. In May 1935, the plenum was lifted from the RV and placed on a storage stand in the deep end of the FTC. The plenum was flushed to remove loose surface debris, prior to its removal from the RV.

The calculation of fuel loading in the plenum is based on analysis of samples from two (2) leadscrews and one (1) leadscrew support tube which are composed of similar material to the plenum and whose fuel deposition is believed to be representative of the plenum. The two (2) leadscrews were in the plenum during the accident and were removed before plenum lift. The fuel activity found on the leadscrews was extrapolated to the total surface area of the plenum components exposed to coolant flow. Data from the leadscrew support tube was used to correct for high and low flow areas in the plenum assembly.

A small fraction of the total surface area of the plenum consists of upward-facing horizontal surfaces. To account for the settling of fine sediment on these surfaces, the difference between threaded and non-threaded leadscrew surface activity was applied. Higher activity levels on threaded surfaces were assumed to be the result of settling of fine debris in the threads. A high and low flow correction was also applied to this portion of the calculation.

A conservative estimate of the residual fuel quantity in the plenum is:

Surface Films	1.5 kg
Silt/Sediment	0.6 kg
TOTAL	2.1 kg

5.2.3 Fuel Transfer Canal

The vast majority of the fuel in the FTC is contained inside the fuel, filter, and knockout canisters located in the fuel racks. The exact number of filled canisters will vary until all fuel bearing canisters have been transferred to Spent Fuel Pool "A" for shipment to INEL. The canisters are stored in an inherently subcritical array within the fuel storage racks. Further, during Mode 1 the TMI-2 Technical Specifications require that the water in the FTC will be borated to a concentration of 4350-6000 ppm. Therefore, subcriticality is currently ensured under all credible conditions notwithstanding that a very small amount of uncontained fuel may be accumulating at the bottom of the FTC, having been transported from the RV to the FTC as debris adherent to the outside of the fuel bearing canisters.

Since each canister is flushed prior to transfer from the RV, the quantity of uncontained residual fuel potentially accumulating in the FTC, as a result of canister transfer operations, is expected to be a very small fraction of the SFML and will pose no criticality concern. Additionally, the residual fuel in FTC will not pose a potential for communicating with other fuel locations in the RB. GPU Nuclear is currently performing fuel measurements of the FTC. Results of these measurements will be provided in a subsequent DCR submittal.

5.2.4 Core Flood System (References 5.9 through 5.13)

The core flood system consists of two (2) tanks and piping into the RV (see Figure 2.4). During LCSA defueling, the top of the "A" CFT was removed and the tank was used for storage of LCSA components. Additionally, the piping from the "A" CFT to the RV was cut and flanged which will prevent the possibility of fuel transport. Storage of the LCSA components outside but in proximity to the RV (e.g., in the "A" CFT) was deemed necessary to permit continuous progress in the RV defueling activities. Prior to removal from the RV, the LCSA segements were flushed and brushed to remove fuel. The segments were then video inspected to ensure that no visible fuel was present. Sample sections of each plate were measured by gamma spectroscopy and/or alpha measurements to determine the quantity of residual fuel. Extrapolation of fuel content in other sections was determined based on the fuel quantity of the measured sections. For example, two (2) of the four (4) quadrants of the lower grid distributor plate were measured for fuel content and determined to contain a total residual fuel quantity of 163 grams. These measurements were extrapolated for the other two (2) quadrants and a total residual fuel quantity of 320 grams of residual fuel was assigned to the lower grid distributor grid (Reference 5.10). Likewise, one (1) of the 11 pieces of the flow distributor plate was measured for fuel content (Reference 5.13). Its residual fuel value (i.e., 10 grams) was deemed to be representative of the remaining segments and a total residual fuel quantity of 110 grams was assigned for the flow distributor plate.

Based on the above approach, the "A" CFT, which contains the LCSA components, has been assigned a total of approximately 2.4 kg (References 5.9 through 5.13) of residual fuel, distributed as follows:

Components	Fuel (kg)
Lower Grid Rib Section	<0.1
Lower Grid Distributor Plate	<0.3*
Lower Grid Forging	1.7
Incore Guide Support Plate	<0.2*
Flow Distributor Plate	0.1
TOTAL	2.4

* = MDL value

The portion of the "B" core flood line between the CFT and the check valve was measured for fuel debris using both a directional gamma probe and a cadmium telluride gamma spectrometer. This measurement determined a maximum residual fuel quantity of 130 grams (Reference 2.12).

Measurement of the residual fuel in the "B" CFT and the "A" core flood line are planned and will be provided in a subsequent DCR submittal. Based on the residual fuel content in the "B" core flood line, the residual fuel quantity in these areas is not expected to substantially increase the current core flood system estimate. There are no post-defueling plans to remove the LCSA components stored in the "A" CFT due to the relatively small quantity of residual fuel involved.

5.2.5 D-Rings (Reference 5.13)

The only residual fuel in the D-rings above the basement level (basement is discussed in Section 5.2.9) is located in the flow distributor plate sections stored therein. Sections of the flow distributor plate removed from the RV which contained IIGTs were too large to be placed in the "A" CFT. These sections were bagged and suspended in the "A" D-ring in order to prevent interference with continued progress in the RV defueling efforts. These sections were brushed and flushed prior to removal from the RV.

Gamma spectrometry performed on 13 of the 14 segments placed in the D-rings, containing a total of 30 IIGTs determined that these segments contain 21 kg of residual fuel. The remaining segment which was not measured for residual fuel, contains three (3) IIGTs. Based on a simple arithmetic average of the amount of fuel per IIGT of the unmeasured segments (i.e., 21 kg per 30 IIGTs), it is reasonably estimated that the unmeasured segment contains approximately 2 kg of residual fuel (i.e., 0.7 kg per IIGT multiplied by 3 IIGTs). This estimate is believed to be conservative because the unmeasured segment was in the northwest quadrant of the flow distributor plate whereas the measured segments which contained the largest quantities of residual fuel were generally located in the southeast quadrant of the flow distributor plate. Thus, the total estimated amount of residual fuel in the "A" D-ring is 23 kg. Further assessment of the LCSA components in the "A" D-rings is provided in Section 6.0.

5.2.6 Upper Endfitting Storage Area

As described in Section 4.4.3.2.1, during RV defueling, loose upper endfittings were removed from the surface of the RV debris bed to allow access for defueling. These endfittings were too large to be inserted into fuel canisters; thus, they were placed in shielded drums filled with borated water (i.e., 4350-6000 ppm) and stored at elevation 347' in the RB. Storage of these upper endfittings is described in an NRC-approved SER (References 5.14 and 5.15).

Currently, there is a total of 18 upper endfittings stored in a total of five (5) containers in the endfitting storage area. The maximum number of endfittings in a single container is six (6). Reference 5.14 conservatively estimated that each endfitting could contain up to 3 kg of fuel if fuel were packed solidly within the flow spaces in the endfitting casings. Based on the maximum of six (6) endfittings per container, the maximum estimated fuel in any container would be 18 kg. This amount is significantly less than the SFML. Additionally, if all of the 18 endfittings were loaded with fuel to the maximum theoretical value (i.e., 3 kg of fuel), the total maximum amount of fuel is conservatively estimated to 54 kg. This quantity is also significantly less than the SFML. Furthermore, the upper endfitting storage area is neutronically decoupled from any other fuel bearing location; thus, subcriticality is assured.

GPU Nuclear is planning to measure the upper endfitting storage containers in order to quantify the amount of fuel in each container (Reference 16). This section will be updated in a subsequent DCR submittal to reflect the results of the survey program.

5.2.7 Reactor Coolant Drain Tank (Reference 4.20)

As described in Section 2.2.3, fuel was deposited in the RCDT as a result of the accident. This tank provided a settling point for particles escaping from the PORV before release to the RB basement. The RCDT has been inaccessible for defueling operations due to the high dose rates in the RB basement.

In 1983, sludge samples were collected and video inspections were performed. Analysis of the samples yielded a uranium concentration of 3.7 mg/g in the sludge. This, combined with an estimate of the quantity of sludge in the tank (2.6×10^4 g), adjusted to UO_2, produced an estimate of fuel in the RCDT of approximately 0.1 kg. This residual fuel quantity is deemed to be valid since there have been no defueling or decontamination activities performed in the RCDT.

5.2.8 Letdown Coolers (Reference 5.17)

The letdown cooler cubicle, located in the RB basement, contains the letdown coolers (MU-C-1A and 1B) and associated piping. This system was designed to cool the reactor coolant before it entered the rest of the MU&P System for processing. Portions of the MU&P System ran continuously before and during the accident, and have run since the accident, potentially transporting small amounts of core debris throughout the system. Residual fuel in most MU&P components is discussed in Section 5.1.

Fuel in the letdown cooler system was measured with a collimated, shielded sodium iodide gamma spectrometer. Calculations were made using computer codes to model the associated piping, coolers, and detector configurations. The calculated residual fuel content of the letdown coolers system is less than or equal to an MDL value of 4 kg.

5.2.9 RB Basement and Sump (Reference 5.18)

The RB basement consists of the space between the floors of elevations 282'6" and 305' of the RB, the RB sump, and the floor drains. Excluded from this section and treated elsewhere in this report is equipment (e. g., the letdown coolers and RCDT) located in the basement.

During the accident, reactor coolant was discharged from the RCS into the RCDT and then into the RB basement. Table 2-1 indicates that the RB basement/sump contained approximately 5 kg of fuel as a result of the accident. The reactor coolant that was discharged into the RB became mixed with sediment-bearing river water, RB spray water, decontamination water, condensation, and additional leakage from the RCS. The basement remained flooded for approximately two (2) years. During this period, sediment and fuel fines settled into a sludge on the basement floor. As discussed in Section 4.2, a significant portion of this sludge was removed during cleanup operations in the RB basement.

The sludge remaining after desludging operations was analyzed by sampling and gamma spectroscopy methods. Uranium concentrations measured in three (3) samples were combined with estimates of residual sediment volume to calculate the total residual fuel on the basement floor excluding the RCDT discharge area. A gamma scan was performed in the RCDT area since the maximum amount of fuel was initially expected to be located in the RCDT. The total fuel contained in the remaining basement sludge following cleanup operations is estimated to be approximately 1.1 kg.

Additionally, fuel particles from washdown of defueling tools was transported through the RB drain system to the RB sump. Reference 5.18 provides an initial estimate that 0.2 kg of fuel could have been added to the basement inventory from this activity. Thus, the total fuel in the RB basement is currently estimated to be 1.3 kg.

5.2.10 Miscellaneous Systems and Equipment

In addition to the residual fuel quantities reported in Sections 5.2.1 through 5.2.9, residual fuel is expected to be contained in various systems/equipment located in the RB which were utilized during the defueling effort. Included are the DWCS and the Defueling Tool Rack which contains the various long-handled tools used to defuel the RV. Residual fuel contained in these operating cleanup systems/equipment is expected to amount to a very small fraction of the SFML and will pose no criticality concern. For example, the NRC approved DWCS Technical Evaluation Report (TER) (Reference 5.19) states that the DWCS has been designed to prevent a possible critical configuration of fuel. Further, the DWCS will be internally flushed and partially disassembled prior to being decommissioned. This action will remove a portion of the internal deposits of residual fuel contained in the DWCS. Additionally, as discussed in Section 5.2.9, defueling tools are generally flushed prior to removal from the RV in order to remove any loose residual fuel. The estimate of residual fuel in these cleanup systems will be provided in a subsequent DCR submittal.

5.2.11 Criticality Assessment

Table 5-2 lists the total quantity of residual fuel in the RB exclusive of the RCS and RV. This table will be updated following the completion of remaining fuel measurements. As indicated, the total fuel mass remaining in the RB is well below the SFML of 140 kg presented in Appendix B. Subcriticality is further enhanced since most of the residual fuel is tightly adhered to RV components or in isolated areas within the RB. Fuel in this configuration is significantly less reactive than in the optimum conditions assumed in Appendix B (i.e., fuel pellets, optimum moderation with unborated water, and spherical geometry). Additionally, the current configuration prevents any significant debris transport, thus minimizing any interactive effects of the various fuel accumulations. The majority of residual fuel in the RB (i.e., "A" D-ring, letdown coolers, and upper endfitting storage containers) is located in areas which are neutronically decoupled from other fuel bearing locations and, consequently, there is no potential for a criticality event due to fuel transport. Thus, subcriticality within the RB is assured. The potential for fuel transport and interaction with the RCS and RV will be described in Sections 5.3 and 5.4.

5.2.12 Summary

The collective evaluation of the material presented in this section demonstrates that an acceptable end to fuel removal activities has been achieved in the RB.

The total estimated quantity of fuel in the RB, listed in Table 5-3, is significantly less than the SFML which assumes optimum moderation and infinite water reflector (worst case) conditions. Additionally, it is expected that the total quantity of residual fuel in the RB following the completion of remaining fuel measurements in the RB will continue to be significantly less than the SFML. Thus, subcriticality is assured.

The current estimate of residual fuel content in the RB is primarily concentrated in:

- o segments of the flow distributor plate containing IIGTs which are stored in the "A" D-ring;
- o upper endfitting storage containers; and
- o letdown coolers.

Each of these areas are addressed below.

<u>"A" D-Ring</u>

Residual fuel is attached to the sections of the flow distributor plate located in the "A" D-ring. GPU Nuclear decided to place these components in the "A" D-ring since ther. were too large to placed in the "A" CFT. The residual fuel quantity in the "A" D-ring does not pose a criticality concern. Additionally, it is anticipated that some of the LCSA components in the "A" D-ring may be shipped off-site for analysis; thus, the total residual fuel quantity in this area may be reduced. Section 6 of the DCR provides a further assessment of the LCSA components in the "A" D-ring.

Upper Endfitting Storage Containers

As stated in Sections 4.4.3.2.1 and 5.2.6, during the early defueling efforts loose upper endfittings were removed from the surface of the core debris bed to permit the continuation of RV defueling. These endfittings were too large to be inserted into fuel canisters; thus, they were placed in shielded drums filled with borated water and stored at elevation 347' in the RB. As stated in Section 5.2.6, it is conservatively estimated that the maximum amount of residual fuel contained in the upper endfitting storage containers is 54 kg which is much less than the SFML. GPU Nuclear currently plans to perform fuel measurements of each upper endfitting storage container as described in Reference 5.16. It is GPU Nuclear's belief that the residual fuel quantity determined as a result of these measurements will be significantly less than 54 kg. The disposition of the upper endfitting storage containers will be determined following their measurements.

Letdown Coolers

Section 2.2.3 states that fuel was transported to the letdown coolers, which are located in the RB basement, as a result of the TMI-2 accident. Due to the high dose rates in the RB basement, the letdown coolers are inaccessible and performance of defueling or water processing activities has been precluded. Fuel measurements of the letdown coolers have determined that their residual fuel quantity is less than or equal to an MDL value of 4 kg which is significantly below the SFML. Thus, the residual fuel in the letdown coolers does not pose a criticality concern.

The residual fuel in the remaining areas of the RB consists of finely divided small particle size sediment material with minor amounts of fuel found as adherent films on metal oxide surfaces. Decontamination activities in the RB served to remove residual fuel, especially in the RB basement where the residual fuel quantity was reduced by approximately 75% (see Tables 2-1 and 5-3). Post-defueling activities (e.g., flushing tanks/pipes, system draindowns) may result in the removal of additional small quantities of fuel. Thus, the quantity of residual fuel in the RB may be further reduced.

Based on the above analysis of the total estimated quantity of residual fuel, there is no potential for transport of fuel within the RB which could result in a critical mass. Thus, subcriticality is assured. The potential for fuel transport and interaction with the RCS and RV will be described in Sections 5.3 and 5.4. GPU Nuclear has determined that no further efforts for the specific purpose of removing fuel from the RB are appropriate or necessary to preclude criticality or otherwise demonstrate that defueling has been completed to the extent reasonably achievable.

TABLE 5-3

RESIDUAL FUEL QUANTIFICATION IN THE REACTOR BUILDING[a]

COMPONENT	RESIDUAL FUEL QUANTITY (KG)
RV Head	1.4[b]
RV Plenum	2.1
Fuel Transfer Canal	(a)
Core Flood System	2.4[b]
D-Rings	23
Upper Endfittings	< 54[b]
Reactor Coolant Drain Tank	0.1
Letdown Coolers	< 4 [c]
RB Basement/Sump	1.3
Cleanup Systems/Equipment (e.g. DWCS)	(b)
TOTAL	< 88 kg[b]

(a) - Excluding the RV and RCS.

(b) - To Be Updated in a Subsequent DCR Submittal.

(c) - MDL