GPU Nuclear

GPU Nuclear Corporation
Post Office Box 480
Route 441 South
Middletown, Pennsylvania 17057-0191
717 944-7621
TELEX 84-2386
Writer's Direct Dial Number:

(717) 948-8400

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US Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, DC 20555

Three Mile Island Nuclear Station, Unit 2 (TMI-2)
Operating License No. DPR-73
Docket No. 50-320
SNM Accountability

Dear Sir:

By NRC letter dated October 17, 1985, GPU Nuclear was granted exemption from certain requirements for periodic inventory and reporting of the special nuclear materials (SNM) balance for Three Mile Island Unit 2 (TMI-2). As a condition of the exemption, GPU Nuclear is required to conduct an assessment of the SNM remaining at TMI-2 following the completion of the defueling effort. This assessment is referred to in the exemption as the "post-defueling survey." GPU Nuclear letter 4410-88-L-0162 dated September 30, 1988, submitted the initial Post-Defueling Survey Reports (PDSRs).

As stated in that submittal, the PDSR documents the GPU Nuclear assessment of the amount of residual SNM in the various facilities, systems, and components of the plant and describes the methodology utilized to determine the quantity of SNM in each case. The attached PDSR transmits the post-defueling survey results for the Reactor Coolant System exclusive of the Reactor Vessel.

The remaining PDSR will be submitted upon completion of the Reactor Vessel draindown and fuel measurement program. A compilation of the individual PDSRs will form the basis for a final assessment of the quantity of residual SNM at TMI-2 for accountability purposes.

Sincerely,

Robert L. Long

R. L. Long
Director, Corporate Services/TMI-2

EDS/dlb

A001
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cc: T. T. Martin - Regional Administrator, Region I
M. T. Masnik - Project Manager, PDNP Directorate
L. H. Thonus - Project Manager, TMI
F. I. Young - Senior Resident Inspector, TMI

TMI-2 POST-DEFUELING SURVEY REPORT

FOR

THE REACTOR COOLANT SYSTEM

Approved: ______________________
Manager, TMI-2 Licensing

Approved: ______________________
Manager, TMI-2 Engineering

TMI-2 INTERNAL REVIEWS

Authors: P. W. Deininger 6-27-91

Responsible Technical Reviewer: R. H. Freeman 6-27-91

Manager, Fuel Measurements & Analysis: C. H. Distenfeld 6-27-91

PDSR Committee Chairman: R. E. Rogan 6-28-91

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TMI-2 POST-DEFUELING SURVEY REPORT
FOR THE REACTOR COOLANT SYSTEM

SUMMARY

The estimate of record of the amount of uranium dioxide (UO_2) remaining in the RCS Components included in this Post Defueling Survey Report (PDSR) was 25.8 kg with an uncertainty of ± 43%, distributed as follows:

Cold Legs '1A/B' & '2A/B'		9.6 kg UO_2
Reactor Coolant Pumps		6.2 kg UO_2
Surface Films		4.6 kg UO_2
Hot Legs 'A' & 'B'		2.7 kg UO_2
Decay Heat Line		1.5 kg UO_2
Core Flood Lines 'A' & 'B'		1.0 kg UO_2
Pressurizer Lines		0.2 kg UO_2
	Total	25.8 kg UO_2

The above summary table shows that 61% of the UO_2 remaining in the RCS Components was located in two (2) categories of components, the Cold Legs and the Reactor Coolant Pumps. The estimates of 9.6 kg UO_2 in the Cold Legs and 6.2 kg UO_2 in the Reactor Coolant Pumps are based on the observations of reactor fuel debris during video examinations which is assumed to have settled from the static volume of coolant containing a uniform dispersion of particles.

The fuel content of each RCS Component was determined using gross gamma-ray surveys, engineering analyses and video inspections. These methods are described

in Section 3.0. Several RCS components not addressed in this PDSR are discussed in other PDSRs as noted in Section 1.0, Introduction.

In addition, 4.6 kg of fuel (UO_2) was estimated to be present in the form of surface films throughout the RCS. This assumes that the RCS surface film deposition pattern was uniform and that the composition was similar to that of the materials present on the components inspected. The error assigned for the surface film estimates was ± 60% (assumed to be one sigma).

The term "uncertainty" in this Post Defueling Survey Report was used to represent the estimated error of each "estimate of record" and was taken as one sigma. The overall uncertainty for the total UO_2 remaining in the RCS Components was estimated as ± 43% based on the square root of the sum of the squares of the uncertainty values for each component.

TMI-2 POST-DEFUELING SURVEY REPORT FOR THE REACTOR COOLANT SYSTEM

1.0 INTRODUCTION

This report presents an analysis of the amount of fuel (UO_2) remaining in the Reactor Coolant System (RCS). The content of this analysis addresses the fuel remaining in the following components/systems.

a. Reactor Coolant Pumps RC-P-1A/B and RC-P-2A/B
b. Core flood lines "A" and "B" from the Reactor Vessel to the CF-V5A/B valves
c. Cold Legs 1A/B and 2A/B
d. Hot Legs A and B
e. Decay Heat Drop Line
f. Pressurizer Lines
g. Surface Films

The remaining components of the RCS are addressed in other Post-Defueling Survey Reports as listed below:

RCS Component	Addressed in PDSR
Core Flood Tanks & Piping	RB Miscellaneous
Cold Leg Nozzles	Reactor Vessel
Hot Leg Nozzles	Reactor Vessel
OTSGs	OTSGs
Pressurizer	Pressurizer
RC Drain Tank	RB Miscellaneous
Reactor Vessel	Reactor Vessel
Letdown Coolers	Letdown Cooler Room

This report is one in a series of reports prepared to fulfill the requirements of the TMI-2 SNM Accountability Program (Reference 1). All statistical uncertainties are expressed as ± one sigma limits (defined as one standard deviation) unless otherwise stated. Other segments of the Reactor Building (RB) are treated in separate Post-Defueling Survey Reports (PDSR).

Section 2.0, "Background", describes the physical attributes of the individual components/systems and their relationship to the accident and subsequent cleanup activities. The boundaries of these components/systems with respect to this PDSR are also presented in this section.

Section 3.0, "Methods", describes how existing video inspections,sample data and gamma spectroscopy data, where available, were used to determine the estimate of record.

Section 4.0, "Analysis", explains how the estimate of record of fuel in the RCS was determined based on video inspections and sample analysis, and gamma spectroscopy data which was collected for selected RCS components/segments reported herein. This section also discusses supporting data, assumptions made and calculations used.

Section 5.0, "Conclusion", presents the estimate of record and associated uncertainty for each RCS component/segment and reports these values in terms of remaining quantities of UO_2 (in kg) for each RCS segment. Additional rationale is presented leading to the conclusion that the estimate of record is reasonable based on the available data and analyses performed.

2.0 BACKGROUND

The March 1979 TMI-2 accident resulted in significant damage to the reactor core and subsequent release of fuel particles and fission products into the Reactor Coolant System (RCS) and other closely interconnected systems/components. The damaged core consisted of loose fuel pellets, solidified fuel, structural metal components, loose rubble, and partial fuel assemblies. Therefore, fuel accountability by the normal method of accounting for individual fuel assemblies was not possible.

During the accident, core debris was transported to the reactor building (RB) as a result of the core degradation event and coolant flow from the reactor vessel (RV) through the pilot operated relief valve (PORV) and the RCS Makeup and Purification (MU&P) System. Less than 2 kg of fuel (UO_2) was transported to the RB during the accident sequence.

The RCS was designed to transfer thermal energy from the reactor core to the steam generators (OTSG's). The RCS also provides neutron moderation and a secondary boundary for preventing the release of fission products to the environment. The RCS consists of the reactor vessel, two (2) vertical OTSG's, four (4) shaft sealed reactor coolant pumps, an electrically heated pressurizer, and interconnecting piping. Only those sections of the RCS presented in Section 1.0 are addressed in this report. In addition, two (2) pipe sections of the Core Flood System and the Decay Heat Drop Line are addressed.

2.1 Reactor Coolant Pumps

Four (4) reactor coolant pumps are connected to the RCS. The pumps are vertical suction, horizontal discharge and single stage centrifugal units manufactured by Bingham Pump & Williamette, Inc. The pumps are electrically driven by 9000 HP Allis Chalmers, squirrel-cage induction motors. The pumps and their locations are shown in Figures 1 and 2. All four (4) pumps are located within the concrete D-ring sections of the Unit 2 Reactor Building at approximately elevation 320 feet. Since the top of the D-rings is at elevation 367 feet, the reactor coolant pumps are about forty-seven (47) feet down into the D-rings.

The reactor coolant pumps were operating during the initial phase of the TMI-2 accident. The plant was operating at about 97% power. At about seventy-three (73) minutes into the accident, the 1B and 2B reactor coolant pumps were turned off to reduce the possibility of serious pump damage due to low system pressure. The 1A and 2A pumps continued to circulate coolant through the system until about one hundred (100) minutes into the accident when they also were shut down. The operators attempted to restart the reactor coolant pumps with little success during the next several hours. Reactor coolant pump 2B was started at about three (3) hours into the accident and ran briefly before being shut down. Twelve (12) hours later reactor coolant pump 1A ran for about one (1) minute and was shut down again, and then restarted (See Figure 3). Core debris was circulated through the four (4) reactor coolant pumps during their subsequent operation (Reference 2).

For purposes of this report, the RCP boundaries are that section of the Reactor coolant pumps between the discharge and suction nozzles (shown in Figure 2).

2.2 Core Flood Lines "A" and "B"

The core flood system consists of two (2) flood tanks containing approximately 7800 gallons of water (2/3 full), each connected to the reactor vessel via fourteen (14)-inch piping. Each piping system contains at least two (2) check valves and one (1) stop valve. The system activates automatically as the RCS pressure drops below 600 psig due to a 600 psig nitrogen over pressure in each tank. Only two (2) sections of the core flood system piping (Figure 4 & 5) between the reactor vessel and the CF-V5A and 5B valves are addressed in this report.

The remaining parts of the core flooding system are covered in the Reactor Building Miscellaneous Components PDSR.

During the accident, the core flood system activated as observed by the reduced nitrogen overpressures. During subsequent repressurization of the RCS, back pressure may have forced fuel debris into the core flood piping on the "A" side (Reference 2). Fuel debris has been detected beyond the CF-V5B valve and has been observed in the piping between the reactor vessel and the CF-V5A/B valves (Reference 3).

2.3 Cold Legs 1A/B and 2A/B

The cold leg discharge piping sections are located at the elevation 315 feet between the reactor coolant pumps and the reactor vessel. All four (4) pipe sections are twenty eight (28)-inches in diameter and are approximately twenty five (25)-feet in length. RCS coolant flow deposited fuel debris in these pipe sections (Figure 6).

2.4 Hot Legs A and B

The "A" and "B" hot legs are horizontal sections of the thirty six

(36)-inch RCS piping that extend east and west from the reactor vessel at about elevation 315 feet. Each hot leg has a horizontal section about twelve (12) feet in length that turns upward (90°) and reaches the 360 foot elevation at the top of the OTSG's (Figure 7). Coolant flow exiting the reactor vessel deposited fuel debris in the twelve (12) foot horizontal section of these two (2) pipe segments.

2.5 Decay Heat Drop Line

The Decay Heat Drop Line is a twelve (12)-inch diameter pipe section that attaches to the "B" hot leg at the 90° elbow (Figure 7 & 8). It extends downward to about elevation 291' and then north for approximately eighteen (18) feet before turning west.

The purpose of the Decay Heat System is to remove decay heat from the core and residual heat from the reactor coolant system during shutdown. During the accident, RCS coolant exiting the reactor vessel into the thirty six (36)-inch "B" hot leg moved past the entrance of the decay heat line and deposited fuel debris into the vertical decay heat piping segment. The Decay Heat System was not used during the accident so that the material deposited in the decay heat piping was due to gravitational settling from the "B" hot leg. For purposes of this report, the fuel debris was measured near the elbow of the decay heat line at elevation 291 feet where the decay heat line turns north toward the Fuel Handling Building.

2.6 RCS Nozzles

The RCS Nozzles are tapered sections of the reactor vessel which form the entrance to the cold and hot leg piping sections. The core flood nozzles are not considered in this section but are contained within the estimated fuel debris values for the core flood piping system (Section 4.2). The hot leg nozzles are assumed to contain no fuel debris because of the fuel removal efforts, which effectively removed the fuel debris deposits. The cold leg nozzles are considered separately in the PDSR covering the dry Reactor Vessel fuel deposition.

2.7 Pressurizer Lines

The pressurizer upper head has three (3) nozzles connected to the safety relief system and one (1) nozzle connected to the spray line. It also has a vent nozzle and a sixteen (16)-inch internal diameter manway opening. The lower head has a ten (10)-inch nozzle connected to the surge line. A surge diffuser is centered in this nozzle, extending up into the lower head a distance of approximately one (1) foot. The surge line is a ten (10)-inch stainless steel pipe and is located inside the A D-ring. It runs from the vertical portion of the reactor coolant hot leg to the bottom of the pressurizer. Fuel debris was measured in the horizontal section of the surge line.

The Power Operated Relief Valve (PORV) stuck open early in the accident resulting in coolant flow through the pressurizer surge line into the pressurizer and out through the relief valve. This flow was terminated later in the accident by closing the block valve upstream of the PORV. Subsequent to the core damage, this block valve was cycled open for significant periods of time, reestablishing flow through the surge line. The varying fluid levels in the pressurizer and the varying flow rates through the surge line are potential separation mechanisms by which fuel fines entrained in the fluid could be deposited in the surge line. Since the L-shaped section of the surge line is much lower than its exit point, a significant rate of flow would be required to transport fuel out.

Fuel debris in the pressurizer spray line was flushed back into the pressurizer and was subsequently removed during defueling operations. Therefore, it is assumed that no measurable quantity of fuel remains in the pressurizer spray line.

2.8 Surface Films

In addition to the concentrations of residual core debris, there was some fuel bound to the surfaces of the components in the RCS. These deposits were not distinguishable by video inspection because they were thin and relatively uniform over a wide area. This film accounts for a very small fraction of the total fuel left in the RCS, but is included in this report for completeness.

Fuel and related materials on the inside surfaces of the RCS, the pressurizer and OTSG manway and inspection port cover plates were inspected, beta/gamma surveyed, alpha counted and sampled (Reference 22). Subsequently, these plates were counted with a gamma-ray spectrometer and the scrape samples were analyzed for fuel isotopes. The film on each plate differed markedly in thickness. The pressurizer had the thinnest film which was semi-transparent and resembled gun metal blue. The 'B' OTSG had the thickest film which resembled a thick coat of flat black paint, with a tint of blue/brown. All of the films were very hard, uniform and adherent. It appeared that the films originated from both corrosion and deposition; the thicker films appeared to be mostly deposition. The amount of fuel deposited was roughly proportional to the film thickness, but evidence suggests that much of the fuel is on the surface of the film.

2.9 Radiation Environment and Component Access

All of the segments of the RCS described under the Introduction Section (Section 1.0) of this report are located in regions of the D-rings or are contained between the reactor vessel and the D-ring openings. In the case of the cold and hot leg sections, these components penetrate the primary shield wall of the reactor vessel and then extend into the D-rings at about elevation 315 feet. Personnel access to these piping segments would require extended worker exposure times in radiation fields of greater than 1 R/hr in the "A" D-ring (Reference 4, 5, and 6). No prior access to the 315 foot elevation in the "B" D-ring has been permitted because exposure rates range from 1 to about 10 R/hr (Figure 9 and References 6, 7 and 8). At the decay heat drop line elbow (elevation 291 feet), the exposure rate is about 16 R/hr. Therefore, personnel access is not warranted or consistent with ALARA.

Because of these elevated exposure rate environments, all sampling and video inspections were performed from the work platform through the reactor vessel or from a higher elevation of the D-rings (above the 350 foot elevation). Access through the reactor vessel via the defueling work platform was performed remotely, with long handled tools and/or equipment of special design. This allowed personnel to work in a 10 to 25 mR/hr (Reference 6) exposure rate environment.

3.0 METHODS

3.1 Reactor Coolant Pumps

The estimate of record of the amount of fuel (UO_2) remaining in the Reactor Coolant Pumps RC-P-1A/B and RC-P-2A/B was obtained by engineering analysis and review of video inspection tapes (Reference 10, 11, and 12).

The first estimate was produced using a video camera inserted from the defueling work platform through the discharge pipes (cold legs) and into the pump casings (Reference 11). The debris estimate is related to the pump internal cavity volume between the discharge and intake nozzles. Close examination of the video tapes provided sufficient evidence to ascribe an average sediment depth of 1/4 inch (6.4 mm) inside RC-P-2A, and the total volume was estimated to be 11.7 liters of material for this pump (Reference 10). An attempt to remove a sample from the RC-P-1A pump casing failed.

In an effort to apply some reasonable limits to the sediment volume in each pump, it was decided to weight the RC-P-1A, 1B and 2B pump sediment volumes by the proportional fuel debris quantity that was measured in each of their related discharge pipes (cold legs) (Reference 12). This method established the RC-P-2A and the 2A cold leg as the reference or standard. The 2A cold leg was measured as containing 3.9 kg of UO_2 distributed in 21.6 liters of debris (Reference 12) and the RC-P-2A pump casing was estimated to contain 11.7 liters of sediment (Reference 12).

The conversion from volume of sediment to fuel (UO_2) was performed by using the results of the sample analysis of materials collected from the cold legs as recorded in Reference 12. The analysis indicated that the cold leg material density was approximately 3.2 grams per cubic centimeter (Reference 12). The UO_2 fraction was assumed to be 0.58 (Reference 13). These values were used to calculate the final estimate of record for the Reactor Coolant pumps.

3.2 Core Flood Lines "A" and "B"

The estimate of record for the core flood lines (from the RV to the CF-V5A and 5B valves) was based on the results produced from gross gamma-ray surveys internal to the Core Flood piping system. The Microshield computer code (Reference 14) was used to model the source geometry established from video inspections of the core flood line deposition patterns. The measured exposure rate was divided by the calculated exposure rate per volume of fuel (UO_2), which provided the quantity of fuel remaining in the core flood piping (Reference 12).

The quantity of fuel remaining in the core flood system is assumed to be represented by the values developed for a measured eight (8)-foot segment of both core flood lines ("A" and "B"). No fuel debris was assumed to have reached the CF-V5A valve in the "A" core flood side. On the "B" side, fuel deposits were measured at the CF-V5B valve and in the small drain line that drops from the core flood line near the CF-V5B valve (Reference 3).

3.3 Cold Legs 1A/1B and 2A/2B

The cold leg sections extending to the reactor coolant pumps are twenty eight (28) inches in diameter and are approximately twenty five (25) feet long. The gross gamma-ray measurement plan for each cold leg was compared with the computer model developed from the video inspection of each cold leg and sample data (Reference 12). The measurement method was the same as described for the core flood lines, Section 3.2.

3.4 Hot Legs "A" and "B"

The estimate of record for the hot leg sections was based on gross gamma-ray results produced from internal surveys of the thirty six (36)-inch hot leg sections (Reference 12). As in Section 3.2 above, a computer model was used to compare the values measured by the GM detectors to the fuel quantity in each hot leg. The measurements were performed after the hot legs were cleared of as much fuel debris as possible using specially developed tooling (Reference 15 and 16).

3.5 Decay Heat Drop Line

The decay heat drop line is located below the elbow of the "B" hot leg where the hot leg turns upward (90°) to eventually meet the top of the "B" OTSG. The decay heat line was inspected with a video camera system. From the depth of insertion it was determined where the fuel debris was located at the lower elbow. Defueling was performed by using a vacuum tool mounted on a steel bar with a video camera on one side of the suction nozzle and a light on the other side. The steel bar was designed to maintain the vacuum nozzle as close as possible to the center of the decay heat drop line. Removal of the material was halted when the vacuum system could not penetrate a solidified mass of material within the pipe (Reference

15, 16, 17, and 18). The solidified mass of material was removed in early 1989 using a drain cleaning machine to break up the hard debris. Vacuuming continued and the rest of the loose debris was removed. A GM detector system, similar to those used in the cold leg measurements, was inserted into the decay heat drop line after the debris was removed (Reference 19). The GM measurements were taken over the first three (3) feet of the horizontal section of the decay heat drop line beyond the lower elbow where it turns north for about eighteen (18) feet of horizontal run. The measured values over the first three (3) foot length of pipe were extrapolated over the entire horizontal pipe length.

Measurement values obtained from the gross gamma-ray measurements internal to the decay heat drop line were correlated to fuel debris quantities determined from decay heat drop line sample results (Reference 20). Those results indicate that the material collected was about 8% UO_2 by weight.

3.6 Reactor Coolant Nozzles

The cold leg nozzles are about seventeen (17) inches long and form the entrance to the twenty eight (28)-inch cold leg pipe sections. They form a tapered entrance of approximately 15°; starting at a diameter of approximately thirty seven (37) inches. Video inspections of three of four nozzles indicated that a sediment layer remained in the flanged sections. Estimates of the total debris remaining are included in the Dry Reactor Vessel Post Defueling Survey Report. No fuel movement in these regions is anticipated except during water flow, and the remaining quantities of fuel debris will generally remain in their present locations until TMI-2 is decommissioned except for the fuel located in the '1B' nozzle.

During the RV fuel measurement sequence, it will be necessary to drain the RV while making passive neutron measurements. During the refill cycle, the RV will be filled using water from the RCBTs via the "B" makeup line (MU-V-16B). This filling operation is expected to wash most of the residual fuel out of the "1B" cold leg and nozzle into the RV.

3.7 Surface Films

Three (3) different methods were employed to measure the film deposits on various RCS components (Reference 9). Beta/gamma exposure rates were measured using an ion chamber type survey meter (Eberline Model RO2A) and the alpha count rates were measured with a thin window proportional counter (Eberline Model PAC-6). The beta exposure rates were used to estimate the Sr-90 activity and the alpha count rates were used to estimate fuel deposition. The manway plates were also counted with a collimated HPGe gamma-ray spectrometer using Ce/Pr-144 and Eu-154 as analogs for fuel estimates. The film deposits were estimated using the three (3) independent measurements: the HPGe spectrometer (Ce/Pr and Eu lines), the direct alpha count rate, and the radiochemistry of the scrape samples. The radiochemistry results directly measured the fuel isotopes and are assumed to be most accurate. The collection efficiency (50%) was estimated visually and by alpha counting before and after scraping. It includes the fraction of the area cleaned and the fraction picked up. Therefore, the accuracy of the scrape sample is controlled by the collection efficiency (i.e., no worse than 50%).

3.8 Pressurizer Lines

The only Pressurizer line that was surveyed was the surge line. A portable directional survey instrument (Eberline Model HP-220A) was used to measure the exposure rates at discrete locations along the horizontal section of the surge line. Higher intensities were noted along the eastward section of the surge line. Directional measurements along the north-south surge line section did not suggest the presence of additional source material. The impact of residual fuel from the pressurizer on these measurements was reduced by use of a 5-centimeter (2-inch) thick lead block shield (Reference 21).

4.0 ANALYSIS

4.1 Reactor Coolant Pumps (RCP's)

Video inspection of the Reactor Coolant Pump RC-P-2A casing and discharge leg indicated a sediment layer existed in both. The sediment volumes were evaluated for RC-P-2A and for the 2A cold leg and estimated to be 11.7 and 21.6 liters, respectively (Reference 11 and 12). Direct gross gamma measurements were used to infer the amount of residual fuel in the cold legs (Reference 12). The quantity of fuel in the 2A cold leg was estimated as 3.9 kg UO_2 (Reference 12). The measurement method was unable to access the pump casing. The fuel estimates for the pumps were based on the cold leg measurements scaled by the ratio of the observed sediment volumes in the pump and its cold leg. For the 2A pump per Reference 12:

$$Pump(2A) = \frac{11.7\,liters\,(pump)}{21.6\,liters\,(coldleg)} \times 3.9\,kg\ UO_2\,(coldleg) = 2.1\,kg\ UO_2$$

It was not possible to inspect the top of the volute, but its volume was scaled from the drawings and is included in the total pump volume (Reference 12).

The total fuel content for RC-P-2A and discharge leg was estimated to be 2.1 kg UO_2. From the Cold Leg analysis performed in Reference 12, it was determined that the Cold Leg "2A" contained most of the fuel debris. On this basis the remaining RC pumps were prorated using the fuel content of their respective cold legs (Reference 12), and the results were as follows:

RCP-1A contained	1.8 kg UO_2
RCP-1B contained	1.0 kg UO_2
RCP-2A contained	2.1 kg UO_2
RCP-2B contained	1.3 kg UO_2
Total fuel	6.2 kg UO_2

The uncertainty was determined using the square root of the sum of the squares of the individual uncertainties. The uncertainty was determined to be ±55% overall for the hot legs, cold legs, RC pumps and CF lines grouped together (Reference 12) and is reflected in Table 2.

4.2 Core Flood Lines "A" and "B"

The fuel content remaining in the Core Flood Lines was determined using gross gamma-ray measurements in conjunction with the Microshield computer code (Reference 14). A one (1)-foot segment of fuel debris on the inside surface of the core flood line piping was modeled on the computer based on a rectangular solid source distribution of RV lower head sample material. Since most of the exposure rate from the deposited material was generated by Cs-137, the cesium-to-fuel ratio and source geometry were the most critical parameters.

The GM detectors were positioned about two (2) centimeters from the bottom of the Core Flood pipe during the measurement sequence. Gross gamma-ray measurements were made by pushing the detector along in one (1) foot increments through a distance of eight (8) feet for each Core Flood line. The values recorded in Reference 22 were for both Core Flood lines. It was assumed that fuel material did not reach the CF-V5A valve or the straight run of piping that approaches the valve from the reactor side. Some fuel material was detected at the CF-V5B valve and this quantity is included in the Reactor Building Miscellaneous PDSR. The quantity of fuel measured on the RV side of the CF-V5 valves was 0.6 kg for the CF-A line and 0.4 kg for the CF-B line which results in a total 1.0 kg UO_2. The uncertainty was determined to be ±55% overall for the hot legs, cold legs, RC pumps and CF lines grouped together (Reference 12) and is reflected in Table 2.

4.3 Cold Legs 1A/B and 2A/B

Radiation measurements were performed using small GM detectors inserted into the cold legs from the reactor vessel defueling work platform in accordance with Reference 23. The gross gamma-ray measurements were compared to the computer models generated by the Microshield computer code (Reference 14) to determine the estimated fuel quantities in each cold leg. The results were (Reference 12):

Cold leg 1A contains	3.3 kg UO_2
Cold leg 1B contains	1.8 kg UO_2
Cold leg 2A contains	3.9 kg UO_2
Cold leg 2B contains	2.4 kg UO_2
Total	11.4 kg UO_2

The computer model selected to represent the fuel debris was based on the video inspections performed during the gross gamma exposure rate measurements. In all cases a sediment region along the bottom of the horizontal pipe sections covering the lower 120 degrees of piping was selected for the computer model. The sediment was assigned a density and thickness, and represented the source of the radiation exposure for a one (1)-foot length of pipe at each measurement location. Surface exposure rates from films and RCS water background were subtracted from the gross gamma measurement values.

In order to measure the reactor vessel for remaining fuel (UO_2), it will be necessary to completely drain the reactor vessel while making passive neutron measurements. After the reactor vessel has been completely drained, it will likely be partially refilled using water from the OTSGs. The filling operation is expected to wash most of the residual fuel out of the '1B' cold leg and nozzle into the reactor vessel. Therefore, the fuel measured in the '1B' cold leg (1.8 kg) is subtracted from the cold leg total shown above. The new fuel estimate is 9.6 kg UO_2.

The uncertainty was determined to be ±55% overall for the hot legs, cold legs, RC pumps and CF lines grouped together (Reference 12) and is reflected in Table 2.

4.4 Hot Legs "A" and "B"

The hot leg sections of the RCS were measured in the same manner described for the cold leg sections in Section 4.3. The results were determined after the hot leg segments were defueled using a specially designed squeegee/vacuum tool to scrape and vacuum the debris in the hot legs. This tool covered the lower third of the hot leg diameter with the vacuum slot located on the bottom six (6) inches at the centerline, Reference 16. As with most of the RCS defueling/quantifying effort, the tooling was deployed from the defueling work platform on elevation 331' of the Reactor Building.

The results of the measurements taken after the defueling effort was completed indicate that the following fuel quantities remain in each hot leg (Reference 12):

"A" hot leg	0.9 kg UO_2
"B" hot leg	1.8 kg UO_2
TOTAL	2.7 kg UO_2

The uncertainty was determined to ±55% overall for the hot legs, cold legs, RC pumps and CF lines grouped together (Reference 12) and is reflected in Table 2.

4.5 Decay Heat Drop Line

The decay heat drop line was measured in the same manner described for the cold leg sections in Section 4.3. A model was developed using the Microshield computer code (Reference 14) that presented the source region as a one (1)-foot length of debris. A decay heat line sample was used to develop the isotopic loading and fuel concentration per unit weight of debris (Reference 20). The decay heat line net sample weight was reported to be 590 g and contained 46.6 g of UO_2 (8% UO_2 by weight). A three (3)-foot section of the decay heat horizontal line was measured, and the results were extrapolated over the remaining fifteen (15) feet of piping. The results indicate that the decay heat line contains 1.5 kg of UO_2. The uncertainty for this value is considered to be the same as that determined for the previously reported RCS components (i.e., ±55%)(Reference 12).

The total fuel remaining in the decay heat drop line is:

1.5 kg UO_2 ± 55% uncertainty

4.6 Pressurizer Lines

Extensive defueling operations were performed in the RCS with the goal of removing the majority of the fuel transported to the RCS as a result of the accident. These activities were generally successful. For example, defueling operations removed greater than 90% of the debris in the Pressurizer.

Debris in the Pressurizer Spray Line was flushed back into the Pressurizer and RCS Cold Leg 2A using water processed through the OWCS. Although the effort did not result in removing fuel from the primary system, it did relocate the fuel debris for ease of removal in subsequent defueling operations. Therefore, it was assumed that no measurable quantity of residual fuel remains in the Pressurizer Spray Line.

A portable directional survey instrument (Eberline Model HP-220A) was used to measure the exposure rate along the Pressurizer surge line. Higher intensities were noted along the eastward section of the surge line. The total quantity was derived for a uniform uranium deposition pattern over the east section of the surge line. The measured results determined a quantity of 0.2 kg UO_2 for the Pressurizer surge line (Reference 24).

The balance of lines connected to the Pressurizer were the safety and relief lines connected to the top of the Pressurizer tank. During the accident, relatively high velocity water was discharged through the PORV and safety valves to the RCDT. The velocity of the discharge flow was sufficient to keep micron sized fuel debris material in suspension and moving along the discharge pipe down to the RCDT. Inspections of the Pressurizer performed during defueling indicated there was only a small quantity of loose debris and that most of the remaining fuel deposits consisted of large pieces of debris (approximately 5 cm wide x 10 cm long x 2.5 cm thick) (Reference 25). There was no indication of significant fuel deposits present in the drain line to the RCDT during the D-Ring surveillance type measurement programs.

The total fuel content for the Pressurizer lines was estimated to be 0.2 kg UO_2. Since no uncertainty was reported for the results of this analysis, an uncertainty of ±60% was arbitrarily assigned to the fuel content value of the Pressurizer lines.

4.7 Surface Films

Reactor fuel is present in the form of surface films on RCS components (Reference 9). Several RCS components were analyzed to determine the quantity of UO_2 present within these adherent and loosely adherent surface film layers. The manway covers from the Once Through Steam Generators (OTSGs) and the Pressurizer, as well as the 'A' OTSG hand hole cover were sampled. Surface materials were removed by scraping and analyzed for fuel content. Reference 9 presents the results of the scrape sample analyses and the total estimated fuel (UO_2) present in the RCS as surface films. Under the assumption that the film characteristics of the three (3) manway plates are equally representative of the RCS, the films averaged 0.0019 inches thick and contained 18 $\mu g/cm^2$ of UO_2. The total fuel (UO_2) estimate was 4.6 kg. The assumed uncertainty for the surface film quantity was ± 60% (one sigma).

5.0 CONCLUSIONS

The estimate of record of the quantity of fuel (UO_2) remaining in the Reactor Coolant System is 25.8 kilograms ± 43% (at one sigma). The uncertainty is based on a grouped uncertainty of ±55% for the hot legs, cold legs, RC pumps and CF lines and individual component uncertainties associated with the DH drop line, surface films and Pressurizer lines addressed in this Post Defueling Survey Report.

This estimate of record is derived from the measured data summarized in Table 2. The data shows that 61% of the remaining fuel is contained in two components, the Reactor Coolant Pumps and the Cold Legs. These components are expected to remain static once drain down is completed. No future water flows are planned except possibly to remove condensation or inleakage from the Reactor Building. Additional measurements of the RCS components are not warranted based on ALARA considerations due to the small quantity of fuel (UO_2) measured to date. After final draindown of the RCS, the Reactor Building will be isolated from all systems outside the RB by maintaining containment isolation.

The goal of the TMI-2 defueling program was to remove more than 99% of the original core inventory of approximately 94,000 kg. In that context, the 25.8 kg quantity of UO_2 remaining in the RCS components is less than 4% of the total allowable fuel (UO_2) remaining at TMI-2.

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TABLE 1

ASSAY METHODS UTILIZED TO MEASURE RCS COMPONENTS IN THE REACTOR BUILDING

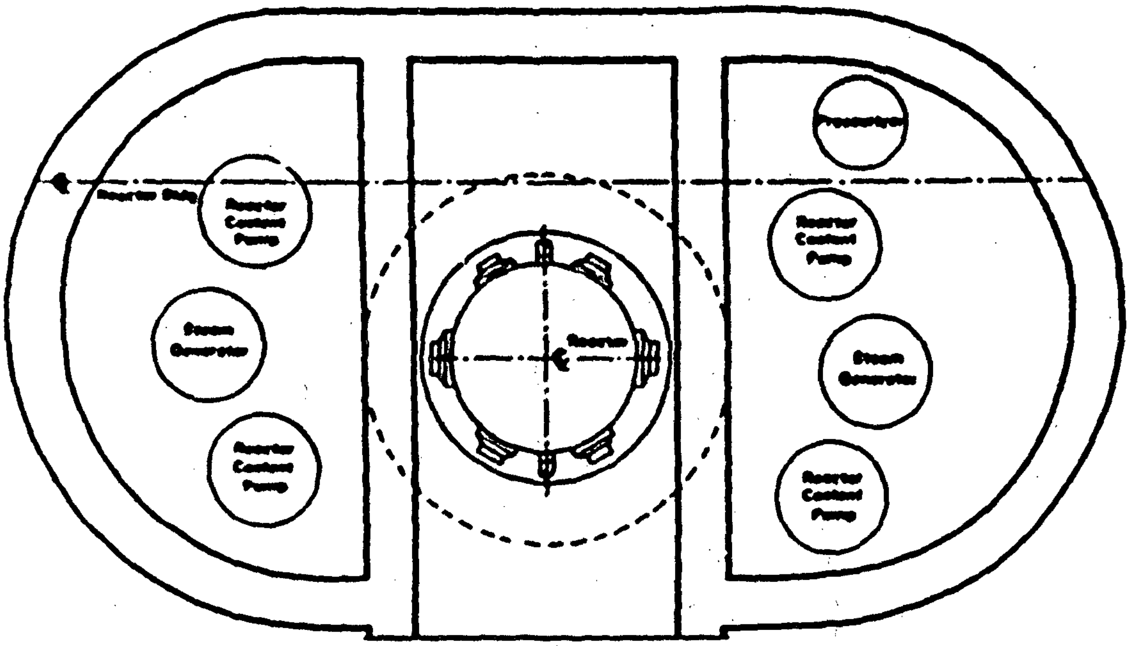
Area Description	Assay Method	Calculation Number
Reactor Coolant Pumps	Engineering Analysis	4249-3220-91-005
Core Flood Lines	Gross Gamma-Ray	4249-3220-91-005
Cold Legs 1 A/B and 2A/B	Gross Gamma-Ray	4249-3220-91-005
Hot Legs 'A' and 'B'	Gross Gamma-Ray	4249-3220-91-005
Decay Heat Drop Line	Gross Gamma-Ray	4800-3212-89-010
Pressurizer Lines	Gross Gamma-Ray	4550-3223-85-004
Surface Films	Beta, Alpha, Gamma, Sampled	Reference 9

TABLE 2

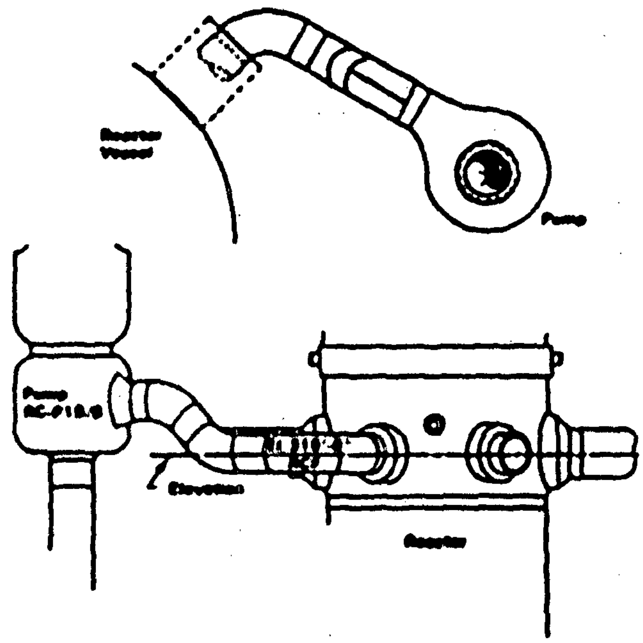
SUMMARY OF SNM INVENTORY FOR RCS AREAS

Area/Component	Fuel Quantity	Determined Uncertainty	Reference
Reactor Coolant Pumps	6.2 kg		PDSR Paragraph 4.1
Core Flood Lines 'A' and 'B'	1.0 kg		PDSR Paragraph 4.2
Cold Legs 1 A/B and 2 A/B	9.6 kg	± 55%	PDSR Paragraph 4.3
Hot Legs 'A' and 'B'	2.7 kg		PDSR Paragraph 4.4
Decay Heat Drop Line	1.5 kg	± 55%	PDSR Paragraph 4.5
Pressurizer Lines	0.2 kg	± 60%	PDSR Paragraph 4.6
Surface Films	4.6 kg	± 60%	PDSR Paragraph 4.7
Estimate of Record and Uncertainty	25.8 kg	± 43%	

FIGURE 1 - REACTOR COOLANT PUMPS

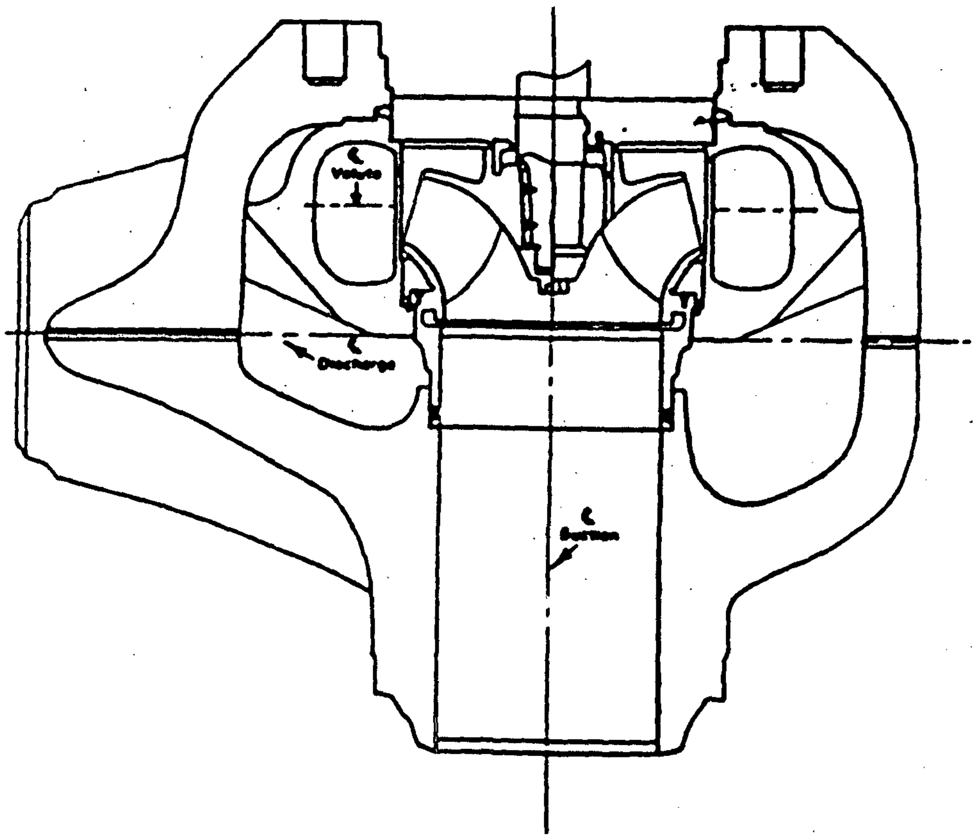


REACTOR COOLANT PUMPS
LOCATIONS INSIDE D RING



REACTOR COOLANT PUMP AND
ADJACENT HORIZONTAL PIPING

FIGURE 2 - RC PUMP CROSS SECTION



REACTOR COOLANT PUMP CASING

FIGURE 3 - RC PUMP TIME HISTORY

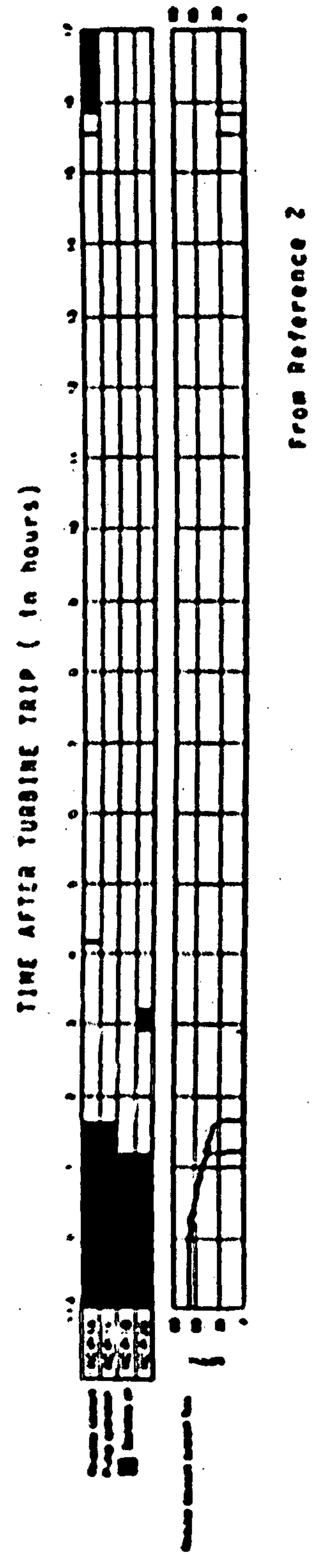


FIGURE 4 - CORE FLOOD TANKS AND PIPING

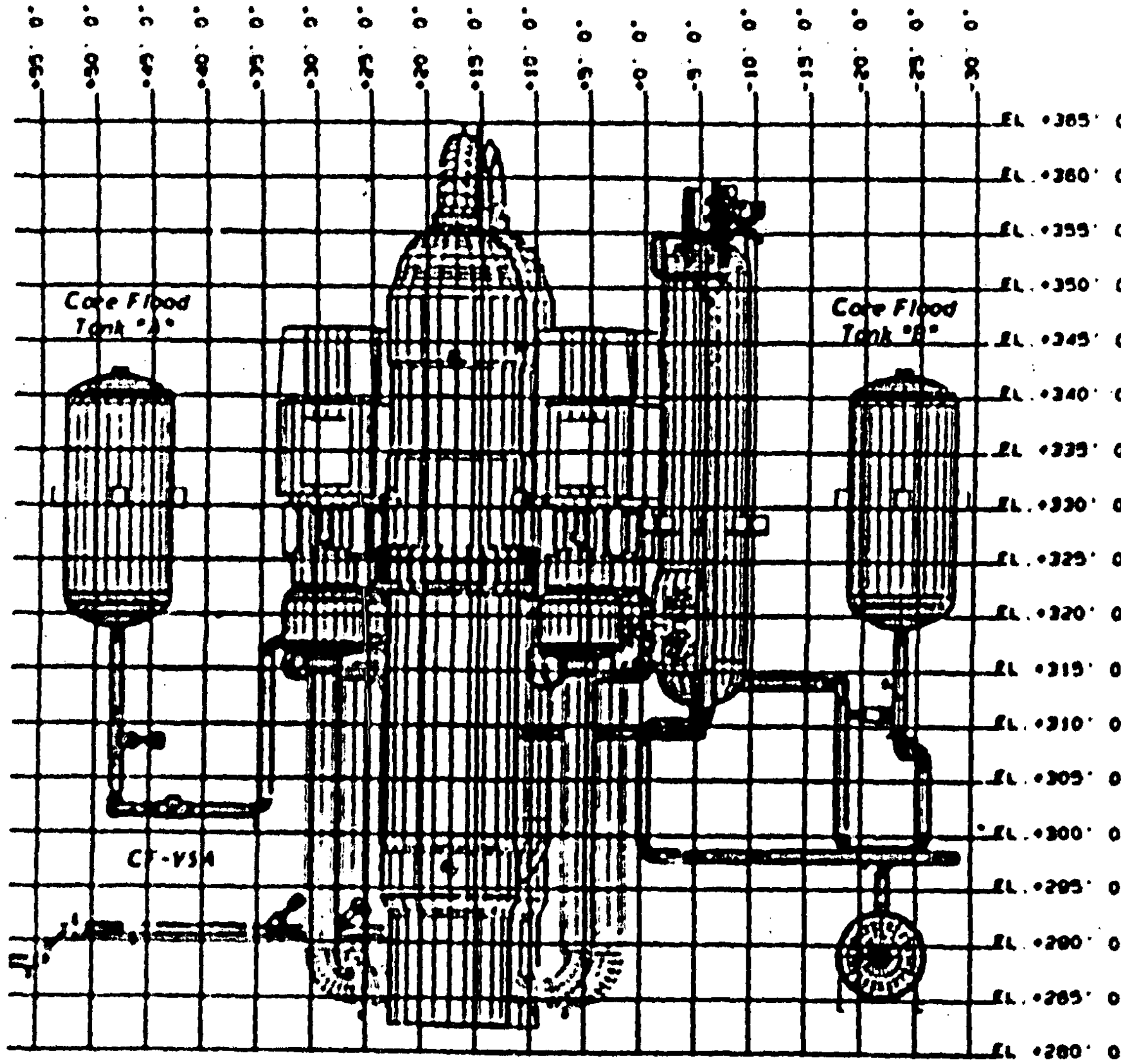


Diagram of RCS Showing Core Flood Tanks and Piping System

FIGURE 5 - CORE FLOOD PIPING

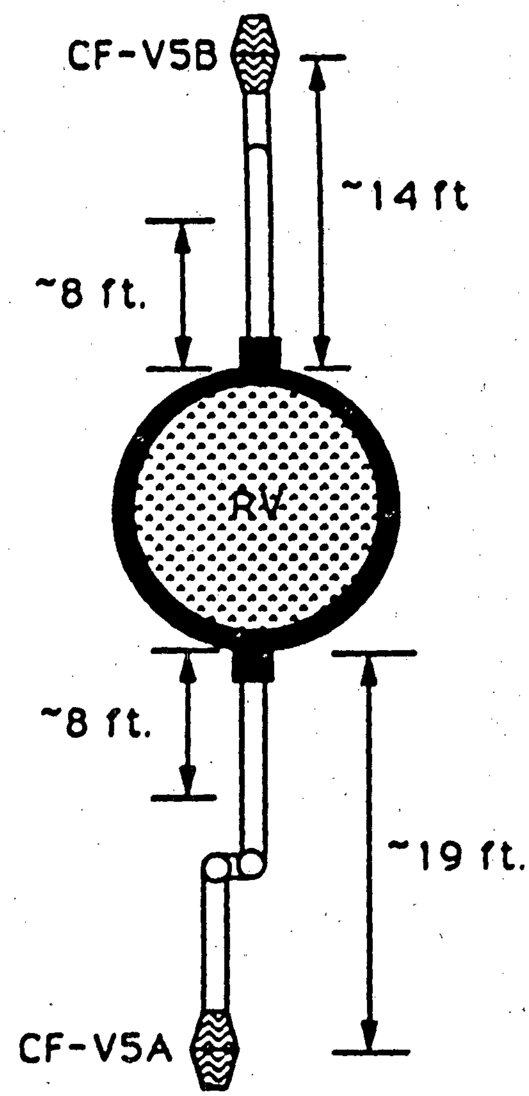


DIAGRAM SHOWING CORE FLOOD PIPING SYSTEM TO "5" VALVES

FIGURE 6 - RCS PIPING

Reactor Coolant System Arrangement – Plan

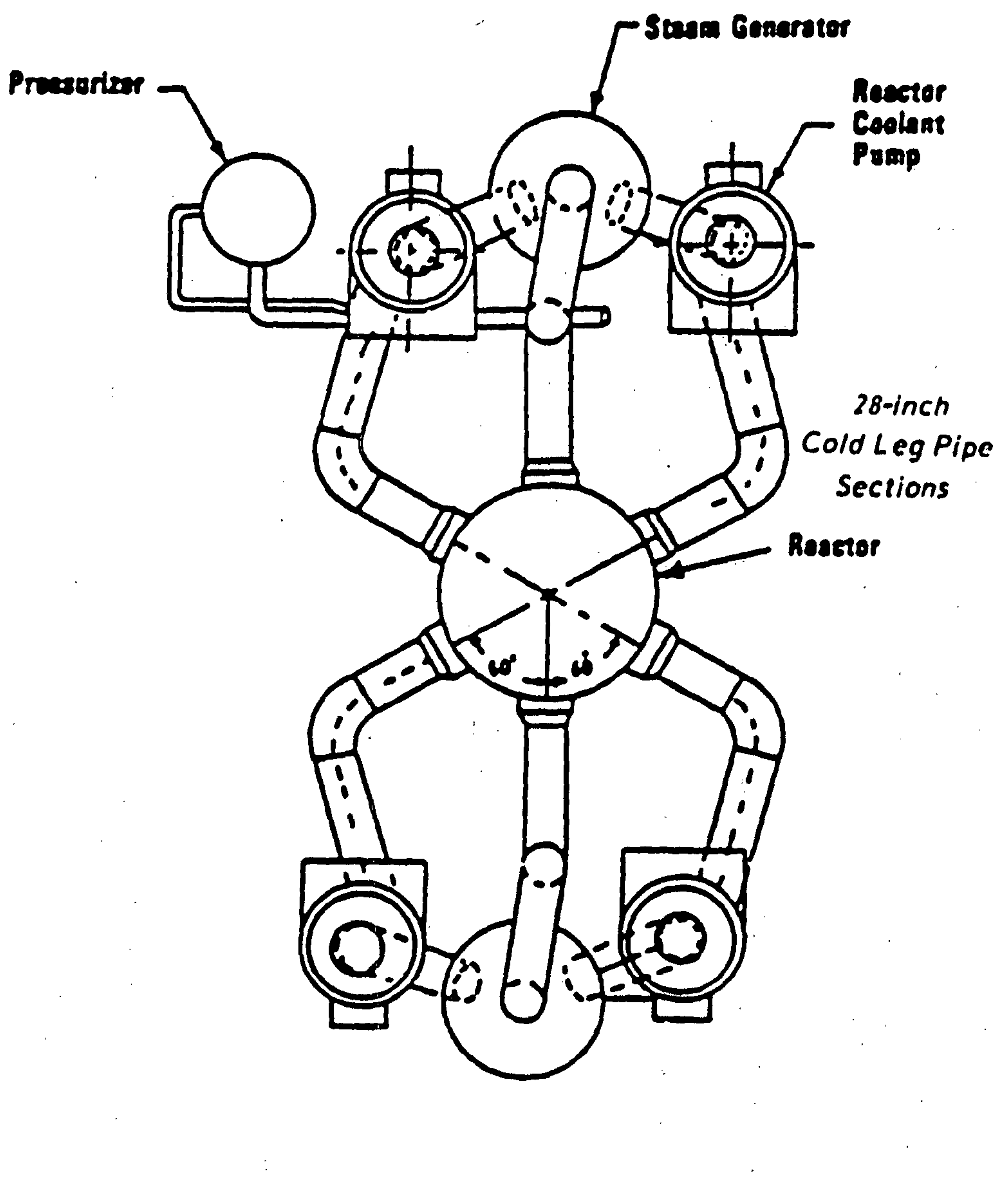
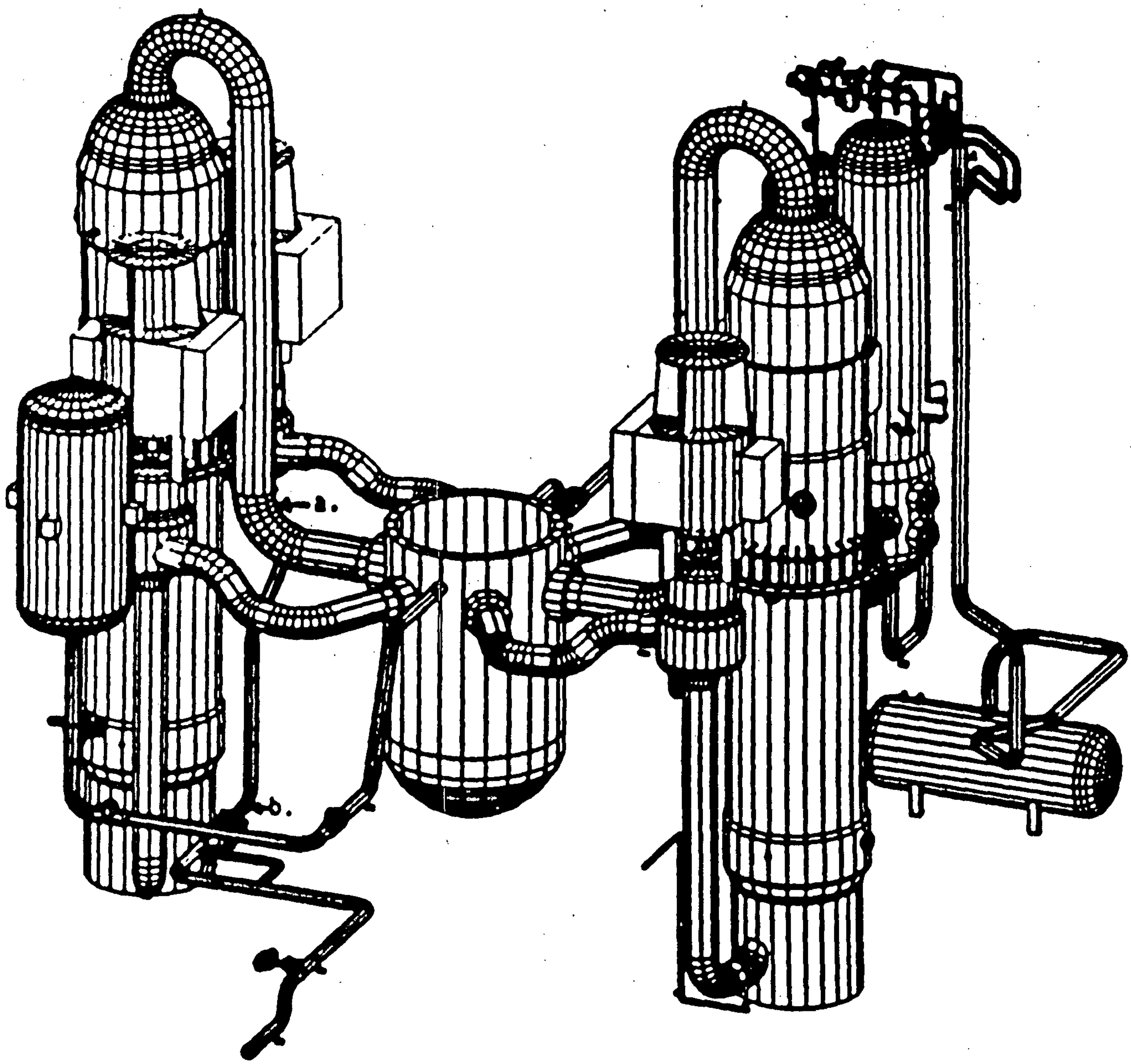
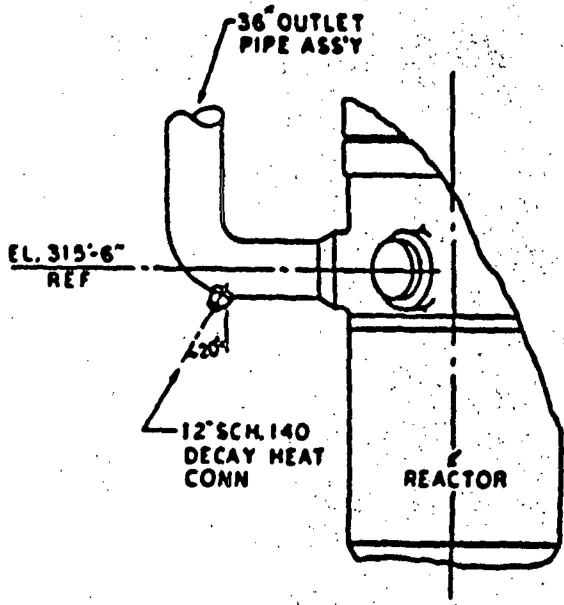


FIGURE 7 - RCS HOT LEGS AND DH LINE

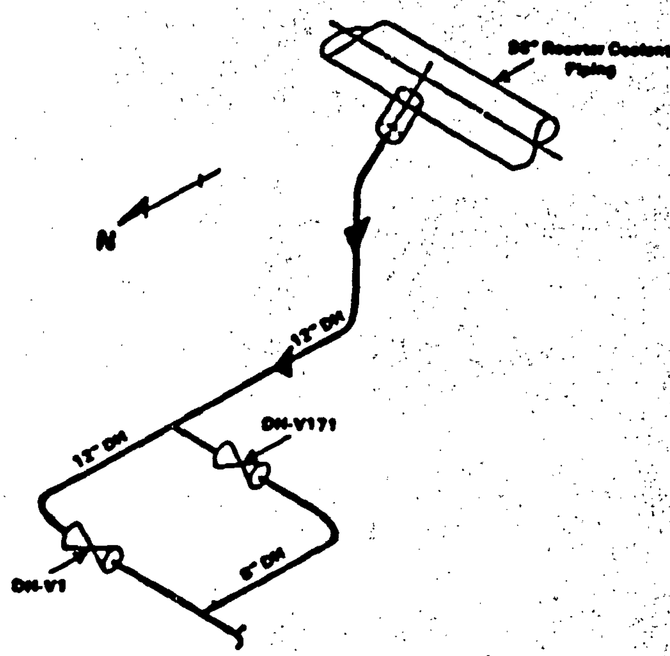


a. "B" hot leg
b. Decay heat line elbow

FIGURE 8 - DECAY HEAT DROP LINE



INTERSECTION OF DECAY HEAT NOZZLE WITH REACTOR COOLANT OUTLET



DECAY HEAT REMOVAL SYSTEM

FIGURE 9 - EXPOSURE RATES IN 'B' D-RING