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TMI-2 FISSION PRODUCT INVENTORY PROGRAM FY-85 STATUS REPORT

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ABSTRACT

This report presents the status of the TMI-2 fission product inventory program through May 1985. The fission product inventory program is an assessment of the location of fission products distributed in the plant as a result of the TMI-2 accident. Included in this report are principal results of samples from the reactor building where most of the mobile fission products (i.e., radiocesium and iodine) are expected to be found.

The data are now complete enough for most reactor components; therefore, it is possible to direct the balance of the examination and sampling program to areas and components where it is likely to be most productive. Those areas are the reactor core and the reactor building basement, with emphasis on the currently unsampled portions of the core.

SUMMARY

During the March 28, 1979, accident at Three Mile Island Unit 2 (TMI-2), the reactor core suffered severe damage, resulting in the release of fission products to the reactor coolant system, auxiliary building, and reactor buildings. In order to compile as complete a list as possible of the location and quantities of fission products released as a result of the accident, a computerized data base was established that permits the calculation of the inventories for key radionuclides at specific times of interest. The most recent update to the data base was performed for FY-1983.

This report presents the results of sample analyses through September 1984, including the estimated total uncertainties associated with these analyses. Systematic changes (i.e., flushing) that may affect the representativeness of the samples, as well as the adequacy of the samples and surface areas or volumes (used to calculate radionuclide inventories), are also discussed. The measured radionuclide concentrations are used to estimate the total radionuclide inventories for system components and the fractions of core fission product inventory retained in the sampled systems. Based on these results, the need for additional sampling of systems and surfaces is evaluated.

The results of the fission product inventory estimates through 1984 (see Appendix A) are summarized in Table S-1. The results are listed as fractions of the total core inventory of radionuclides retained by a system or component. Principal repositories for radioactive materials are the reactor building components where ∿98% of the fission products are located. About 1% of the radiocesium and 2% of the radioiodine inventories were transported to the auxiliary building by the reactor coolant.

Recent examinations indicate that ∿20% of the core mass is located in the core debris present at the top of the damaged core. The core samples obtained from this debris bed late in 1983, and characterized in 1984, suggest that significant fractions of the core inventory are located in the debris bed and in the unexposed portions of the core. Approximately 80% of the core mass yet to be sampled probably represents the single most significant repository for the majority of radionuclides. The samples from the debris bed are used to characterize the debris bed only, not the entire core, whose examination is the subject of an ongoing research program.

Samples of the reactor building air cooler assembly surfaces, reactor building sump, reactor coolant drain tank, a reactor coolant system resistance temperature detector (RTD),[a] makeup and purification demineralizers, control rod leadscrews, and the core debris bed were analyzed during 1984. The majority of components sampled contain only small fractions of the core inventory (< 1%). The makeup and purification demineralizers in the auxiliary building are estimated to have retained approximately 2% of the total radioiodine inventory, making them the most significant fission product repository other than the reactor building basement and core. Details of these measurements are included in Appendix C.

Further characterization of reactor systems and components is suggested for a number of sample locations because, in many cases, the fraction of core inventory calculated to be retained in a component is based on a single sample analysis. Nine samples have been taken from the reactor building basement. Furthermore, because some samples were obtained under adverse conditions (requiring remote sampling), they may not be representative of the component for which the calculations were made. Locations recommended for further sampling are sediments and surfaces of the reactor building basement, the makeup and purification system components, and the reactor coolant drain tank.

The results of the fission product generation codes (e.g., ORIGEN-2, LOR-2, and CINDER) that have been used to calculate the initial fission product inventories of the TMI-2 reactor are evaluated in Appendix B. A comparison of the individual fission product inventories calculated by the several codes indicates differences as great as 25% for some radionuclides, although the majority of the code predictions agree within 10%. A recent calculation based on the power histories of all 177 fuel assemblies has been included in the data base and should provide the most accurate estimate of core inventory. For the final fission product inventory report, a detailed uncertainty analysis will be performed for the initial calculated and final measured inventories to define the uncertainty associated with the total fission product content at TMI-2. This report does not treat all fission products, but emphasizes those that are highly mobile, constitute serious biological hazards, and are representative of a fission product group. The choice of radionuclides in the inventory is made on the basis of ease of detection, half-life, abundance, etc.

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a. From the A loop hot leg near the steam generator.

Table S-1. Location of fission products inventory in plant buildings

Location	Reference	Fraction of Core Inventory													
		Tritium	^{85}Kr	^{90}Sr	^{133}Xe	^{106}Ru	^{125}Sb	^{129}I	^{131}I	^{132}Te	^{137}Cs	^{137}Cs	^{144}Ce	U	Pu
1. Reactor building	8[b]	0.57	0.47	0.017	0.28	—	0.003	0.22	0.21	—	0.42	0.41	3 E-05	4 E-07	9 E-06
Reactor coolant system[a]	8	0.02	—	0.01	—	—	0.001	0.012	0.11	—	0.008	0.008	4 E-04	—	—
Reactor pressure vessel	—[b]	—	—	0.12	—	—	0.08	0.05	—	—	0.05	0.06	0.26	—	—
2. Auxiliary building	7[b]	0.04	—	—	—	—	7 E-05	0.02	—	—	0.01	0.008	7 E-06	—	—
3. Fuel handling building	7	(0.62)	—	(0.02)	—	—	—	—	—	—	(0.46)	(0.45)	—	—	—
4. EPICOR II building[a,c]	7	(0.042)	—	(0.001)	—	—	—	—	—	—	(0.034)	(0.027)	—	—	—
5. TMI-1 buildings	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6. Releases	7	4 E-04		8 E-10	0.07	—	—	—	1 E-06	—	—	7 E-12	—	—	—
Total[a]	—	0.63	0.47[e]	0.15	0.35	—	0.08	0.30	0.32	—	0.49	0.49	0.26	—	—
Alternate Total[a,d]	—	0.63	0.47	0.63	0.35	—	0.40	0.50	0.32	—	0.69	0.73	1.30	—	—

a. Measurement errors not given in reference.

b. This study.

c. Not additive towards total inventory. See footnote c of Table 9.

d. Based on the assumption that the debris bed constitutes 20% of the core and the concentration in the debris bed is representative of the concentration in the entire core.

e. The Kr-85 content of the reactor building atmosphere vented in April-June 1980, but activity was not released during the accident.

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ACRONYMS

AEP	-	Accident evaluation program
AR	-	Accident release
B&W	-	Babcock and Wilcox
CCTV	-	Closed circuit television
FPI	-	Fission product inventory
GEND	-	A group of organizations consisting of GPU Nuclear Corporation, the Electric Power Research Institute, the Nuclear Regulatory Commission, and the Department of Energy
INEL	-	Idaho National Engineering Laboratory
LWR	-	Light water reactor
MUP	-	Makeup and purification system
PALR	-	Postaccident leach release
PNL	-	Pacific Northwest Laboratory
PORV	-	Pilot-operated relief valve
R	-	Total release
RCDT	-	Reactor coolant drain tank
RCS	-	Reactor coolant system
RPV	-	Reactor pressure vessel
RTD	-	Reactor temperature detector
SDS	-	Submerged demineralizer system

TMI-2 FISSION PRODUCT INVENTORY PROGRAM FY-85 STATUS REPORT

INTRODUCTION

During the March 28, 1979, accident at Three Mile Island Unit 2 (TMI-2), the reactor core suffered severe damage, resulting in the release of fission products to the reactor coolant system, reactor and auxiliary buildings and, to a small degree, the environment. Immediately after the TMI-2 accident, four organizations with interests in plant recovery and the acquisition of accident data formally agreed to cooperate in these areas. These organizations, commonly referred to as the GEND Group (*G*PU Nuclear Corporation, the *E*lectric Power Research Institute, the *N*uclear Regulatory Commission, and the *D*epartment of Energy) are presently involved in postaccident evaluations. One of the objectives identified by this group is to determine as accurately as possible the locations and quantities of important radioactive species (i.e., the fission product inventory) relocated as a result of the accident and reactor recovery operations.[1] A computerized data base was established that permits ready access to the estimated inventories of important radionuclides at specific times of interest.[2] As cleanup efforts proceeded and plant components were inventoried, the data were added to the data base (see Appendix A). This effort is known as the Fission Product Inventory (FPI) program.[a]

The objective of the FPI program is to determine the location of fission products in the reactor core and in other plant systems. The fission product release data, for important fission products, is required:

- To assist in defueling and decontaminating the reactor
- As essential data for understanding the accident and calibrating the severe accident analysis codes being developed to predict the outcome of severe reactor transients
- To assist in resolving fission product technical issues that are relevant to reducing the source term for severe accidents.

The FPI program is *not* intended to improve estimates of releases to the environment during the accident, the so-called "source term." The best estimates of releases to the environment have been published and subjected to peer review.[3-5] The large uncertainties inherent in an FPI program make it highly unlikely that these estimates will be changed significantly. For all except the noble gases, the source terms were of the order of 10^{-6} (or less) of the core inventory. FPIs cannot attain such precision.

The scope of this report includes:

- The current location of quantities of important fission products
- An assessment of the initial fission product inventory at the beginning of the accident
- A brief discussion of the reactor components and locations assayed for fission products in FY-84
- An evaluation of the fractions of core inventory accounted for by the inventoried locations
- Sampling requirements and analyses necessary to better define the location of the remaining fission product inventory
- An assessment of the uncertainty of the known inventory.

Locations of Fission Product Inventory

The fission products released from the core during and *after* the TMI-2 accident are now in essentially three locations:

- Systems within the reactor containment building (including the reactor pressure vessel and the reactor coolant system) or on surfaces within the building itself
- Systems within the auxiliary building

a. In the past, this effort has frequently been referred to as the "Mass Balance Program". With this report, the nomenclature is changed to avoid confusion with the reactor coolant inventory assessment effort, which has also been referred to as a "mass balance" program.

- Systems (or components thereof) used to decontaminate the auxiliary building and the reactor containment (some that have been subsequently shipped offsite).

Plant systems in each of these locations are shown in Figure 1. In addition, very small amounts of fission products were released to the environment in plant liquids (Reference 5). Noble gases retained within the containment were released to the environment in a controlled operation (References 3 and 4).

Initial Inventory and Limits on Inventory Closure

It is worthwhile to emphasize, *a priori,* that a total FPI, carried out with rigorous accounting procedures, is not to be expected from this inventory program. Radionuclide inventories in the vessels of nuclear power plants cannot be counted as accountants count dollars; measurement errors are associated with each analysis. These errors are compounded by the errors due to the nonrepresentative and heterogeneous nature of the limited number of samples. Additionally, and perhaps of a more fundamental nature, the initial core inventory of fission products at the time of the accident is not a "known" or measured quantity; it is a *calculated quantity,* based on fission product yields, the variation of reactor power with time, the fuel burnup, the axial and radial power profiles of the reactor, the fuel zone enrichment, etc. Further, the various calculational codes yield different inventories based on the same input data for reactor power, operating time, etc. The variations due to code differences are discussed in some detail in Appendix B. For the reasons noted in Appendix B, the ORIGEN-2 model calculation is adopted as the reference inventory for the Accident Evaluation Program[a]. The uncertainty in the initial inventory itself may be on the order of 30% for certain nuclides. However, for most fission products the uncertainty is less than 10%.

Important Fission Products

This report does not attempt to account for all fission product species; that is not feasible. It does attempt to account for those fission products that are important contributors to accident "source terms." Source terms are, in part, determined by the fission product release from the core. Important radionuclides in the fission product mix of a large nuclear power reactor were listed in the "Technical Basis for Estimating Fission Product Behavior During LWR Accidents," NUREG-0772.[7] This list is reproduced as Table 1. In the companion report to the fission product behavior volume, "Regulatory Impact of Nuclear Reactor Accident Source Term Assumptions," NUREG-0771,[8] sensitivity studies on the effect of reductions in source terms for individual radionuclides were carried out. A conclusion was reached that the reduction of the consequences of severe accidents required "the systematic reduction in the predicted atmospheric release of all of the significant radionuclide species" (Reference 7). Thus, of the species listed in Table 1, it is necessary to determine more precise source term estimates than those previously *assumed* for all of these species. It is necessary to be able to *predict* the source terms, for those that cannot be readily measured, by comparison with the properties of those with similar behavior, which can be readily monitored.

As can be seen from the half-lives of some of the fission product species, it is, and was, virtually impossible to obtain sufficient data on a number of the very short-lived species so that their behavior during the course of the accident could be reliably determined. Further, short half-lives means that the species are no longer present in detectable amounts so that their present locations in plant systems can be determined. This is, of course, true of all the iodine, tellurium, and the noble gas species in Table 1. Fortunately, I-129 (not listed in the table) has a 1.7×10^7 year half-life and can be used to trace the behavior of other iodine isotopes. In summary, it is the intent of the FPI program to account for as many of the species in Table 1 as practical, or at least a representative species for each major group of fission products. Currently, measurable radionuclides are I-129, Cs-134, Cs-137, Xr-85, Sr-90, Ru-106, Ce-144, and all actinides except Cm-242.

Accident Release vs. Postaccident Release

From the standpoint of the TMI-2 Accident Evaluation Program (AEP) it is important not only to know the current location of important fission products, but also to determine how and when they got there. This issue will be discussed in more detail

a. In contrast, the FPI (mass balance) program carried out by NUS Corporation used the LOR-2 Code of B&W.[6]

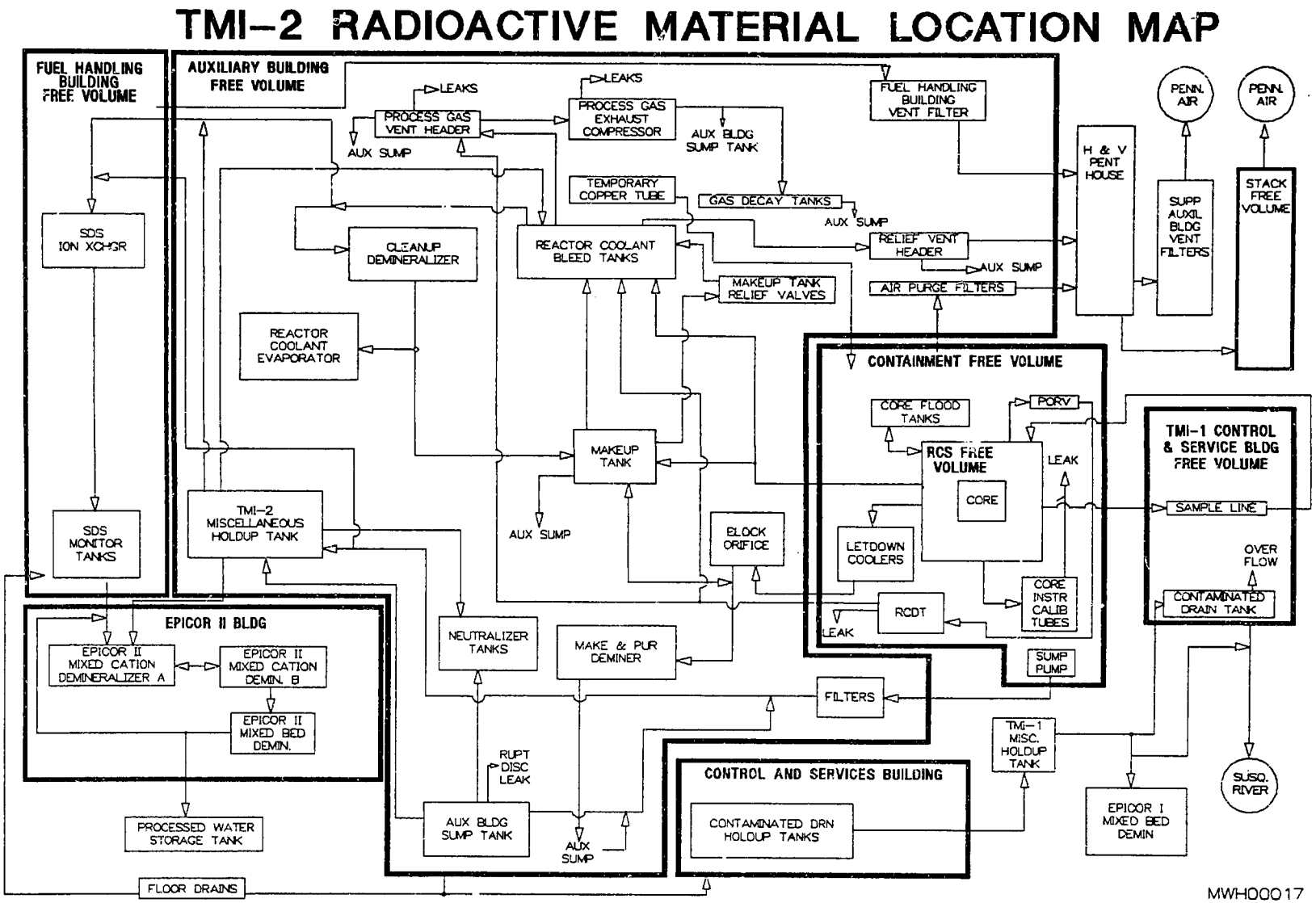


Figure 1. TMI-2 radioactive material location map.

Table 1. Important radioactive nuclides[a]

	Half-Life (d)	Radioactive Inventory[b] (Ci x 10^{-8})
Iodine Isotopes		
^{131}I	8.05	0.87
^{132}I	0.0958	1.3
^{133}I	0.875	1.8
^{135}I	0.280	1.7
Noble Gases		
^{85}Kr	3,950	0.0066
^{85m}Kr	0.183	0.32
^{87}Kr	0.0528	0.57
^{88}Kr	0.117	0.77
^{133}Xe	5.28	1.8
^{135}Xe	0.384	0.38
Cesium Isotopes		
^{134}Cs	750	0.13
^{137}Cs	11,000	0.065
Other Fission Products		
^{90}Sr	11,030	0.048
^{106}Ru	366	0.29
^{132}Te	3.25	1.3
^{140}Ba	2.8	1.7
^{144}Ce	284	0.92
Actinide Isotopes		
^{238}Pu	32,500	0.0012
^{239}Pu	8.9×10^6	0.00026
^{240}Pu	2.4×10^6	0.00029
^{241}Pu	5,350	0.052
^{242}Cm	163	0.014
^{244}Cm	6,630	0.00084

a. From Reference 5.

b. The inventories of fission products in this table and discussed later in this report are for a 3412 MW reactor operated for 3 y as predicted by the ORIGEN code.

in subsequent reports. For this report, however, it is sufficient to state that a necessary piece of input data to the analysis of the accident progression is the fraction of the core inventory of the important nuclides that were released from the fuel and transported from the core *during the accident*. This quantity is termed the "accident release" (AR). Additional fractions of the core inventory of these nuclides may have been leached from the fuel material and transported to other parts of the plant at later times. This release is termed the "postaccident leach release" (PALR). For some nuclides, it may even exceed the accident release. Neither of these release quantities are known at the present time, nor can they be measured. Only the "total release" (R) from the core[a] can be measured. The "total release" is the subject of this report.

This is not the final report on the FPI program. It is a status report on data available from the plant as of May 1985. To date, only a limited number of samples from the debris bed at the top of the core have been analyzed; these samples were selected because they had the potential of providing vital data about the condition of the core and the progression of the accident. They may not be "representative" samples of the core debris. The major portion of the core has not yet been sampled. Thus, for the purposes of the FPI program, the likely major repositories of many fission products have yet to be analyzed. This report, then, can only be expected to account for some fraction of the more mobile fission products.

a. That is, during the accident and the period following until the reactor and auxiliary buildings were sampled.

INVENTORY OF THE FISSION PRODUCTS

Location of Fission Products

The uncovering of the TMI-2 core and consequent severe fuel damage released fission products to the reactor coolant. These fission products were transported throughout the reactor coolant system and subsequently through several effluent pathways to other plant components in the reactor and auxiliary buildings and finally, by overflow and/or rupture disk failure, to the floors of these buildings. A small quantity of radioiodine (0.23 Ci) is known to have been released to the Susquehanna River (Reference 5), while about 1% of fission product xenon was released to the atmosphere during the initial phase of the accident. About 45% of the krypton was released to the reactor building atmosphere.[9] The krypton was retained in the reactor building until it was subsequently vented in a controlled manner about a year later. Some of the noble gases are known to have been retained in the core materials.

The plant components known to contain fission products, which are included in this status report on the FPI program, are shown in Figure 2. The emphasis of the program has now shifted from the auxiliary building to the reactor building. Still, several major fission product sinks have not yet been sampled. Among these are:

- The consolidated core mass below the core debris bed
- Oxidized fuel rods on the periphery of the core that have essentially retained geometric integrity
- Core materials that have been relocated below the active core region to the lower plenum of the reactor vessel, or the area between the lower core support grid and the flow distributor
- Reactor coolant letdown coolers.

In addition, larger and more representative samples of the core debris bed, RCS surfaces, and the basement sediment are required for more accurate characterization of the fission product content of these components. Until these important samples have been obtained and analyzed, a reliable estimate of the final FPI is not possible.

In addition to the major fission product sinks discussed above, a number of plant components have been identified that may have been in one of the transport pathways during or following the accident. These components are identified in the section on fission product inventory program completion. A sampling program for these components is recommended later in this document.

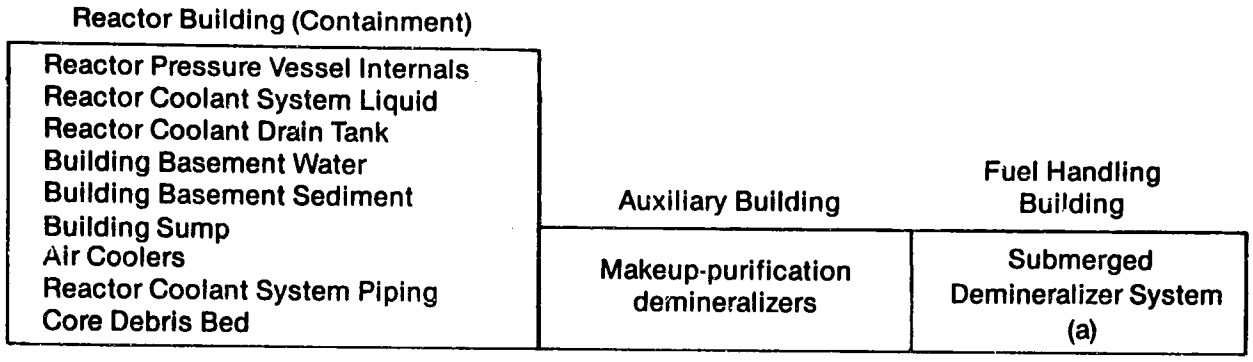
Fission Product Inventories

Since the previous status report on radionuclide inventories in TMI-2 (Reference 9), several important components in the reactor building have been sampled and, most recently, initial samples of the reactor core were obtained. As samples of the core are obtained, it is expected that major increments in the fission product inventories accounted for will be made. However, as discussed in Appendix C, determining the radionuclide content of some vessels or surfaces involves the *direct measurement* of a radionuclide concentration and the *estimation* of a vessel volume or the area of a surface. This does not imply that vessel volumes or the surface areas cannot be measured; merely that, in its current fabricated, installed, and contaminated state, it is exceedingly difficult (or impossible) to confirm design values. Estimates are, therefore, employed to calculate inventory retention. Although one factor is a measurement and the other an estimate, the error involved in the estimate may be either smaller, equal to, or larger than the total error involved in the direct measurement of the concentration. The error in the fractional retention is calculated by standard methods based on the stated errors in the measurements given in Appendix C.

Components Outside the Reactor Coolant System

Reactor Building Air Coolers. The reactor building air coolers (Figure 3) were expected to be a potential plate-out location for radioactivity because of their large surface area, the large volume of air moving through them, and the known contamination of the reactor building.

Coupons removed from the inner and outer surfaces of the air cooler access panels were used to obtain the concentration of several important fission products on these surfaces. These measurements were used in conjunction with estimates of the surface areas of the various parts of the air coolers to estimate the total fission product inventory on the air cooler surfaces.



(a) The Submerged Demineralizer System was used to remove the fission product inventory from water in the Reactor Building Basement. The consolidated resin beds were shipped offsite for disposal.

6 3415

Figure 2. Plant components inventoried in this report.

Details of the measurement and estimation techniques are presented in Appendix C and the results are shown in Table 2. The data demonstrate that the air cooler surfaces were not a major sink for the deposition of radionuclides ($<3 \times 10^{-3}$ fraction of core inventory for any radionuclide). The data suggest that exposed reactor building surfaces were not significant fission product repositories following the accident.

Reactor Building Sump. The reactor building sump is the lowest drainage point in the reactor building and, therefore, it collects all debris washed into it by water flowing from the building basement or draining from other reactor building drains. The sump activity has been decreased significantly by processing the basement water through the Submerged Demineralizer System (SDS). Still, it should be indicative of residual elevated levels of the activity remaining on the basement floor.

Both solid and liquid phases of the material in the sump were sampled using the sump pump discharge as the sampling device. The results are given in Table 3, which clearly shows that (a) the reactor building sump is not now a major repository of fission products, and (b) as in the case of the reactor building basement itself, the major fraction of the fission products does not appear to be in the liquid phase.[10] The liquid-phase concentration is approximately the same as that seen in the reactor building basement and other components. However, the solid phase may be finely divided fuel material from the core, which has not been fully leached. Details of the analysis are given in Appendix C.

Reactor Coolant Drain Tank (RCDT). As shown in Figure 1, the RCDT was the first vessel in the release pathway from the pressurizer pilot-operated relief valve (PORV) to the reactor building basement, the sump, and finally to the auxiliary building. Following failure of the RCDT's safety rupture disk at 15 min into the accident, the tank became a relatively low linear velocity conduit in which insoluble core materials, carried out of the reactor vessel and pressurizer by the primary coolant, could settle. Both liquid and solid samples were collected from the RCDT to determine its fission product contents. Approximately 1.9×10^6 L of water have passed through the RCDT (Reference 10); consequently, it was not expected that high concentrations of soluble materials would be found in the sediment in the bottom of the tank. The fractions of the inventories in liquid and solid phases in the RCDT are listed in Table 4. In contrast to other fission products and to data on components reported earlier,[a] the solid residue appears to have a higher loading of Sr-90 (by a factor of 5) than the liquid phase. The reasons for these differences are not obvious. It is also evident that the RCDT is not now a major repository for fission products. Details of the RCDT sampling and analyses are given in Appendix C.

Reactor Coolant System. The Reactor Coolant System (RCS) surfaces have the potential to be a repository for major quantities of fission products. While the reactor coolant itself is continuously processed to remove fission products, plate-out in

a. The reactor building basement sediment and the sump.

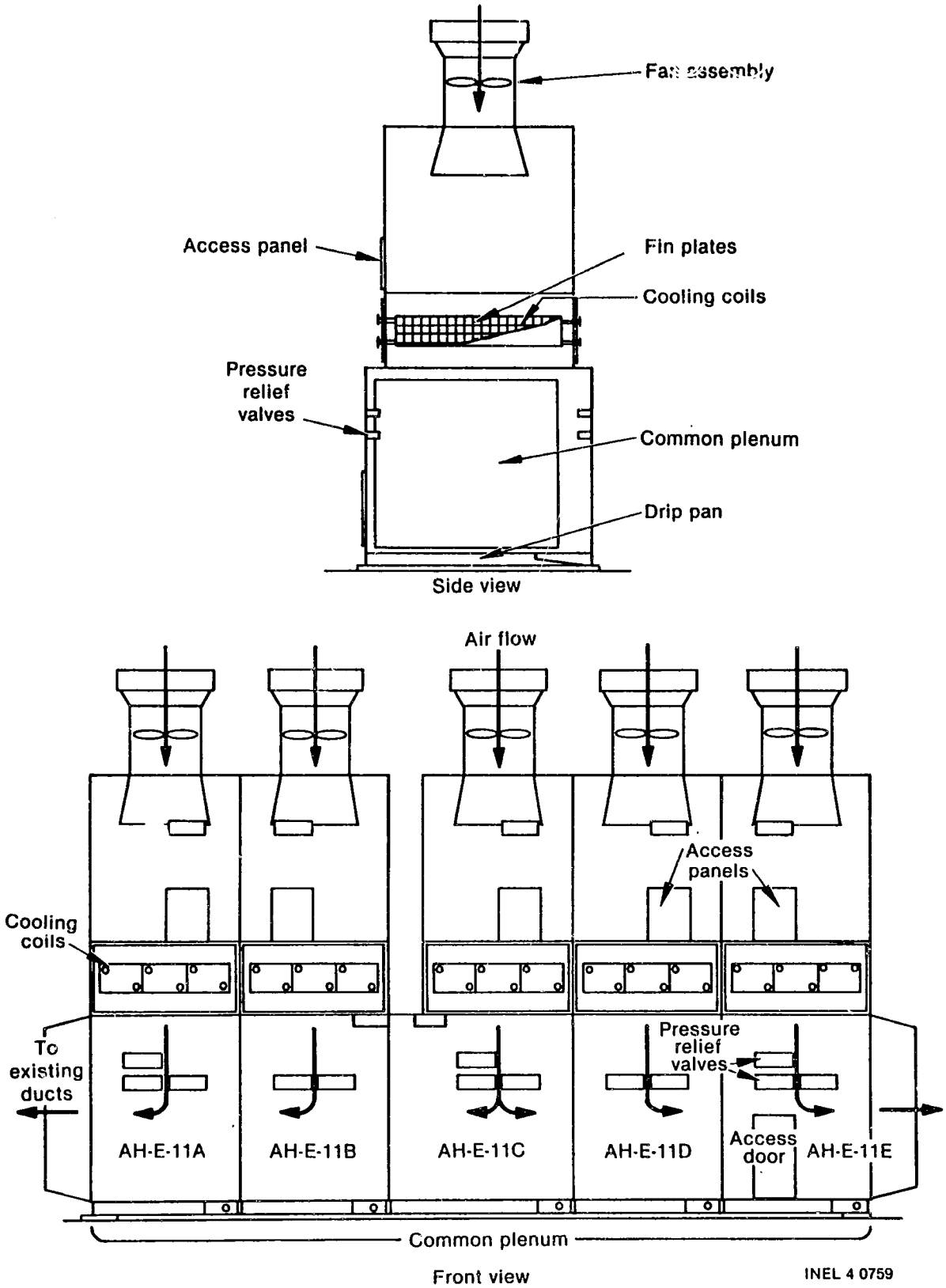


Figure 3. Reactor building air coolers assembly.

Table 2. Fractions of core inventory retained on reactor building air cooler surface[a]

Radionuclides	Fraction of Core Inventory
^{134}Cs	1 ± 1 E-4
^{137}Cs	1 ± 1 E-4
^{90}Sr	3 ± 3 E-6
^{129}I	3 ± 1 E-3

a. Data decay corrected to March 1, 1984.

the RCS can remove significant quantities of fission products from the circulating coolant, while retaining them within the primary system. In considering the surfaces of the RCS (excluding the reactor vessel itself), it is clear that plate-out could be significantly different throughout the system, based on the temperature of the component, the complexity of its geometry, the surface area, etc. Clearly, the surfaces of several of the components should be sampled. To date, this has not been possible. Only a single sample from an internal surface of the RCS has been obtained. A resistance temperature detector (RTD) was removed from the hot leg of the "A" steam generator. Analysis of the deposits on this 15 cm^2 surface (10^{-5}% of the total RCS surface) is the sole basis of the estimate of the fission product inventory on the interior surfaces of the entire RCS. It is clearly an inadequate sample.

Estimated fractions of the core inventory of various fission products retained on the surfaces of the RCS are shown in Table 5. These estimates are based on the measured surface concentration, determined by sequential leaching, of the RTD thermowell tip. The surface area estimates (see Appendix C) for components of the RCS were:

- Hot legs 9.7×10^5 cm^2
- Cold legs 9.8×10^5 cm^2
- Steam generators 3.7×10^7 cm^2.

Other components of the RCS are not included in the surface area estimates. These are the pressurizer, reactor vessel, makeup and purification units, and the residual heat removal system. Based on the above estimates, the RCS surfaces have retained approximately 0.1% of most of the mobile fission products, even after being subjected to continual leaching by primary coolant for 5 y. This estimate is subject to revision when samples more representative of horizontal surfaces, cold legs, etc., are obtained. Sampling of these surfaces does not take account of the (possibly) different affinities of the RCS materials for fission products (304 SS, Inconel, 17-4 pH steel).

Reactor Pressure Vessel and Internals. Three control rod drive leadscrews were removed from the reactor pressure vessel (RPV) in 1982 in preparation for television inspection of the central core region. Two of these leadscrews have been analyzed

Table 3. Fractions of core inventory retained in the reactor building sump[a]

Radionuclide	Fraction of Core Inventory: Solids	Fraction of Core Inventory: Liquids
^{54}Mn	—[b]	—[b]
^{60}Co	—[b]	—[b]
^{90}Sr	8.3 ± 0.9 E-7	9.0 ± 1.0 E-5
^{106}Ru	—[b]	—[b]
^{125}Sb	1.4 ± 0.2 E-7	—[b]
^{129}I	<5 E-7	—[b]
^{134}Cs	2.9 ± 0.3 E-7	1.4 ± 0.1 E-3
^{137}Cs	2.6 ± 0.3 E-7	1.3 ± 0.1 E-3
^{144}Ce	1.0 ± 0.3 E-7	—[b]

a. Data decay corrected to March 24, 1984.

b. Not Detected.

Table 4. Fractions of core inventory retained in the reactor coolant drain tank[a]

Radionuclide	Fraction of Core Inventory: Solids	Fraction of Core Inventory: Liquids
^{3}H	—[b]	2.9 ± 0.06 E-4
^{60}Co	—[c]	—[c]
^{90}Sr	5.0 ± 5.0 E-4	1.0 ± 0.2 E-4
^{106}Ru	2.0 ± 0.2 E-5	—[b]
^{125}Sb	1.0 ± 1.0 E-5	4.0 ± 1.0 E-6
^{129}I	6.0 ± 6.0 E-9	5.0E + 1.0 E-5
^{134}Cs	4.0 ± 4.0 E-6	5.0 ± 1.0 E-5
^{137}Cs	3.0 ± 3.3 E-6	4.4 ± 0.9 E-5
^{144}Ce	1.0 ± 1.0 E-6	—[b]

a. Data decay corrected to March 1984.

b. Not detected.

c. Not a fission product.

for surface deposits of radionuclides in an initial attempt to estimate the quantity of fission products plated out on the internal metallic surfaces of the RPV.

The leadscrews were obtained from position H8 at the core center, position E9 at the mid-radius of the core, and the outer edge of the core at position B8. The locations of these control rod positions are shown in Figure 4. Leadscrews H8 and B8 were analyzed for the radionuclides at various laboratories after being sectioned, as shown in Figure 5. In an attempt to characterize surface deposition on the leadscrews, the deposits were removed initially by brushing, followed by acid etching of the tightly adherent material.

On both leadscrews, the radionuclide concentrations were found to be the highest at the top of the leadscrew, which was also exposed to the lowest maximum temperature. Details of the examination and the evaluation of the axial gradient radionuclide concentrations are presented in Reference 11. To estimate the quantity of each radionuclide retained on the internal RPV surfaces, the maximum value of the concentration of each radionuclide on the two leadscrews was used, along with the estimated average surface area of the RPV plenum. A more detailed description of this evaluation is given in Appendix C, and details of the calculational techniques and analytical methods are shown in References 11 and 12. The final estimates of fission product retention on the RPV plenum are listed in Table 6. The data suggest insignificant fission product deposition, indicating that further evaluation of the plenum deposits may not be required.

Reactor Core. The present condition of the TMI-2 reactor core is shown in Figure 6.[13] The core consists of a peripheral region of relatively intact rods

Table 5. Fractions of core inventory retained in the reactor coolant system[a]

Radionuclide	Fraction of Core Inventory
^{54}Mn	—[b]
^{60}Co	—[b]
^{90}Sr	5.6 ± 0.6 E-4
^{125}Sb	1.4 ± 0.2 E-3
^{129}I	1.3 ± 0.9 E-3
^{134}Cs	1.0 ± 0.1 E-3
^{137}Cs	1.1 ± 0.1 E-3
^{144}Ce	3.6 ± 0.4 E-6

a. Data decay corrected to March 1984.

b. Not a fission product.

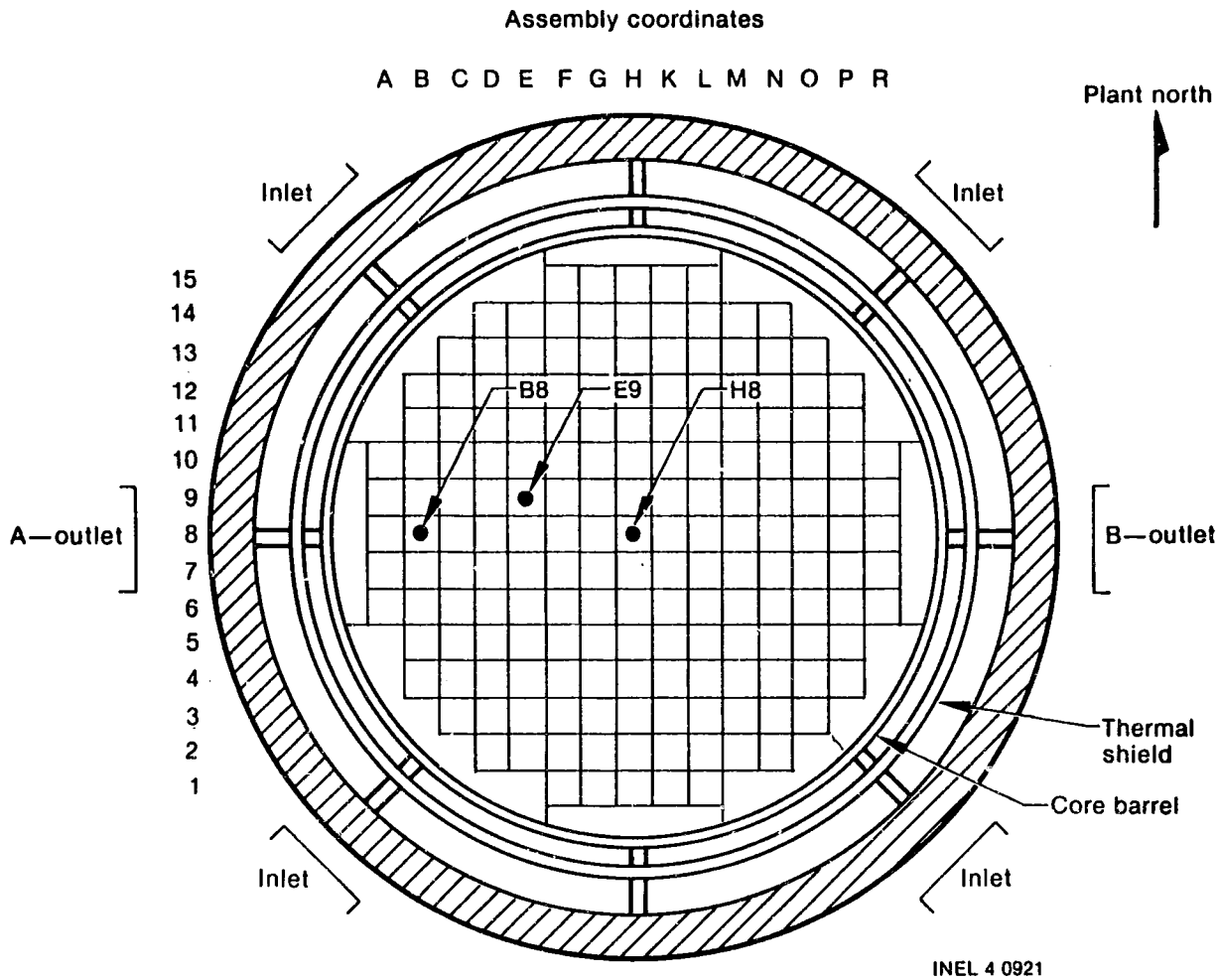


Figure 4. Control rod drive leadscrew locations in reactor core.

(equivalent to about 33 out of 177 assemblies), a debris bed about 1 m deep with a radius equivalent to about 80% of the initial core radius, resting on an impenetrable layer of solidified core material in the lower two-thirds of the core. In addition, approximately 10 to 20 t of resolidified core material has relocated to the RPV lower plenum region. No information is available yet on the composition or the fission product content of any of the core materials below the debris bed (∿75% of the core). Although additional samples of the debris bed are planned, this report is based on the analysis of five samples of the debris bed weighing a total of ∿150 g. While the analytical data on these samples is quite uniform, how well these samples represent the 25 t of core material (one-fifth of the entire core) in the debris bed is an open question. The samples were obtained from the locations shown in Figure 7, at three different depths into the debris bed: the surface (0 in.), 3 in., and 22 in. The core debris samples contain all of the materials present in the core including fuel, control rod materials, cladding, burnable poison, etc. Inventories for these materials are not considered in this report; we are interested here in fission products exclusively.[a]

The average[b] fission product concentrations and fraction of core inventories retained in the debris bed are shown in Table 7. Details are given in Appendix C. Between 5 and 26% of the total fission product inventories are found in the debris bed. If the debris bed is assumed to be

a. Fuel materials, uranium and plutonium, will be included in future inventories.

b. The average fission product concentration in the debris samples was calculated using a mass weighted averaging of radionuclide concentration in each of the five samples shown in Table 7.

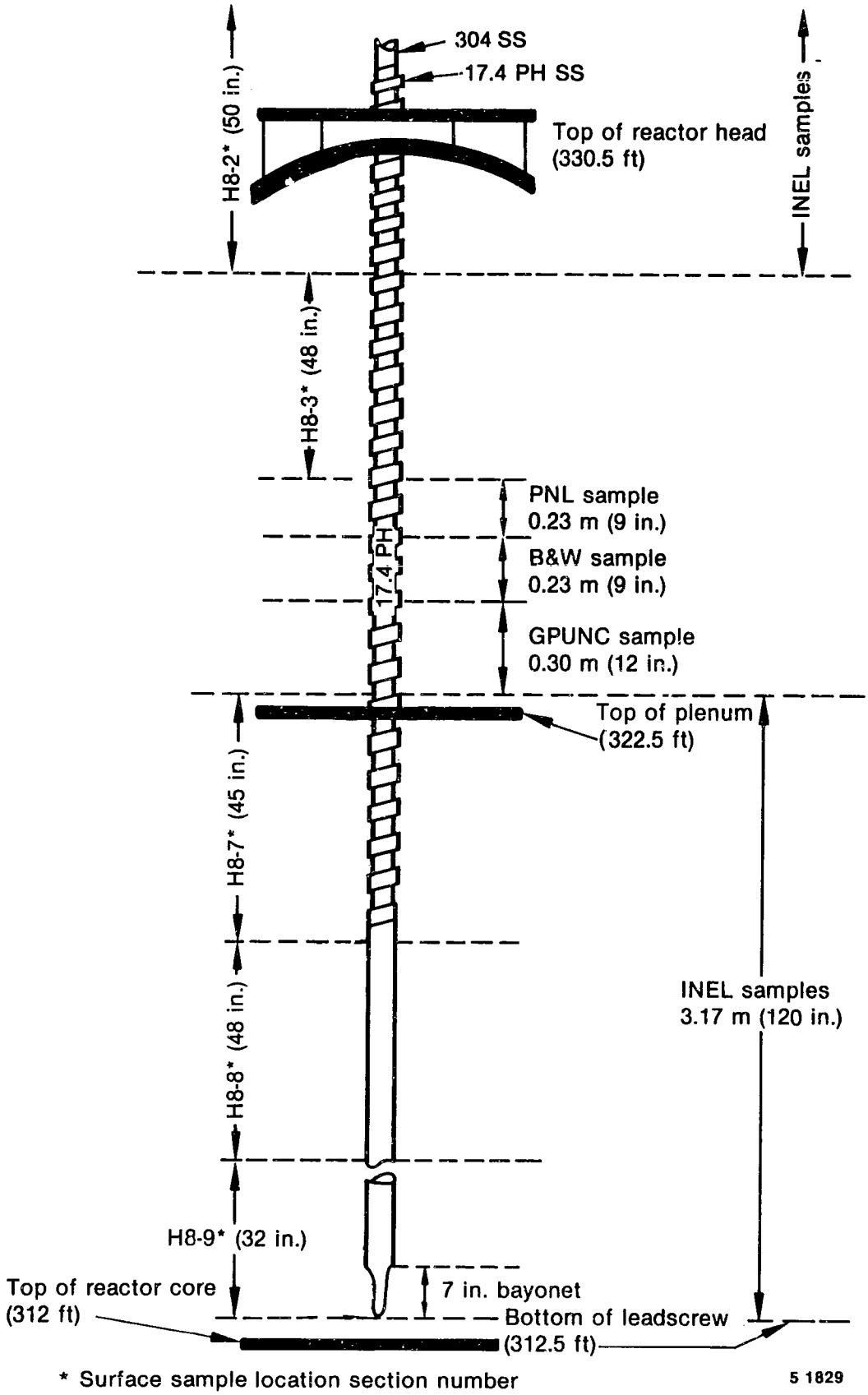


Figure 5. H8 control rod drive leadscrew and sections analyzed.

Table 6. Fractions of core inventory retained on the reactor plenum and associated surfaces[a]

Radionuclide	Fraction of Core Inventory
^{90}Sr	9.0 ± 7.0 E-5
^{106}Ru	1.0 ± 0.9 E-4
^{125}Sb	8.0 ± 5.0 E-4
^{129}I	8.0 ± 4.0 E-4
^{134}Cs	9.0 ± 7.0 E-4
^{137}Cs	8.0 ± 6.0 E-4
^{144}Ce	7.0 ± 4.0 E-5

a. Assume 3.54 ± 0.71 E6 cm^2 surface area from Reference 12.

representative of the content of the entire core weighing 1.23 x 10^5 kg, then a large fraction of the initial inventory of fission products can be accounted for. These data are also shown in Table 7. At this time, there is no information on the validity of this assumption. This calculation is carried out solely to demonstrate that a major fission product sink has not been sampled and evaluated.

Auxiliary Building Components

Makeup and Purification Demineralizers. During normal operation, the Makeup and Purification (MUP) system receives reactor coolant from the steam generator cold leg for filtration and demineralization. This system operated only intermittently during the accident and not at all thereafter. The system contains two ion-exchange resin beds that remove radionuclides from the RCS. Resin samples were obtained for analysis from both demineralizers, and a liquid sample was taken from the "B" demineralizer in March/April 1983.

The radionuclide inventory of the MUP system was estimated using the measured concentrations (in μCi/g) for the selected isotopes on the resin beds, and estimates of the mass of resin remaining in each demineralizer vessel based on remote visual observation of the postaccident resin volumes[a] and the preaccident resin density. While this method of estimating the inventory is subject to large errors (50% or perhaps more), it is the best available data. In any event, the current MUP fission product inventory represents, at most, 2% of the core inventory. The fractional inventory data are given in Table 8 and are treated in more detail in Appendix C.

Inventory Summary to Date

This section summarizes the current status of the FPI program. An accounting of the fraction of the FPI found in each major plant repository and a summation of the total FPI now accounted for is presented. Table 9 shows the FPI in all plant components that have been assayed to date, with the exception of some minor sinks in the auxiliary building (Reference 9), which are shown collectively. Assays of several major sinks in Table 9 have been only partially completed or inadequately studied (e.g., RCS, RPV surfaces, reactor core). For these components, the data in Table 9 should be considered only interim values. For other components, while the data may be incomplete or subject to significant errors, the indicated inventory fraction is sufficiently small that further study is not warranted as part of the FPI program. An abbreviated listing of major and minor sinks (excluding gaseous fission products) of the components in Table 9 is given in Table 10. Table 10 clearly shows where the major effort should be focused to complete the FPI.

A further simplification of Table 9 is useful to provide some perspective on the dispersion of fission products throughout the TMI-2 plant. This perspective is gained by localizing the fission products to the site building where the various components are located. Table 11 shows the FPI in each plant building. These data are also plotted in Figures 8, 9, and 10. The data clearly show that, with the exception of the released fission gases, virtually all of the fission products remain in the reactor building. Even the well-publicized pumping of

a. The resins suffered severe degradation because of high temperatures and a large radiation dose.

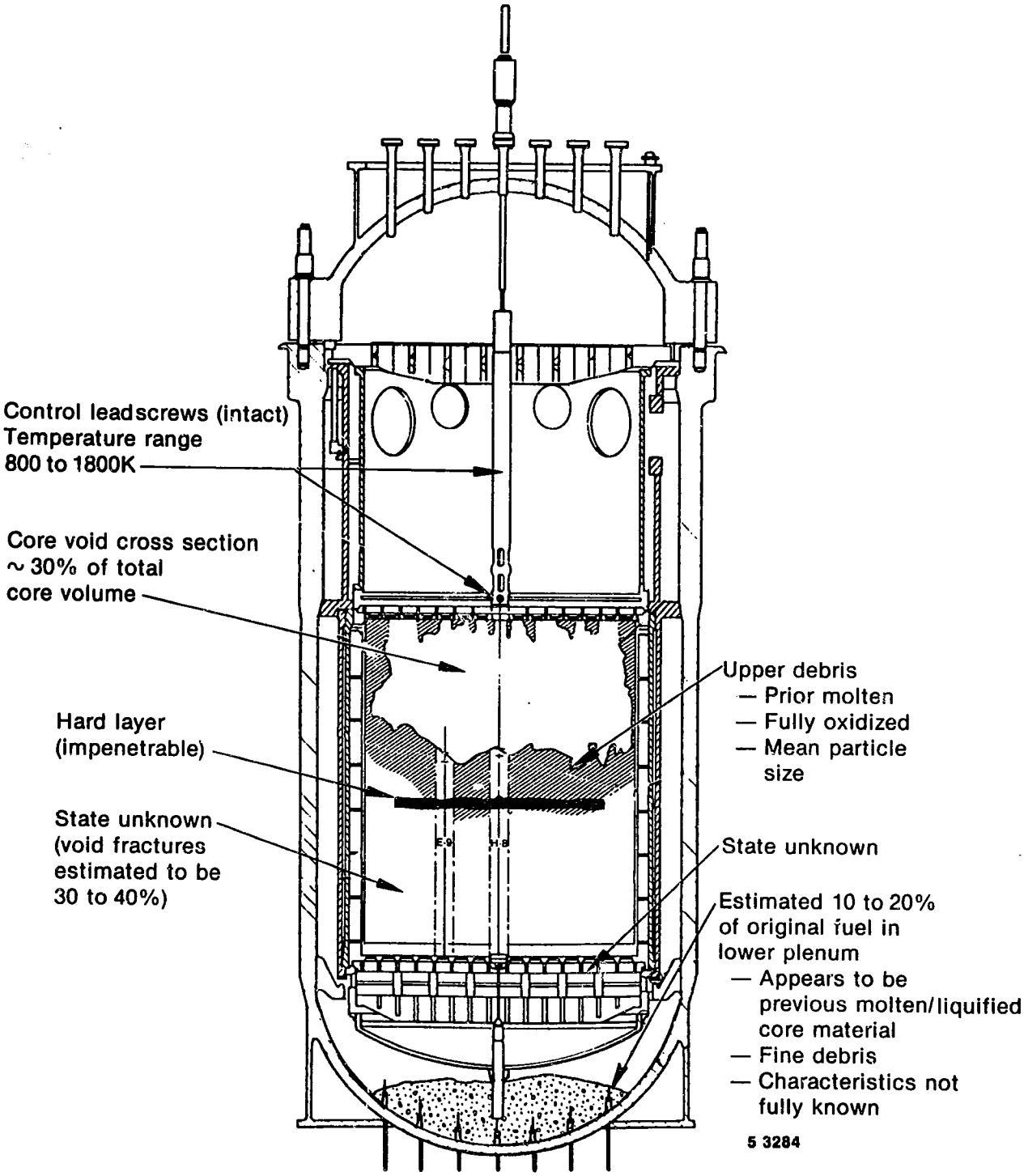


Figure 6. Known core and reactor vessel conditions.

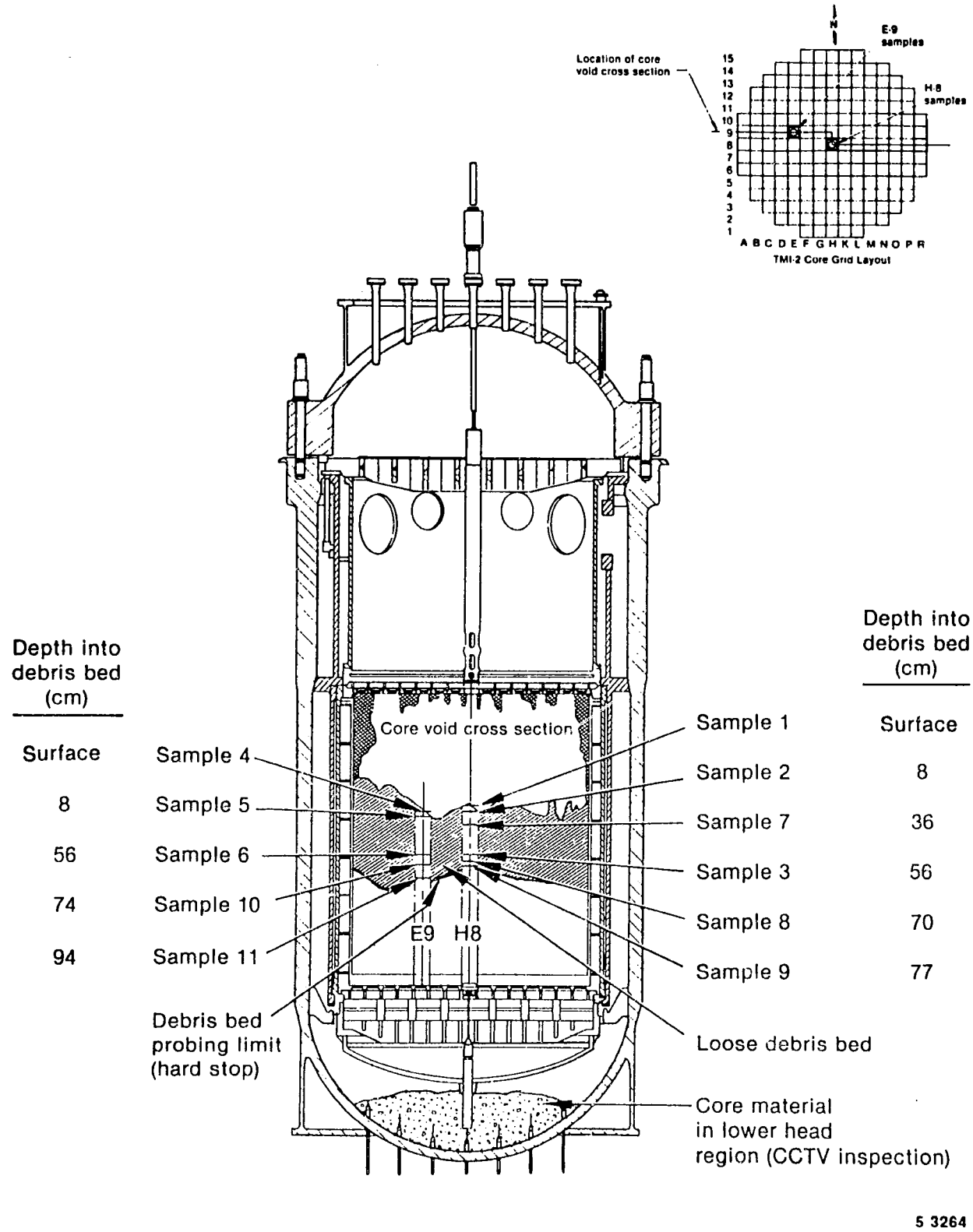


Figure 7. TMI-2 core debris sample locations.

Table 7. Fractions of core inventory retained in core debris bed[a]

Radionuclide	Average Radionuclide Concentrations in Core[b] (μCi/g)	Sample Weighted Radionuclide Concentrations[c] (μCi/g)	Retained Fraction of Core Inventory	
			In Entire Core	In Debris Bed[d]
^{90}Sr	5.30 E+3	3.0 ± 1.0 E+3[e]	6.0 ± 2.0 E-1	1.2 ± 0.4 E-1
^{106}Ru	9.20 E+2	7.0 ± 2.0 E+2	8.0 ± 2.0 E-1	1.6 ± 0.4 E-1
^{125}Sb	2.96 E+2	1.1 ± 0.2 E+2	3.8 ± 0.7 E-1	8.0 ± 1.0 E-2
^{129}I	1.83 E-2	4.0 ± 1.0 E-4[f]	2.4 ± 0.6 E-1	5.0 ± 1.0 E-2
^{134}Cs	2.96 E+2	8.0 ± 3.0 E-1	2.5 ± 0.9 E-1	5.0 ± 2.0 E-2
^{137}Cs	6.08 E+3	1.8 ± 0.7 E+3	3.0 ± 1.0 E-1	6.0 ± 2.0 E-2
^{144}Ce	2.20 E+3	2.8 ± 0.4 E+3	1.3 ± 0.2	2.6 ± 0.4 E-1
^{154}Eu	5.10 E+1	4.6 ± 0.9 E+1	9.0 ± 2.0 E-1	1.8 ± 0.4 E-1

a. Data decay corrected to March 1984.

b. Calculated from initial core inventory decayed to March 1, 1984. The inventory has been divided by the mass of the core (1.25×10^5 kg) to provide an average concentration per gram of core.

c. The sample weighted concentrations in column 3 are assumed to be representative of the entire core.

d. The debris bed is assumed to account for 20% of the core.

e. Preliminary estimate to be revised based upon bulk dissolution sample analysis results that were unavailable at the time of this report.

f. Estimate based upon individual particle and particle-size aliquots. The result may be low by as much as 50%.

water from the reactor building basement to the auxiliary building carried only insignificant amounts of the iodine and cesium to the auxiliary building.[a] Of course, even smaller quantities of these radionuclides represent a radiation source that should be avoided. However, the TMI-2 accident has clearly demonstrated that in some accidents, virtually all of the fission products can be contained within the plant and essentially within the reactor building itself; thus, public exposure was limited. In addition to emphasizing the minimal effect of the TMI-2 accident on the public health, this perspective aids in setting priorities for further efforts in the FPI search program, as described in the section on fission product inventory completion.

The uncertainties in the total retentions of several of the fission products in Table 11 are large, 30% for iodine and cesium. The principal reason for these large uncertainties is the even larger

a. It is now known that the RB sump pump was stopped before fuel rod damage occurred. Thus, only small quantities of cesium and iodine were transferred by this route. The dominant pathway for fission-product transport to the auxiliary building appears to be the normal operation of the makeup-purification system.

Table 8. Fractions of core inventory retained in the makeup and purification demineralizers[a]

Radionuclide	"A" Demineralizer Resin	"B" Demineralizer Liquid and Resin	Total
^{90}Sr	1.2 ± 0.6 E-4	4.6 ± 0.3 E-4	6.0 ± 3.0 E-4
^{125}Sb	8.1 ± 3.0 E-5	—[b]	7.0 ± 3.0 E-5[c]
^{129}I	3.0 ± 1.0 E-2	—[b]	2.0 ± 1.0 E-2[c]
^{134}Cs	1.4 ± 0.5 E-4	1.0 ± 0.6 E-2	1.0 ± 0.5 E-2
^{137}Cs	1.2 ± 0.6 E-4	8.6 ± 5.0 E-3	8.0 ± 5.0 E-3
^{144}Ce	7.3 ± 4.0 E-6	—[b]	7.0 ± 4.0 E-6[c]

a. Data decay corrected to March 1984.

b. Not measured.

c. Total based on "A" demineralizer results only.

uncertainties[a] estimated for the retention of iodine and cesium in the reactor building basement sediment. Comparable uncertainties[a] exist for the retention of most fission products in the debris bed. Because these locations are the major contributors to the present total inventories, the large uncertainties[b] propagate from the measurement uncertainty at the given location to the total fraction of the inventory currently accounted for. While final closure uncertainties in the range of 10% are about the best that can be expected, 30% appears to be excessive.

The large uncertainty estimated for cesium and iodine in the sediment in the reactor building basement is due in part to the limited sampling that has been possible because of the high radiation levels in the basement. The large uncertainty for samples from the core debris bed is the result of the:

- Small sample size (150 g) relative to the mass of the debris bed (2.5×10^4 kg)
- Nonrepresentative nature of the individual particle samples relative to the bulk dissolution analyses (See Appendix C)
- Use of the individual particle analyses for I-129 and Sr-90 rather than bulk dissolution samples.

The uncertainties in the core retention will be narrowed as more extensive debris bed sampling and analyses are carried out and as the lower core region and the material in the lower plenum are assayed. The uncertainties in the retentions in the basement sediment are expected to be narrowed as cleanup proceeds and representative sediment samples and concrete floor borings are obtained.

As the uncertainties in the contents of the major sinks are reduced, the even larger uncertainty estimates (for example, ±50% for cesium retention in the auxiliary building) will become insignificant and have little impact on the overall inventory closure. Thus, placing emphasis on reducing the errors associated with the contents of the major sinks becomes a priority of the fission product search program.

a. These uncertainties are unrelated to the environmental releases that were measured independently.

Table 9. Fractions of core inventory in assayed plant components

		Phase	T	^{85}Kr	^{133}Xe	^{90}Sr	^{125}Sb
1.	Reactor Building						
1.1	Basement liquid[a]		5.7 ± 0.2 E-01	—	—	1.6 ± 0.07 E-02	2.1 ± 0.6 E-03
1.2	Basement sediment		—	—	—	6.1 ± 7.2 E-04	1.2 ± 1.4 E-03
1.3	Basement sump[a]	Solid	—	—	—	8.3 ± 0.9 E-07	1.4 ± 0.2 E-07
		Liquid	—	—	—	9 ± 1 E-05	—
1.4	Reactor coolant drain tanks[a]	Solid	—	—	—	5 ± 5 E-04	2.6 ± 1 E-05
		Liquid	2.9 ± 0.06 E-04	—	—	1.0 ± 0.2 E-04	1 ± 1 E-05
1.5	Reactor building air		—	4.7 E-01	2.8 E-01	—	—
1.6	Reactor building surfaces[a]		—	—	—	3 ± 3 E-06	—
2.	Reactor Coolant System						
2.1	Reactor coolant[a]		2.2 E-02	—	—	9.6 E-03	—
2.2	Reactor coolant system surfaces[c]		—	—	—	5.6 ± 0.6 E-04	1.4 ± 0.2 E-03
3.	Reactor Pressure Vessel						
3.1	Reactor vessel plenum		—	—	—	9 ± 7 E-05	8 ± 5 E-04
3.2	Reactor vessel internal surfaces		—	—	Not	Yet	Measured
3.3	Partially intact core rods		—	—	Not	Yet	Measured
3.4	Reactor core debris bed		—	—	—	1.2 ± 0.4 E-01	8 ± 1 E-02
3.4a	Debris bed extrapolated to entire core		—	—	—	6.0 E-01	3.8 E-01
3.5	Reactor core solid mass		—	—	Not	Yet	Measured
3.6	Core material in lower plenum		—	—	Not	Yet	Measured
4.	Auxiliary Building						
4.1	Makeup and purification demineralizers[c]		—	—	—	6 ± 3 E-04	7 ± 3 E-05
4.2	Reactor coolant bleed tanks		3.0 E-02	—	1 E-02	1 E-04	—
4.3	Auxiliary building sump		—	—	—	—	—
4.4	Minor sinks		1 E-02	—	4 E-04	1 E-03	—
5.	Fuel handling building						
5.1	Submerged demineralizers[a,c]		6.2 E-01	—	2.3 E-20	—	
6.	EPICOR II Building						
6.1	EPICOR II resins[a,c]		4.2 E-02	—	—	1 E-03	—

	^{129}I	^{131}I	^{134}Cs	^{137}Cs	^{144}Ce	U/Pu	Reference
3	1.4 ± 0.04 E-01	1.9 ± 0.09 E-01	4.2 ± 0.16 E-01	4.1 ± 0.12 E-01	1 ± 0.6 E-05	4 ± 3 E-07 U	8
					—	3 ± E-06	8
3	7.6 ± 8.7 E-02	1.6 ± 0.4 E-02	4.6 ± 5.7 E-04	4.2 ± 4.9 E-04	9.1 ± 5.7 E-06	8 ± 6 E-06 U	8
					—	6 ± 5 E-07 Pu	8
7	<5 E-07	—	2.9 ± 0.3 E-07	2.6 ± 0.3 E-07	1.0 ± 0.3 E-07	—	8
	—	—	1.4 ± 0.1 E-03	1.3 E-03	—	—	8
	6.9 ± 6 E-09	—	3.8 ± 4 E-06	3.4 ± 3 E-06	9.5 ± 1 E-06	—	8
	5.5 ± 1.0 E-05	—	4.8 ± 1 E-05	4.4 ± 0.9 E-05	1.2 ± 1 E-06	4 E-08 U	7, 8
	—	1 E-04	—	—	—	—	7
	3 ± 1 E-03	—	1 ± 1 E-04	1 ± 1 E-04	—	—	6
	1.2 E-02	1.1 E-01	7.7 E-03	8.1 E-03	—	—	8
3	1.3 E-03	—	1.0 ± 0.1 E-03	1.1 ± 0.1 E-03	3.6 ± 0.4 E-04	—	—[b]
	8 ± 4 E-05	—	9 ± 7 E-04	8 ± 6 E-04	7 ± 4 E-05	—	—[b]
	5 ± 1 E-02	—	5 ± 2 E-02	6 ± 2 E-02	2.6 ± 0.4 E-01	—	—[b]
	2.4 E-01	—	2.5 E-01	3.0 E-01	—	—	—
	2 ± 1 E-04	—	1.0 ± 0.5 E-02	8 ± 4 E-03	7 ± 4 E-06	—	—[b]
	10^{-4} to 10^{-2}	—	—	2 E-02	—	4 E-07/ 1 E-07	7
	—	—	—	—	—	—	—
	—	1 E-02	2 E-02	1.6 E-02	—	—	7
	—	—	4.6 E-01	4.5 E-01	—	—	7
		—	3.7 E-02	2.7 E-02	—	—	7

Table 9. (continued)

	Phase	T	^{85}Kr	^{133}Xe	^{90}Sr	^{125}Sb	
7. TMI-I Buildings		—	—	—	—	—	—
8. Releases							
8.1 Gaseous releases		4.0 E-04	4.7 E-01	7.1 E-02	8 E-10	—	—
8.2 Liquid releases[a]		—	—	—	—	—	—

a. Measurement errors are not given in reference.

b. This study.

c. Fission products on the resin beds were transferred from other components by processing of the RCS and leakage coolant. These terms are, therefore, not additive toward the inventory total. They represent activity physically transported offsite on the resins.

^{129}I	^{131}I	^{134}Cs	^{137}Cs	^{144}Ce	U/Pu	Reference
—	—	—	—	—	—	—
—	—	—	7 E-12	—	—	7
—	1 E-06	—	—	—	—	7

Table 10. Major and minor fission product sinks

Location	Major Sinks	Minor Sinks
Reactor building	Basement liquid	Basement sediment[a] Basement sump RCDT Building surfaces Basement wall
Reactor coolant system	Reactor coolant	Coolant system surfaces
Reactor pressure vessel	Core debris bed Core solid mass[a] Core material in lower plenum[a]	Plenum surfaces Vessel internal surfaces[a]
Auxiliary building	Makeup and purification demineralizers[b] RCBT[b]	Miscellaneous tanks and piping letdown coolers[a]
Fuel handling building	SDS[c]	
Epicor II building	Epicor II resins[c]	
TMI-1 buildings	—	All components

a. Not yet examined or inadequately assayed, but likely to be in this category.

b. For certain radionuclides only.

c. Fission products on these resins were transferred from other components. See Reference 9.

Table 11. Location of fission products inventory in plant buildings

Location	Reference	Fraction of Core Inventory													
		Tritium	^{85}Kr	^{90}Sr	^{133}Xe	^{106}Ru	^{125}Sb	^{129}I	^{131}I	^{132}Te	^{137}Cs	^{137}Cs	^{144}Ce	U	Pu
1. Reactor building	8[b]	0.57	0.47	0.017	0.28	—	0.003	0.22	0.21	—	0.42	0.41	3 E-05	4 E-07	9 E-06
Reactor coolant system[a]	8	0.02	—	0.01	—	—	0.001	0.012	0.11	—	0.008	0.008	4 E-04	—	—
Reactor pressure vessel	—[b]	—	—	0.12	—	—	0.08	0.05	—	—	0.05	0.06	0.26	—	—
2. Auxiliary building	7[b]	0.04	—	—	—	—	7 E-05	0.02	—	—	0.01	0.008	7 E-06	—	—
3. Fuel handling building	7	(0.62)	—	(0.02)	—	—	—	—	—	—	(0.46)	(0.45)	—	—	—
4. EPICOR II building[a,c]	7	(0.042)	—	(0.001)	—	—	—	—	—	—	(0.034)	(0.027)	—	—	—
5. TMI-1 buildings	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6. Releases	7	4 E-04		8 E-10	0.07	—	—	—	1 E-06	—	—	7 E-12	—	—	—
Total[a]	—	0.63	0.47[e]	0.15	0.35	—	0.08	0.30	0.32	—	0.49	0.49	0.26	—	—
Alternate Total[a,d]	—	0.63	0.47	0.63	0.35	—	0.40	0.50	0.32	—	0.69	0.73	1.30	—	—

a. Measurement errors not given in reference.

b. This study.

c. Not additive towards total inventory. See footnote c of Table 9.

d. Based on the assumption that the debris bed constitutes 20% of the core and the concentration in the debris bed is representative of the concentration in the entire core.

e. Kr-85 content of the reactor building atmosphere vented in April-June 1980, but activity was not released during the accident.

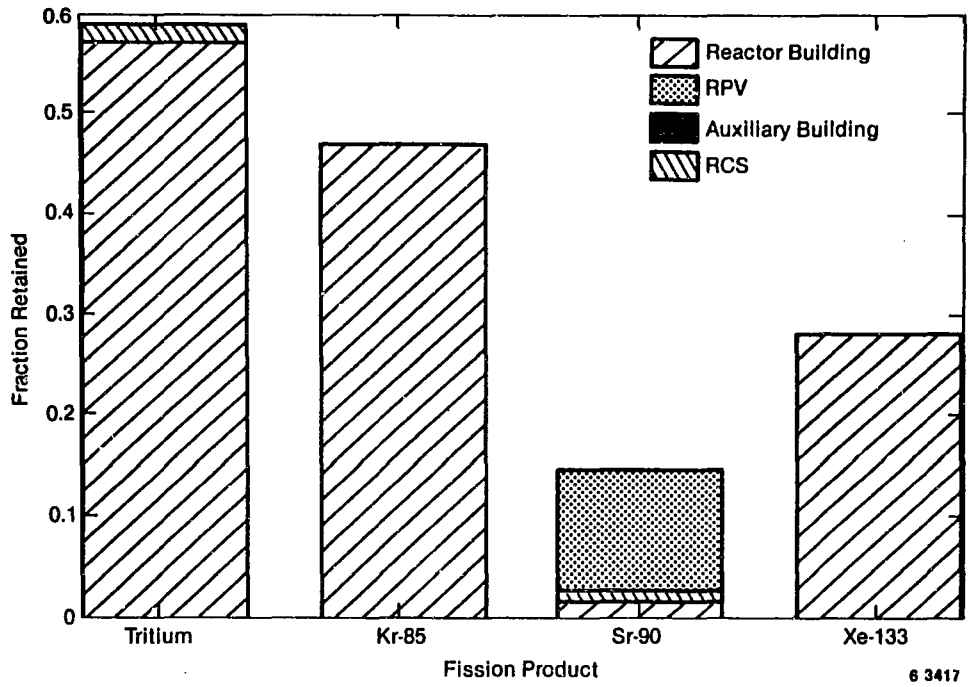


Figure 8. Location of retained fission product inventories (T, ^{85}Kr, ^{90}Sr, ^{133}Xe).

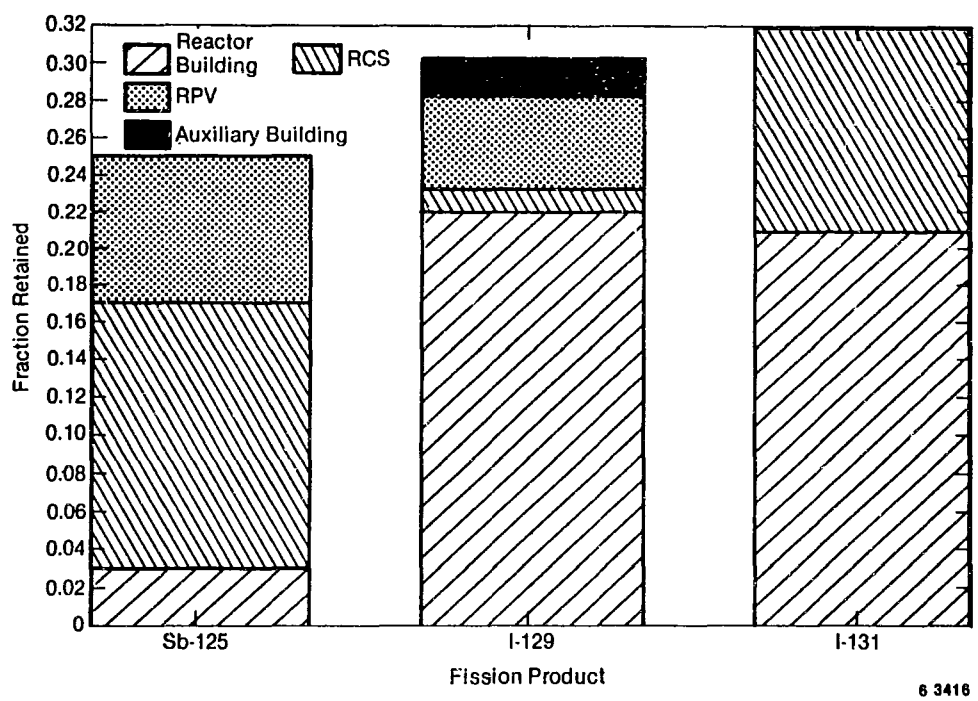


Figure 9. Location of retained fission product inventories (^{125}Sb, ^{129}I, ^{131}I).

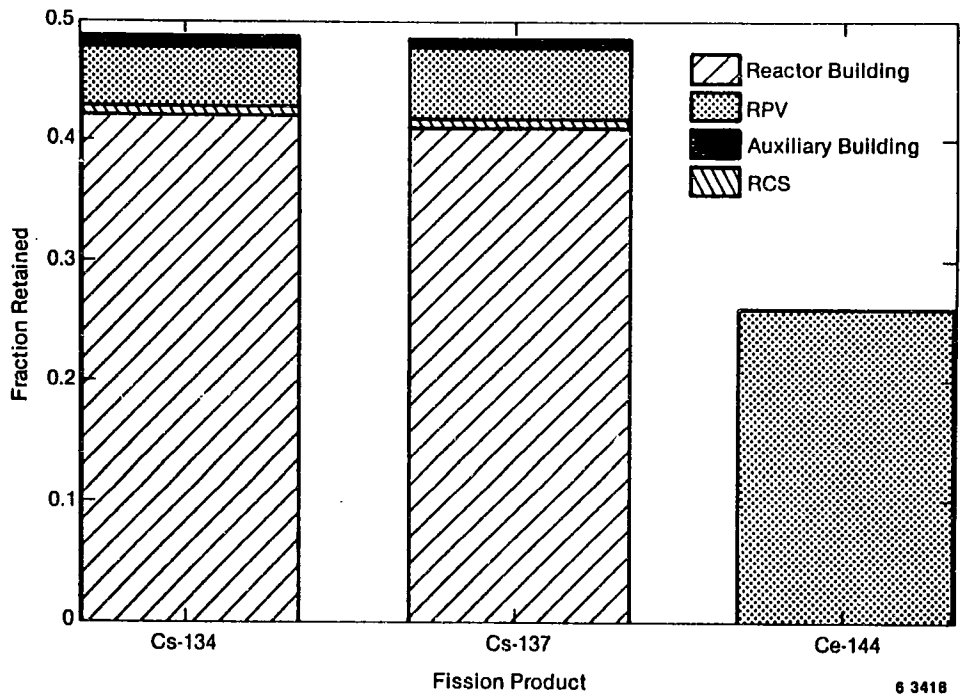


Figure 10. Location of retained fission product inventories (^{134}Cs, ^{137}Cs, ^{144}Ce).

FISSION PRODUCT INVENTORY PROGRAM COMPLETION

The purpose of this section is to identify a program extension that will complete the search for the fission product inventory. The fission product search program has been a continuous effort since the accident. The approach to identifying a program extension was to evaluate the current completeness of the program by locating equipment and buildings that had not, or had only partially, been inventoried for fission products. In the evaluation, the following documentation was developed:

- List of TMI-2 accident and postaccident radiologically significant events (see Table 12)
- Schematic map showing the equipment, buildings, and areas where fission products may be present (Figure 11)
- Matrix chart showing the extent of the already completed fission product search program (Table 13)
- List of equipment and buildings where the search program should be completed (Table 14).

Also, the evaluation developed some findings that have been considered in the conclusions and recommendations of this document.

Table 14 is a comprehensive plan for extending and completing the TMI-2 accident fission product inventory search program. The plan assumes that the extended search does not discover additional surprises. The subcore and subreactor-vessel regions include unexplored areas where possible surprises could result in the need for additional search activities. The principal repositories identified are the reactor core, including the debris bed, and the reactor building basement. The core proper is the subject of a major examination program.[14] Most of the other possible sampling locations have been sampled, though not all have been adequately characterized. Therefore, two criteria were developed to determine whether further sampling of a system or component should be done to meet the requirements for closure of the inventory. They are:

- Is it probable, based on previous sample analyses and knowledge of the mass transport of materials in the system, that a significant increase in the fraction of core inventory (>1%) will be identified by further sampling of a component?
- Will further sampling provide more information concerning the behavior of fission products during, or shortly after, the accident?

Satisfaction of either criteria would be sufficient justification to perform further sampling of a system component. Additional comments on the components to be sampled and an evaluation of the need for further sampling are given below.

Air Cooler Assembly

Analyses of the air cooler assemblies indicate that Cs-137, Sr-90, and I-129 are measurable. However, the fraction of core inventory retained for all radionuclides is ≤0.3%, making it unlikely that further sampling of this component would significantly change the calculated inventory. Also, because this component has been further decontaminated since acquisition of the access panels, it is unlikely that new samples would be useful.

Reactor Building Sump and Basement

These portions of the reactor building are significant repositories for fission products (>40% for Cs-137). Nine samples have been obtained to date from the liquid and sediment in the basement and sump (Figure 12). Although the surface water has been processed through the submerged demineralizer system, significant portions of the basement sediment have not been characterized for retention of radionuclides. Also, sorption of radionuclides into the concrete has yet to be measured. Because of the large fission product concentration found in the basement water, there is a significant probability that the fractions of core fission product inventory in the basement solids and concrete can be better defined and will exceed a 1% change. Samples that should be taken include sediment from a number of locations, and concrete samples that characterize various locations in the reactor building basement, including the sump.

Table 12. TMI-2 accident event calendar (preliminary)

	Event	Date	Schedule Elapsed Time			
			Years	Days	Hours	Minutes
1.	Accident initiation (4:00 a.m.)	03-28-79		Not Applicable		
2.	Fuel rod burst commences	03-28-79			2	18
3.	B-loop pump started	03-28-79			2	54
4.	Probable major core material relocation	03-28-79			3	47
5.	Containment hydrogen burn	03-28-79			13	49
6.	Sustained core cooling commences	03-28-79			15	40
7.	Core natural circulation cooling commences (2:08 p.m.)	04-27-79		30	10	03
8.	Auxiliary building decontamination commences	04-27-79		30		
9.	Auxiliary building venting through supplemental filters commences	05-01-79		34		
10.	Station vent stack capped	05-20-79		53		
11.	EPICOR-II water cleanup commences	10-?-79		?		
12.	Containment building venting commences (vent stack uncapped)	06-28-80	1	92		
13.	Containment building personnel entry commences	??-?-80	1	xx		
14.	SDS/EPICOR II water cleanup commences	07-12-81	2	106		
15.	Reactor building decontamination	03- ?-82	3	?		
16.	SDS/EPICOR-II reactor building basement water decontamination completed	05- ?-82	3	?		
17.	Reactor vessel head removal	07-24-84	5	118		
18.	Plenum assembly removal	05- ?-85	6	?		

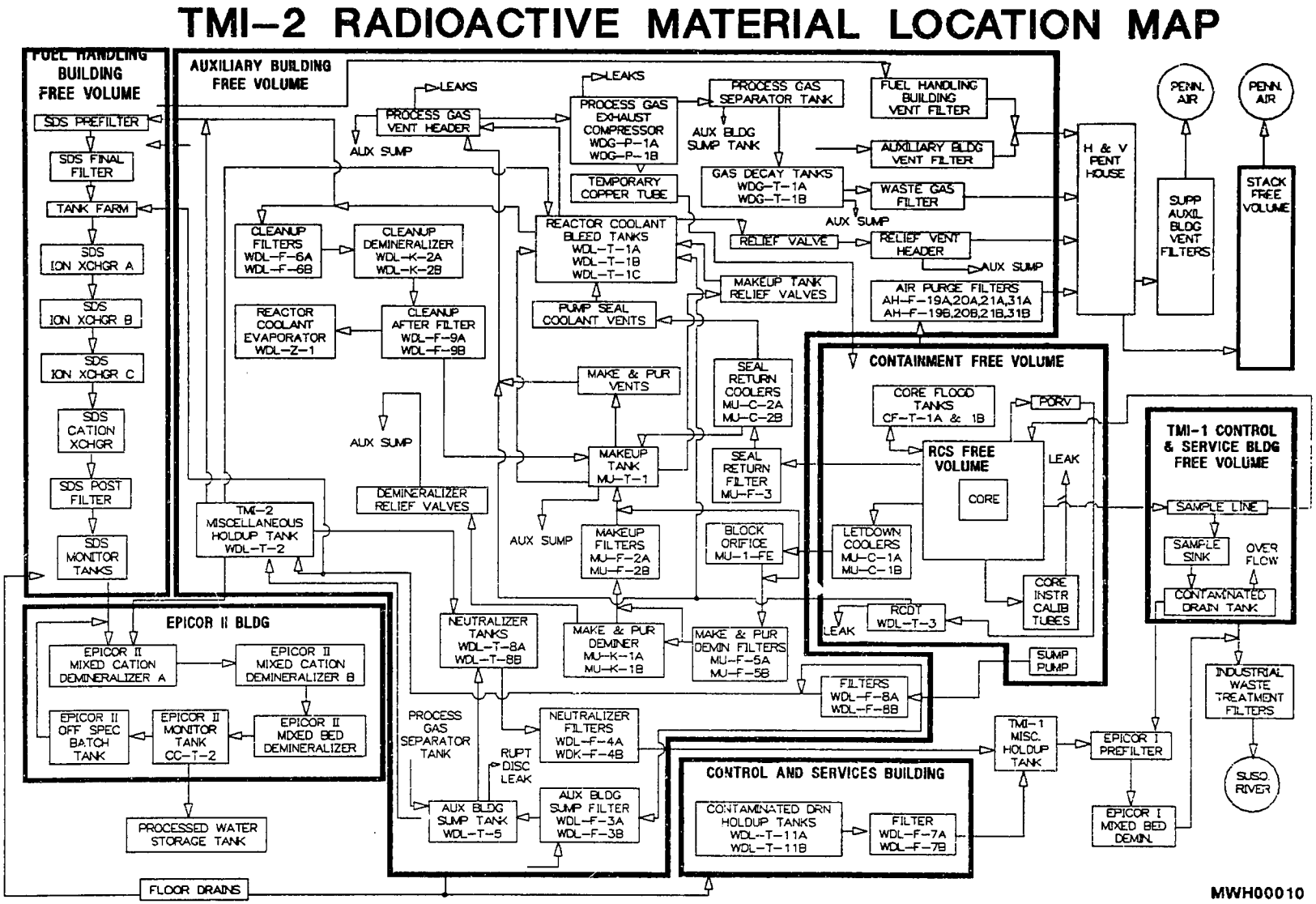


Figure 11. Detail of TMI-2 radioactive material location map.

Table 13. Matrix table of completed fission product inventories[a]

Location	Area Radiation Emission Mapping		Radiochemical Composition Examinations				
	Gamma and Beta	Gamma Spectra	Liquid	Gas	Solids and Sediment	Surface Deposit	Ab
Core and reactor vessel lower plenum	X	—	X	NA	X (.2)[b]	—	NA
Reactor vessel upper plenum	X	—	X	NA	X (.5)[b]	X (.5)[b]	NA
Steam generators	X	X	X	NA	—	—	NA
Pressurizer	X	X	X	NA	—	—	NA
RCS piping, pumps, and valves (PP&V)	X	—	X	NA	—	X (partial)	NA
Core flood tanks	X	—	—	—	—	—	NA
Core flood piping	X	X	—	NA	—	—	NA
M&P letdown coolers	—	—	—	NA	—	—	NA
RCS drain tank	—	—	X	NA	X	—	NA
Containment building free volume							
1. 347 ft to dome	X	X	NA	X	NA	X	X (p
2. 305 to 347 ft	X	X	NA	X	NA	X	X (p
3. Basement to 305 ft	—	—	X	X	X	X	—
Core instrument tubes	X (seal table)	—	—	—	—	—	—
M&P block orifice	X	X	—	NA	—	—	NA
M&P demineralizer filters (5A and 5B)	1 of 2	Post filter	—	NA	—	1 of 2	NA
M&P demineralizers	X (partial)	—	X (partial)	NA	X	—	NA
Makeup filters (2A and 2B)	1 of 2	Post flush	—	NA	X	—	NA
Makeup tanks	Post filter	Post flush	—	—	—	—	NA
M&PS PP&V	Post flush	Post flush	X	NA	—	—	NA
Pump seal return filter (F-3)	X	X	—	NA	—	—	NA
Pump seal return coolers	X	X	—	NA	—	—	NA
Pump seal injection filters (F-4a and -4b)	X	—	—	NA	X	—	NA
Pump seal PP&V	—	—	—	NA	—	—	NA
Reactor building sump filters (8A and 8B)	—	—	—	—	—	—	—

	Chemical Composition Examinations					
Absorber	Liquid	Gas	Solids and Sediment	Surface Deposit	Absorber	Miscellaneous Information
NA	X	NA	X (.2)[b]	—	NA	—
NA	X	NA	X (.5)[b]	X (.5)[b]	NA	—[c]
NA	X	NA	—	—	NA	—[c]
NA	X	NA	—	—	NA	—[c]
NA	—	NA	—	X (partial)	NA	—[c]
NA	—	NA	—	—	NA	—[c]
NA	—	NA	—	—	NA	—
NA	—	NA	—	—	NA	(one may be blocked)[c]
NA	—	NA	X (partial)	—	NA	—[c]
X (partial)	NA	X	NA	X	—	—[c]
X (partial)	NA	X	NA	—	—	(partial)[c]
—	X (partial)	X (part L)	—	—	—	10 in. water depth at 227 min
—	—	—	—	—	—	—
NA	—	NA	—	—	NA	—[c]
NA	—	NA	—	—	NA	—[c]
NA	X (partial)	NA	X	—	NA	—[c]
NA	—	NA	X	—	NA	—[c]
NA	—	—	—	—	NA	—[c]
NA	X	NA	—	—	NA	—[c]
NA	—	NA	—	—	NA	—[c]
NA	—	NA	—	—	NA	—[c]
NA	—	NA	X	—	NA	—[c]
NA	—	NA	—	—	NA	—
—	—	—	—	—	—	Pre-rod burst contamination

Table 13. (continued)

Location	Area Radiation Emission Mapping		Radiochemical Composition Examinations			
	Gamma and Beta	Gamma Spectra	Liquid	Gas	Solids and Sediment	Surface Deposit
RCS liquid waste PP&V						
1. Reactor building	—	—	—	—	—	—
2. Auxiliary building	—	—	—	—	—	—
RCS bleed holdup tanks						
1. WOL-T-1A	X	X	X 12/79	—	X	—
2. WOL-T-1B	X	—	X 1/80	—	X	—
3. WOL-T-1C	X	X	X 2/80	—	X	—
Auxiliary building sump filters (3A and 3B)	—	—	—	—	—	—
Auxiliary building sump tank	X	—	X 2/80	—	—	—
Miscellaneous waste holdup tanks	X	—	X	—	—	—
Neutralizer tanks	—	—	—	—	—	—
Neutralizer filter (4A and 4B)	9-25-81	—	X	—	—	—
Radwaste disposal, auxiliary building PP&V	—	—	X	—	—	—
M&P relief valve header	—	—	—	—	—	—
Reactor coolant process gas decay tanks	—	—	—	X	—	—
Reactor coolant process gas exhaust compressor	—	—	NA	—	—	—
Reactor coolant process gas exhaust filter	—	—	NA	NA	—	—
Reactor coolant process gas duct and valves	—	—	NA	X	—	—
Auxiliary building vent filter	—	—	NA	X	—	—
Fuel handling building vent filter	—	—	NA	—	—	—
Auxiliary building vent duct, valves and compressor	—	—	NA	X	—	—
Fuel handling building vent duct valves and compressor	—	—	NA	—	—	—
Reactor containment building air purge filters	—	—	NA	—	—	—

	Chemical Composition Examinations					
Absorber	Liquid	Gas	Solids and Sediment	Surface Deposit	Absorber	Miscellaneous Information
NA	—	—	—	—	—	—
NA	—	—	—	—	—	—
NA	X (partial)	—	X	—	NA	8/20/81, start flushing[c]
NA	X (partial)	—	X	—	NA	—[c]
NA	X (partial)	—	X	—	NA	—[c]
—	—	—	—	—	—	Post-core damage contamination
NA	X 2/80	—	—	—	NA	Post-core damage contamination[c]
NA	X	—	—	—	NA	Post-core damage contamination[c]
—	—	—	—	—	—	Post-core damage contamination[c]
—	X	—	—	—	—	Post-core damage contamination
—	—	—	—	—	—	—
—	—	—	—	—	—	—
NA	—	—	—	—	NA	—
NA	—	—	—	—	NA	—
?	NA	NA	—	—	NA	—
NA	NA	—	—	—	NA	—
?	NA	—	—	—	NA	—
?	NA	—	—	—	NA	—
NA	NA	—	—	—	NA	—
NA	NA	—	—	—	NA	—
?	NA	—	—	—	NA	—

Table 13. (continued)

Location	Area Radiation Emission Mapping		Radiochemical Composition Examinations				
	Gamma and Beta	Gamma Spectra	Liquid	Gas	Solids and Sediment	Surface Deposit	Absor
RB air purge duct, valves and compressor	—	—	NA	—	—	—	NA
Auxiliary building free volume							
1. 328 ft to roof	—	—	—	X	—	—	—
2. 305 to 328 ft	—	—	—	X	—	—	—
3. 281 to 305 ft	—	—	X	X	—	—	—
Fuel handling building free volume	—	—	X	—	—	—	—
Process gas separator tank	—	—	—	—	—	—	NA
Vent stack free volume	—	—	NA	X	—	—	—
Auxiliary building supplemental filters	—	—	NA	—	—	—	?
Contaminated drain tank	X	—	X	NA	—	—	NA
Contaminated drain tank filters	—	—	—	—	—	—	—
Radwaste disposal containment and service building PP&V	—	—	—	—	—	—	—
Reactor coolant sample line and valves	—	—	X	—	—	—	—
TMI-1 contaminated drain tank	—	—	—	—	—	—	—
TMI-1 contr. and service building free volume	—	—	—	—	—	—	—
TMI-1 miscellaneous holder tanks	—	—	—	—	—	—	—
Industrial waste treat filters	—	—	—	—	—	—	—
Industrial waste treat PP&V	—	—	X	—	—	—	—
EPICOR I prefilter	—	—	—	—	—	—	—
EPICOR I demineralizers	—	—	—	—	—	—	—
EPICOR I PP&V	—	—	—	—	—	—	—
EPICOR II demineralizer A	—	—	—	—	—	—	—
EPICOR II demineralizer B	—	—	—	—	—	—	—
EPICOR II mixed bed demineralizer	—	—	—	—	—	—	—

sorber	Chemical Composition Examinations					Miscellaneous Information
	Liquid	Gas	Solids and Sediment	Surface Deposit	Absorber	
	NA	—	—	—	NA	—
	—	—	—	—	—	—
	—	—	—	—	—	—
	X	—	—	—	—	—
	X	—	—	—	—	—
	—	—	—	—	NA	? NUREG-0600, pII-3-11
	NA	—	—	—	—	Capped 5/20/79 through 6/28/80
	NA	—	—	—	—	5/1/79 through 6/28/80
	X	NA	—	—	NA	—[c]
	—	—	—	—	—	—
	—	—	—	—	—	—
	—	—	—	—	—	Until 6/17/80
	—	—	—	—	—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
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	—	—	—	—	—	—

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Table 13. (continued)

Location	Area Radiation Emission Mapping		Radiochemical Composition Examinations			
	Gamma and Beta	Gamma Spectra	Liquid	Gas	Solids and Sediment	Surface Deposit
EPICOR II monitor tank	—	—	X ?	—	—	—
EPICOR II off-spec batch tank	—	—	—	—	—	—
EPICOR II PP&V	—	—	—	—	—	—
SDS prefilter	—	—	—	—	X	—
SDS final filter	—	—	—	—	X	—
SDS tank farm	—	—	—	—	—	—
SDS ion-exchanger A	—	—	—	—	X	—
SDS ion-exchanger B	—	—	—	—	X	—
SDS ion-exchanger C	—	—	—	—	X	—
SDS post filters	—	—	—	—	—	—
SDS monitor tanks	—	—	X?	—	—	—
SDS PP&V	—	—	—	—	—	—
Pennsylvania Air	X	X	NA	X	NA	—
Susquehanna River	—	—	X?	—	—	—

a. The symbol "X" indicates record exists of in-situ measurement or sample examination.

b. The symbol "X( )" indicates fraction of equipment, building, or area inventories.

c. SAI history.

	Chemical Composition Examinations					
Absorber	Liquid	Gas	Solids and Sediment	Surface Deposit	Absorber	Miscellaneous Information
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	X (TRU)	—	—	—
—	—	—	X (TRU)	—	—	—
—	—	—	—	—	—	—
—	—	—	X (TRU)	—	—	—
—	—	—	X (TRU)	—	—	—
—	—	—	X (TRU)	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	NA	—	NA	—	—	—
—	—	—	—	—	—	—

Table 14. List of equipment and buildings remaining to be surveyed

Measurement/Examination Activity	Status		Information Needs					Justification/Information
			Radioactivity					
	Planned	Proposed	Gross	Gamma Spectroscopy	Radio-Chemistry	Chemistry Composition	Volume	
Core Bores								
Core bore samples of fused/joined core material under loose debris and subcore	X	X	X	X	X	X	X	Determine condition and quantity of fused/joined core material under loose debris and between core and reactor vessel head.
Core Distinct Components								
1. Upper core region								
a. Six 6-in. long fuel rod segments from core cavity periphery	X	X	X	X	X	X	X	Determine condition of unrelocated fuel rods in upper core region. In-situ separation of segments.
b. Twenty-five 6-in. long fuel rod segments from core cavity periphery fuel assembly remnants	X	X	X	X	X		X	Study interactions between fuel rods and control or burnable poison material and variations in fuel rod damage around the core periphery. Segment separation from fuel assembly remnant in INEL Hot Cell.
c. Guide tube/BPR segments (5)	X	X	X	X	X	X	X	Adjacent to fuel rod segments
d. Guide tube/control segments (5)	X	X	X	X	X	X	X	Adjacent to fuel rod segments
e. Instrument tube/instrument string segments (3)	X	X	X	X	X	X	X	Same elevation as instrument tube/string segments
f. Instrument tube segments (3)	X	X	X	X	X	X	X	Same elevation as instrument tube/string segment
g. Spacer grids (9)	X	X	X	X	X	X	X	
h. Upper end boxes (16)	X	X	X	X	X	X	X	Fuel assembly rings 3,4,5,6,7 and 8
i. Hold-down springs (14)	X	X	X	X	X	X	X	Fuel assembly rings 4,5,6,7 and 8
j. Burnable poison rod spiders (16)		X	X	X	X	X	X	Fuel assembly rings 3,4,5,6 and 7
k. Control rod spiders (7)	X	X	X	X	X	X	X	Fuel assembly rings 3,4,5,6 and 7
l. APSR spider surface deposit		X	X	X	X	X	X	Upper plenum region during accident

Table 14. (continued)

Measurement/Examination Activity	Status		Information Needs					Justification/Information
			Radioactivity					
	Planned	Proposed	Gross	Gamma Spectroscopy	Radio-Chemistry	Chemistry Composition	Volume	
2. Lower core region								Additional data needed to complete selection
a. Fuel rod segments	X		X	X	X	X	X	
b. Guide tube/BPR segments		X	X	X	X	X	X	
c. Guide tube/control rod segments	X	X	X	X	X	X	X	
d. Instrument tube/instrument string segments	X	X	X	X	X	X	X	
e. Instrument tube segments		X	X	X	X	X	X	
f. Spacer grids	X		X	X	X	X	X	
g. Lower end boxes	X		X	X	X	X	X	
Reactor Vessel Internal Examination								
Core cavity topography after loose debris removal	X						X	Volume of loose debris and distinct fuel assembly component material
CCTV survey of lower core-support structure	X						X	Determine structure ablation
Lower Vessel Debris								
Six core material samples from lower head region	X		X	X	X	X	X	From four azimuthal locations via downcomer access
Reactor vessel lower region gamma scans		X	X				X	Ion-chamber survey of any of 35 unsurveyed core instrument string calibration tubes. Data may be convertible to uranium location
Samples of loose debris in lower core-support structure region	X		X	X	X	X	X	Character of loose debris in lower core-support structure region

Table 14. (continued)

Measurement/Examination Activity	Status		Information Needs					Justification/Information
			Radioactivity					
	Planned	Proposed	Gross	Gamma Spectroscopy	Radio-Chemistry	Chemistry Composition	Volume	
Reactor Coolant System Characterization								
1. RCS gamma scans	X			X			X	Capability to convert data to radionuclide and uranium abundance and location uncertain
a. Steam generator inside	X			X			X	B loop steam generator survey uncertain
b. Pressurizer inside and outside	X			X			X	
c. Pressurizer surge line	X			X			X	
d. Decay heat removal line	X			X			X	
e. Pump volutes	X			X			X	
f. Hot legs	X			X			X	
2. RCS adherent surface deposits								
a. Plenum cylinder outlet screen surface deposit		X		X	X	X	X	Boundary between upper plenum and hot leg
b. B loop RTD thermowell surface deposit	X			X	X	X	X	Character of adherent deposits in B loop piping
c. A loop steam generator handhole cover liner	X		X	X	X	X	X	Character of adherent deposits on steam generator surfaces
d. B loop steam generator manway cover backing plate		X		X	X	X	X	Character of adherent deposits on steam generator surfaces
e. Pressurizer manway cover backing plate		X		X	X	X	X	Character of adherent deposits on pressurizer surfaces

Table 14. (continued)

Measurement/Examination Activity	Status: Planned	Status: Proposed	Information Needs: Radioactivity: Gross	Information Needs: Radioactivity: Gamma Spectroscopy	Information Needs: Radio-Chemistry	Information Needs: Chemistry Composition	Information Needs: Volume	Justification/Information
3. RCS sediment								
a. Steam generator tube sheet top loose debris	X		X	X	X	X	X	Character of sediment in both steam generator upper heads
b. Steam geneator lower head loose debris	X		X	X	X	X	X	GPUN project character of sediment in both steam generator lower heads
c. Pressurizer sediment		X	X	X	X	X	X	Character of sediment in pressurizer lower head
Exreactor Coolant System Characterization								
1. RB basement sediment								
a. Floor (282 EL.)								
(1) RCDT discharge area	X		X	X	X	X	X	Four 100 cm^3 samples, GPUN project S.P. RB-85-012
(2) Impingement, leakage cooler room, RCDT room, inside D-ring outside,		X	X	X	X	X	X	1 kg samples, GPUN proposal
O-ring		X	X	X	X	X	X	
b. Core instrument cable chase		X	X	X	X	X	X	1 kg samples, GPUN proposal, floor depression
c. Elevator and sump wells		X	X	X	X	X	X	Edge proposal
2. RB basement concrete absorption								
Eight 5000-psi (O-ring) wall bores		X	X	X	X	X	X	GPUN proposal, bore depth not specified, includes "unflooded" wall samples and surface smears
Eight 3000-psi (shield) wall bores		X	X	X	X	X	X	
Eight block (elev./stairwell) bores		X	X	X	X	X	X	
Ten floor samples		X	X	X	X	X	X	GPUN proposal after floor dewatering and desludging
3. RB basement wall liner adherent surface deposit		X	X	X	X	X	X	GPUN proposal to determine liner coating and paint absorption includes surface smear

Table 14. (continued)

Measurement/Examination Activity	Status		Information Needs					Justification/Information
			Radioactivity					
	Planned	Proposed	Gross	Gamma Spectroscopy	Radio-Chemistry	Chemistry Composition	Volume	
4. Equipment internal deposits		X	X	X	X	X	X	
a. Reactor coolant drain tank								
(1) Sediment (only 9 mg collected and examined)		X	X	X	X	X	X	May be convertible to solid particle escape through PORV via suspension correlations.
(2) Adherent surface deposit	X	X	X	X	X	X	X	May use pipe wall cutout dropped into tank during previous entry
5. Letdown coolers		X	X	X	X	X	X	

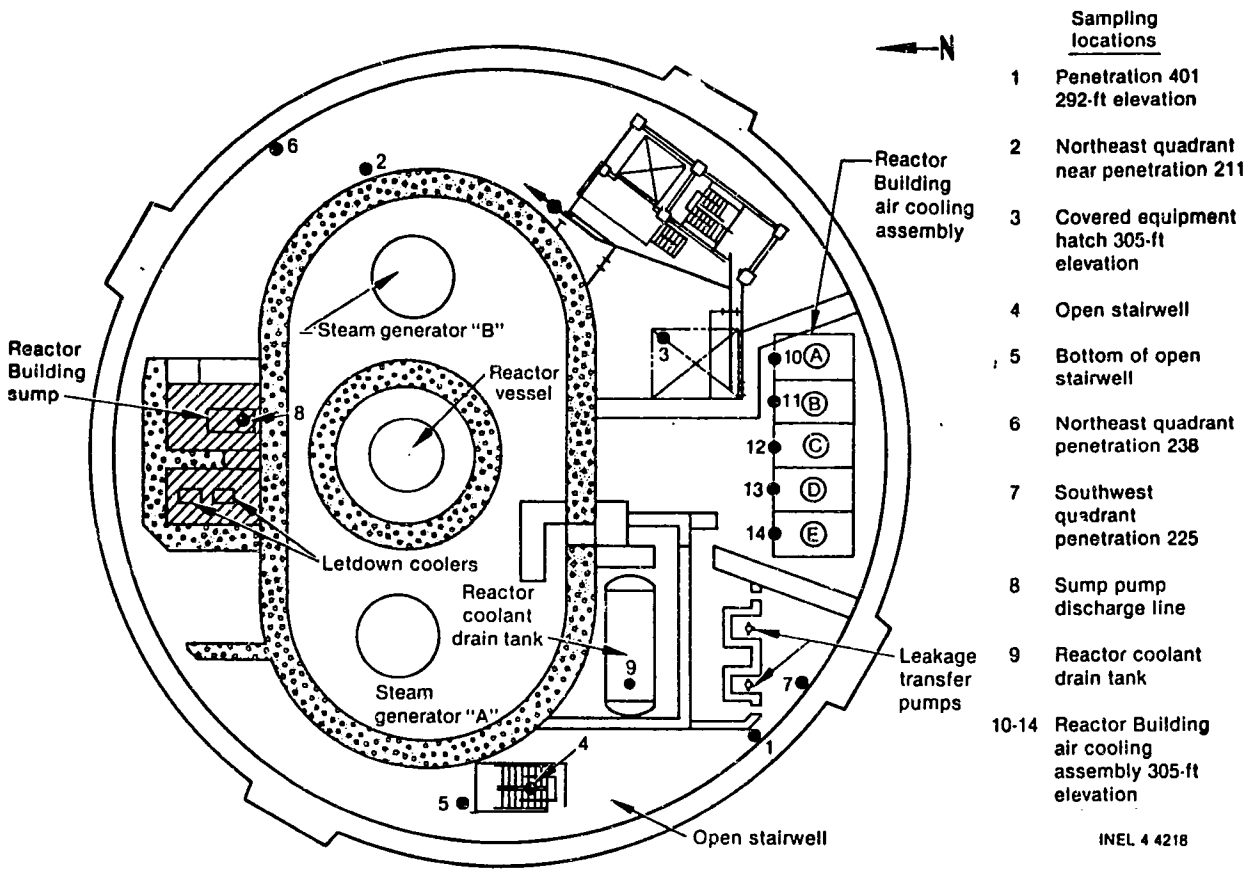

Figure 12. Sample locations in reactor building basement.

Reactor Coolant Drain Tank

Based upon the sample analyzed, the reactor coolant drain tank is an insignificant radionuclide repository. However, the sample analyzed was obtained using the sump pump, which would not collect adherent material on the tank walls, or particles too heavy to be moved by the coolant flow. Gross radiation measurements and closed circuit television (CCTV) examinations have indicated that this tank is probably not a significant location for fission product retention, but an evaluation of fission product concentrations might still be useful in confirming the first sample analysis results or in better defining fission product behavior.

"A" Steam Generator RTD

This sample was used to characterize radionuclide deposition on reactor coolant system surfaces. Although the fraction of core inventory retained on the surfaces is small ($\leq 0.1\%$), this sample (15 cm^2) is inadequate to characterize a surface area of $3.9 \times 10^{+3}$ m^2. Small errors in measurement of surface radionuclide concentrations on the RTD thermowell tip could have a significant impact on the calculated fraction of inventory retained on RCS surfaces. Therefore, more samples should be acquired from other RCS surfaces to better characterize surface deposition in this system.

Makeup and Purification Demineralizers

The MUP demineralizers are a significant repository for radionuclides in the auxiliary building. Based on one sample, the estimated retention of Cs-137 and I-129 as fractions of core inventory are $\sim$1% and $\sim$2%, respectively. Sampling of this system could have been used to better define the retention of fission products in the demineralizers. However, the system has been chemically backwashed to remove the majority of fission products from the demineralizer resin. Samples of the backwash solution and the depleted resin are being analyzed, which might change the estimated fission product retention. However, based on gross radiation measurements, it is unlikely that the

calculated fission product inventory could be increased by 1% of the total.

Location H8 and B8 Control Rod Leadscrews

The control rod leadscrews have been used to characterize radionuclide deposition on the plenum surfaces. Retention of fission products is small (0.5-1%) based on the H8 and B8 leadscrew sample analyses. CCTV surveys, however, indicate varying degrees of deposition at different leadscrew locations. New data based on further sampling may change the fraction of core inventory retained on the surfaces by 1% or more. Further support for continued leadscrew examination is that more information might be obtained concerning fission product behavior during the accident. The principal radionuclide measured is Cs-137, which was deposited in the tightly adherent layer on the surface of the leadscrew, probably early in the accident. Further samples of the reactor vessel plenum structure would be preferred.

Other Locations

Several new sample locations in the reactor and auxiliary buildings have been proposed for further analysis (i.e., the letdown cooler, letdown block orifice, and pressurizer surfaces). Because much of the lost reactor coolant passed through the pressurizer, it may be a significant fission product repository. The reactor coolant letdown system was a major escape path during much of the accident after closure of the PORV block valve. Also, because the letdown block orifice was plugged early in the accident, and still exhibits a high residual radiation level for a physically small piece of equipment, it appears to be worthy of further evaluation. The letdown system coolers, with their large surface areas, could also be repositories for significant levels of activity. The reactor core, with its associated debris bed, is the reactor component most likely to close the inventory.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations of this review are based on the fission product inventory accounted for to date, and the list of plant components remaining to be assayed as discussed in the section on FPI program completion.

- Only a small fraction of the core fission product inventory was deposited on the reactor building air coolers (<0.3%), suggesting that the reactor building air coolers did not function as a major repository for airborne radionuclides.
- The reactor building sump itself did not contain a significant fraction of the fission product inventory (<0.1%) at the time sampled. However, a significant fraction of core inventory is indicated to be present elsewhere in the basement.
- Although the reactor coolant drain tank provided the principal flow path for reactor coolant to the reactor building basement, the tank itself contained less than 0.01% of the core inventory of any radionuclide at the time it was assayed.
- The internal surfaces of the reactor coolant system did not retain a significant quantity of fission product radionuclides (<0.1%), based on the analysis of the "A" steam generator RTD thermowell tip. As these results are based on a very small fraction of the RCS surface area ($\sim 10^{-5}$%), additional measurements could affect the mass balance.
- Based on analyses of deposition on control rod drive leadscrews, the reactor vessel plenum did not retain a significant fraction of fission products (<0.1%). However, the sample was quite small compared to the surface it represented. The CCTV surveys of the plenum show that deposition appears to vary based on location relative to the core. To adequately characterize radionuclide deposition in the plenum, additional samples should be taken.
- The core debris bed samples suggest that most of the measurable fission products, except Cs-134, -137 and I-129, still reside in the core material. There is still a large uncertainty in the estimated core inventory retained in the debris bed, due to the small number of core debris samples taken.
- The makeup-purification demineralizers were the only components outside the reactor building that contained a significant fraction of the core inventory. Cesium (1%) and iodine (2%) were transported to the demineralizers by primary coolant. About 98% of the fission products were retained in the reactor building.
- The only probable locations in the reactor that could significantly change the current fission product inventories are the reactor building basement and the core.
- A number of locations in the reactor system should be better characterized to complete closure of the mass balance: the reactor building basement, reactor coolant system surfaces (possibly including the pressurizer), and reactor core. Other possible sampling locations include the reactor coolant drain tank, letdown cooler, and letdown block orifice.
- There are significant differences, as high as 25%, in the predicted fission product inventories of some radionuclides present in the TMI-2 core at the time of the accident, based on the various code calculations performed. A detailed uncertainty analysis should be performed to determine all uncertainties in the code predictions. Further, a procedure should be adopted to normalize the inventory data to a fission product specie that is essentially 100% retained.

REFERENCES

1. GEND Group, *GEND Planning Report,* GEND-001, June 1980.

2. M. I. Goldman et al., *Radionuclide Mass Balance for the TMI-2 Accident: Data Base System and Preliminary Mass Balance,* Volumes 1 and 2, GEND-INF-032, April 1983.

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4. R. E. Shuping, *Use of Photographic Film to Estimate Exposure Near the Three Mile Island Nuclear Power Station,* U.S. Department of Health and Human Services, Bureau of Radiological Health, FDA-81-8142, February 1981.

5. N. Rogovin, *Three Mile Island: A Report to the Commissioners and to the Public,* U.S. Nuclear Regulatory Commission Report, NUREG/CR-1250, V. 2, Pt. 2, p. 351.

6. Babcock & Wilcox Co., *TMI-2 Power History, Isotopic Analysis,* LOR-2, Version 2, November 2, 1979

7. United States Nuclear Regulatory Commission, *Technical Basis for Estimating Fission Product Behavior During LWR Accidents,* NUREG-0772, June 1981.

8. United States Nuclear Regulatory Commission, *Regulatory Impact of Nuclear Reactor Accident Source Term Assumptions,* NUREG-0771, June 1981.

9. R. J. Davis et al., *Radionuclide Mass Balance for the TMI-2 Accident: Data through 1979 and Preliminary Assessment of Uncertainties,* GEND-INF-047, November 1984.

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APPENDIX A

FISSION PRODUCT INVENTORY RESULTS THROUGH FY-1983

APPENDIX A

FISSION PRODUCT INVENTORY RESULTS THROUGH FY-1983

The most recent update of the fission product data base for locations outside the reactor vessel was performed for sample data obtained through 1983.[A-1,A-2] A summary of these data are shown in Table A-1. Table A-1 indicates that about 50% of the noble gases, 53% of the tritium, 51% of the cesium (i.e., Cs-137), 22% of the radioiodine, and 2% of the strontium have been accounted for in ex-vessel locations. Also, less than 0.01% of the uranium/plutonium inventory had been identified outside the reactor vessel. These data are listed with associated uncertainties. The principal cause of the wide ranges is that some locations (e.g., the reactor building basement) had not been well characterized, and the actual inventories may be significantly different from those listed in Table A-1. To reduce the uncertainty associated with these data, a better characterization of individual repositories is necessary.

Table A-1. Summary of fission product inventory results through 1983

Component	Fraction of Core Inventory					
	Tritium	Noble Gases	^{90}Sr	^{129}I	^{137}Ce	U & Pu
Reactor building sump and basement	0.47		0.01	0.18	0.41	<1.0 E-6
Reactor coolant	0.018	<1.0 E-5[a]	0.01	0.014	0.018	<1.0 E-4
Reactor coolant drain tank	0.002	<1.0 E-6[a]	0.001	0.001	0.002	<1.0 E-5
Reactor coolant bleed tanks	0.030	<1.0 E-5[b]	<1.0 E-3	0.02	0.02	<1.0 E-6
Reactor building air	—[c]	0.47[a]	—[c]	1.0 E-3	—[c]	—[c]
Gaseous releases	—[c]	0.07[b]	—[c]	1.0 E-6	—[c]	—[c]
Plenum surfaces	—[c]	—[c]	—[c]	—[c]	0.05	—[c]
Makeup and purification demineralizers	—[c]	—[c]	—[c]	—[c]	0.012	—[c]
Other repositories	0.010		0.001	0.006	0.002	
Total	0.53	0.5	0.02	0.22	0.51	1.0 E-4
Uncertainty	±0.1	+0.5-0.2	±0.004	±0.04	±0.09	

a. Krypton.

b. Xenon.

c. Not reported.

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A-1. R. J. Davis et al., *Radionuclide Mass Balance for the TMI-2 Accident: Data Through 1979 and Preliminary Assessment of Uncertainties,* GEND-INF-047, November 1983.

A-2. C. V. McIsaac, *Surface Activity and Radiation Field Measurements of the TMI-2 Reactor Building Gross Decontamination Experiment,* GEND-037, October 1983.

APPENDIX B

CALCULATION OF INITIAL CORE FISSION PRODUCT INVENTORY

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CALCULATION OF INITIAL CORE FISSION PRODUCT INVENTORY

In order to define the fission product distribution in the reactor system, the initial fission product inventory in the TMI-2 core at the time of the accident must be known. The fission product retention fraction for a system or component is then determined by dividing the calculated radionuclide inventory in a component by the predicted core inventory.[B-1] Several codes used for calculating fission product generation were run to determine the inventory of the TMI-2 core at the time of the accident and for specific times after the accident. The NUS mass balance report[B-2] presented a comparison of three codes, LOR-2, ORIGEN-2, and CINDER.

The input data for the above-mentioned code comparisons were based on average irradiation (i.e., burnup) and core loading. A more recent ORIGEN-2 analysis that considers power distribution, core loading, and a detailed power history was used for this report. The irradiation history model was developed by combining calculated axial and radial power distribution data[a] with the full core thermal power history data.[B-3] Burnup data used in this calculation for each of 1239 fuel nodes (177 elements, 7 axial nodes per element) were taken from a plant performance data summary for March 19, 1979. An ORIGEN-2 calculation was performed for each fuel group using the average group burnup and the plant operating history. Fuel node burnups range from 910 to 6213 MWd/MTU. The 1239 fuel nodes were distributed among 12 fuel groups based on initial enrichment and burnup. The node burnup values were all normalized to the full core burnup to correct for the final few days of operation not included in the plant performance summary. This methodology preserves both the detailed axial and radial profiles and the detailed irradiation history data. Little additional uncertainty is introduced, because the power profiles during the last 9 d would probably not vary significantly from those inferred from the previous 87 d of full power operation.

When the fraction of retained radionuclide core inventory is calculated for a measured radionuclide concentration (e.g., reactor building basement sample), a reactor inventory for that radionuclide must be predicted for a point in time near the sample time. The inventory of some radionuclides will increase (or not decrease with their decay rate) from time of shutdown as a result of parent-daughter interactions. A long half-life parent will continue to produce more of a longer half-life daughter radionuclide, which results in a continuous increase in concentration.

Table B-1 lists the comparison of the fission product inventories for the core average irradiation predictions as described in Reference 3 of the main report, and the nodular (i.e., based on individual fuel assembly power histories) core inventory assessment. Also shown is the predicted inventory for March 1984. A variance was calculated that assumes that the nodular inventory calculation is the most accurate. The data indicate good agreement for Cs-137 (1.6%) and Ce-144 (2.5%), with the worst agreement for Cs-134 (34.7%) and I-129 (21.3%). These data suggest that the calculated fission product inventories may be significantly different (for some radionuclides) than the actual core inventory. Therefore, there is an uncertainty associated with the total fission product inventory that is radionuclide dependent.

The direct comparison of values from these codes provides at least a general idea of the variability of results from such calculations, although the input to the nodular ORIGEN-2 code analysis was more detailed and should be more accurate. This analysis, calculated for March 1984, has been used to calculate fission product retentions in this report.

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a. G. R. Eidam, letter to H. M. Burton, *TMI-2 Core Radial and Axial Power History Data,* GPU Nuclear 4550-83-0412, September 29, 1983.

Table B-1. Comparison of TMI-2 core initial fission product inventory code predictions (curies)

	At Shutdown, March 29, 1979					March 1, 1984
Radionuclide	ORIGEN-2[a]	CINDER[b]	LOR-2[b]	ORIGEN[b]	Variance (%)	ORIGEN-2[a]
^{90}Sr	7.46 E+5	8.0 E+5	7.8 E+5	7.5 E+5	7.2	6.63 E+5
^{106}Ru	3.58 E+6	2.9 E+6	3.2 E+6	3.3 E+6	19.0	1.15 E+5
^{110m}Ag	3.32 E+3	—[c]	—[c]	—[c]	—[c]	2.09 E+1
^{125}Sb	1.22 E+5	—[c]	—[c]	—[c]	—[c]	3.70 E+4
^{129}I	2.16 E-1	1.7 E-1	1.7 E-1	2.1 E-1	21.3	2.29 E-1
^{134}Cs	1.99 E+5	1.3 E +5	1.7 E+5	1.6 E+5	34.7	3.70 E+4
^{137}Cs	8.54 E+5	8.4 E+5	8.4 E+5	8.4 E+5	1.6	7.6 E+5
^{144}Ce	2.36 E+7	2.4 E+7	2.3 E+7	2.5 E+7	2.5	2.75 E+5
^{154}Eu	9.55 E+3	—[c]	—[c]	—[c]	—[c]	6.39 E+3
^{155}Eu	3.24 E+4	—[c]	—[c]	—[c]	—[c]	1.61 E+4

a. Based on individual fuel assembly power histories.

b. As reported in Reference A-1 for core average irradiation.

c. Radionuclide concentrations not listed in Reference A-1.

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B-1. GEND Group, *GEND Planning Report*, GEND 001, June 1980.

B-2. R. J. Davis et al., *Radionuclide Mass Balance for the TMI-2 Accident: Data Through 1979 and Preliminary Assessment of Uncertainties*, GEND-INF-047, November 1983.

B-3. T. R. England and W. B. Wilson, *TMI-2 Decay Power: LASL Fission Product and Actinide Decay Power Calculations for the President's Commission on the Accident at Three Mile Island*, LA-8041-MS, Revised, March 1980.

APPENDIX C

DETAILS OF ANALYSES OF PLANT COMPONENTS

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DETAILS OF ANALYSES OF PLANT COMPONENTS

Details of Recent Fission Product Inventory Sampling Data

This Appendix presents a detailed discussion of the sampling of plant components studied during FY-84 and updates the previous inventory report.[C-1] Details of the radionuclide concentrations are included along with the component volume or surface areas that permit calculation of the radionuclide inventories in the plant components and the fractional inventories retention in the main body of the report. The uncertainties are also discussed.

The analysis results and discussion are divided into two groups: samples obtained outside the reactor vessel, and those from inside the reactor vessel.

Samples Outside the Reactor Coolant System

Samples have been acquired and analyzed from a number of locations outside of the RCS. Some of these were obtained from previously inaccessible locations. Other samples were obtained from previously sampled components, necessitating changes in the FPI assays for those components.

The reactor building air cooler panels were sampled for radionuclide surface deposition, the reactor building sump was sampled for radionuclide content in liquids and solids, the "A" steam generator resistance temperature detector (RTD) thermowell tip was analyzed to determine surface deposition in the reactor coolant system, and the makeup and purification demineralizers were sampled for retained radionuclide content. Complete analysis results have been published in other documents;[a,C-2,C-3] however, summaries of these results are listed in the following sections.

Air Cooler Assembly Surfaces. The reactor building air coolers (shown in Figure 3 of the main report) were expected to be a potential collection point for radioactivity because of their large surface area and the large volume of air moving through them. Condensation of water on the coolers would provide an additional mechanism for radionuclide removal from the air and deposition on surfaces. In-situ gamma scans of the cooling coils and drip pans were made in October 1981 with a mobile gamma spectrometer. Subsequently, metal coupons were removed from the access panels in August 1983, and the surface concentrations of radionuclides were measured during 1984.

The reactor building air cooler assembly consists of five air cooling units connected to a common system of duct work for air distribution (see Figure 3 of the main report). Each cooling unit consists of finned, water-type cooling coils and an axial flow fan. All five units are assembled in a common metal housing with divider plates and backdraft dampers. Air cooler drip pans are located at the base of the common plenum, providing a catch basin for condensation generated on the cooler coils. Table C-1 summarizes the surface areas of components associated with the reactor building air coolers.[C-4] There is an estimated 10% uncertainty in the surface area reported for each component, with an overall uncertainty of 7% for the total surface area of the coolers.

Coupons removed from five reactor building air cooler access panels (four from each air cooler) were analyzed for radionuclide surface concentrations. The sample coupon locations were selected after gamma scans of the panels were made to determine representativeness. The results of those analyses, given as average radionuclide surface concentrations, are shown in Table C-2. The only gamma-emitting radionuclides measurable on the exterior surface of the air cooler access panels (i.e., normally exposed to the reactor building environment) were Cs-137 and Cs-134. The concentrations for all air coolers are similar (within a factor of 4), indicating a relatively consistent radionuclide surface disposition.

On the interior surfaces of the air cooler access panels, analyses were performed for Sr-90 and I-129, in addition to the gamma spectroscopy analysis used to measure Cs-134, -137. The concentrations of all radionuclides are similar (within a factor of 10), indicating a relatively consistent surface deposition on the air cooler surfaces. It should be noted that (a) all air coolers were not in operation at all times

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a. T. E. Cox, letter to K. C. Sumpter, *A Steam Generator Resistance Thermowell Detector Analysis Results*, TEC-54-84, September 25, 1984.

Table C-1. Surface areas of reactor building air cooler components

Component	Surface Area per Air Cooler (ft^2)	Surface Area per Air Cooler (cm^2)	Total Surface Area for Five Air Coolers (ft^2)	Total Surface Area for Five Air Coolers (cm^2)
Housing	—	—	10,400	9.7 ± 0.9 E+6
Vent ducts	—	—	24,860	2.3 ± 0.2 E+7
Cooling coils	14,500	1.35 E+7	72,500	6.8 ± 0.7 E+7
Drip pans	88	8.2 E+4	440	4.1 ± 0.4 E+5
Total	—	—	107,760	1.0 ± 0.07 E+8

during the accident, and (b) air coolers 11A, 11B, and 11C were decontaminated with water before the surface sample acquisition. Therefore, these analytical results may not be representative of deposition on the air cooler surfaces after the accident. However, other analyses suggest that these radionuclide concentrations are similar to other surfaces in the reactor building, and that the air coolers did not

Table C-2. Average radionuclide surface concentrations on reactor building air cooler access panels[a] ($\mu Ci/cm^2$)

	Exterior Surface		Interior Surface			
	^{137}Cs	^{134}Cs	^{137}Cs	^{134}Cs	^{90}Sr	^{129}I
11A	5.2 ± 0.5 E-1	2.9 ± 0.3 E-2	4.3 ± 1.7 E-1	2.5 ± 1.0 E-2	1.5 ± 0.8 E-2[b]	5.2 ± 0.5 E-6[b]
11B	3.8 ± 0.2 E-1	2.1 ± 0.1 E-2	1.1 ± 0.3 E-1	6.7 ± 1.3 E-3	6.4 ± 0.2 E-3[b]	—[c]
11C	1.2 ± 0.4	6.6 ± 2.0 E-2	8.5 ± 0.9 E-1	4.7 ± 0.4 E-2	—[c]	6.9 ± 0.7 E-6[b]
11D	4.8 ± 1.0 E-1	2.6 ± 0.5 E-2	3.1 ± 0.9 E-1	1.7 ± 0.5 E-2	7.6 ± 0.4 E-3[b]	2.7 ± 0.3 E-6[b]
11E	1.3 ± 0.4	7.0 ± 2.0 E-2	2.1 ± 0.6	1.2 ± 0.3 E-1	4.3 ± 0.2 E-2[b]	7.5 ± 0.8 E-6[b]
Mean	7.8 ± 4.4 E-1	4.2 ± 2.4 E-2	7.6 ± 8.0 E-1	4.3 ± 4.5 E-2	1.8 ± 1.7 E-2	5.6 ± 2.2 E-6

a. All errors quoted represent the deviation for all samples analyzed on an access panel. Data decay corrected to March 1984.

b. The errors listed are counting statistics only, as a single sample analysis was performed.

c. Not measured.

serve as a major repository for radionuclides. Table C-3 (Reference C-5) shows the comparison of the air cooler access panel data with data from surface samples obtained from the 305-ft elevation of the reactor building. The comparison suggests that deposition was similar for all radionuclides at both locations and that the air coolers did not function as a repository for fission products released to the reactor building atmosphere.

Table C-4 (Reference C-6) shows the results of the gamma spectroscopy measurements of the cooling coils and drip pans. These analyses were performed before decontamination of the system. A comparison of these analyses results, presented in Table C-4, shows that the gamma scan results are quite similar to the more accurate sample analysis results shown for the access panels. The analysis of gamma spectral scans of the cooling coils and drip pans shows surface concentrations slightly lower than the levels found on the access panels, a difference that may have been caused by condensation washing the surfaces of the coils and pans, or by unknown uncertainties in the gamma scan procedures.

The method used to determine the fraction of the total reactor inventory of a radionuclide retained on the surface of a system component or in a volume of liquid is defined by the following equation:

$$F = \frac{Cs \times S}{C_c}$$

where

F = Fraction of fission product core inventory retained by the system or component

Cs = Summation of radionuclide concentrations measured in samples from the component (in $\mu Ci/cm^2$ or $\mu Ci/cm^3$)

S = Summation of the surface areas (cm^2) or volumes (cm^3) to which the measured concentrations are extrapolated

C_c = Core fission product inventory (in μCi), decay corrected to a date approximate to the date when the samples were taken.

The fraction of core inventory present on the air cooler surfaces can be determined from the surface area (Table C-1), radionuclide surface concentrations (Table C-2), and core fission product inventory (Table B-1).

Because the gamma scan measurements of the drip pans and cooling coils did not yield results for Sr-90 and I-129, the air cooler access panel analyses, rather than the measurements of the pans and coils, were used in calculating the fraction of core inventory on the internal surfaces of the air cooler systems, as listed in Table C-5. These results show that only small fractions of the total core fission product inventories of the measurable radionuclides were deposited on air cooler surfaces, and it might be inferred that equally small fractions were deposited on other surfaces of the reactor building.

Reactor Building Sump. Leakage from the reactor coolant system collected in the reactor building sump and on the reactor building basement floor shortly after the accident. Before and after processing of the reactor building basement water by the submerged demineralizer system, samples of water and solids were taken at various locations (Figure 12) in the reactor building basement and the sump. Data obtained from these samples have been reported (Reference C-1). The results of subsequent analyses of the sump are presented in this report. Though the quantity of radionuclides measured in the sump is small compared to that measured in the entire reactor building basement (because of the much larger surface area), the sump, nevertheless, provides useful samples that help to characterize the profile of radionuclide concentrations in the basement, and better quantifies the radionuclide content and quantity of solids in that location.

The reactor building sump was sampled August 22, 1983, after the reactor building basement water had been processed by the submerged demineralizer systems and after decontamination operations had washed radioactivity and solids into the basement from upper floors of the reactor building. Although mixing of the decontamination water with the sump water appears to be minimal, based on sump and basement radionuclide concentrations measured before and after the decontamination operation (Reference C-2), the sample analyses may not be representative of conditions during or shortly after the accident.

The sump sample was obtained from the sump pump discharge line after recirculation and after the line had been purged. The sample was filtered, and the radionuclide concentrations of the liquid and solids as reported (Reference C-2) are shown in

Table C-3. Comparison of radionuclide surface concentrations on reactor building air cooler with 305-ft elevation vertical metal surface[a] (μCi/cm^2)

Radionuclide	Vertical Metal Surfaces[a]	Cooler External Surface	Cooler Internal Surface
^{90}Sr	1.6 ± 0.2 E-2	—	1.8 ± 1.7 E-2
^{129}I	4.2 ± 0.8 E-6	—	5.6 ± 2.2 E-6
^{134}Cs	1.6 ± 0.5 E-2	4.2 ± 2.4 E-2	4.3 ± 4.5 E-2
^{137}Cs	2.9 ± 1.0 E-1	7.8 ± 4.4 E-1	7.6 ± 8.0 E-1

a. Data decay corrected to March 1984.

Table C-6. The total radionuclide mass in the sump can be estimated from the amount of the solids in the August 22, 1983, sample and the volume of water in the sump. The sump sample contained 36 mg/mL of solids, and the sump was estimated to contain 1.03 E7 mL of water (±10%). These values yield a total solids mass of 3.7 ± 0.4 kg in the sump when the sample was taken. The fraction of core inventory retained in the sump is shown in Table C-6. These data suggest that the sump is a

Table C-4. Radionuclide surface concentrations on reactor building air cooler from gamma scans[a]

Air Cooler Number	^{137}Cs on Cooling Coils		^{137}Cs on Drip Pans	
	(total Ci)	(μCi/cm^2)[b]	(total Ci)	(μCi/cm^2)[c]
11C	5.6 ± 1.0	4.3 ± 0.7 E-1	6.6 ± 2.8 E-2	8.1 ± 3.5 E-1
11D	1.5 ± 0.4	1.2 ± 0.3 E-1	1.9 ± 1.0 E-2	2.3 ± 1.2 E-1
11E	7.6 ± 4.0 E-1	5.9 ± 2.9 E-2	2.8 ± 2.8 E-2	3.5 ± 3.5 E-1

a. Quoted uncertainties include statistical uncertainties, estimates of the uncertainties in the detector efficiency calibration, and uncertainties in the data analysis. Data decay corrected to March 1984.

b. Assumes surface area of coil ~1.3 E+7 cm^2.

c. Assumes surface area of drip pans ~8.2 E+4 cm^2.

Table C-5. Surface radionuclide inventories and fractions of core inventory on reactor building air coolers[a]

Radionuclide	Total Surface Activity (Ci)	Fraction of Core Inventory
^{134}Cs	4 ± 5	1 ± 1 E-4
^{137}Cs	8 ± 8 E+1	1 ± 1 E-4
^{90}Sr	2 ± 2	3 ± 3 E-6
^{129}I	6 ± 2 E-4	3 ± 1 E-3

a. Data decay corrected to March 1, 1984.

minor repository for fission products in the reactor building basement, and that the soluble portion of the sample contains the majority of the fission product inventory, a result of the small quantity of solid material relative to the large quantity of liquid present in the sump. However, the results of this analysis should be used cautiously as (a) the sample was obtained through recirculation with a pump and may not be representative of solid sediment in the sump, and (b) the estimate of the quantity of solids in the sump is based only on solids transportable by the sump pump.

The sump sample results indicate the amount of activity left in the sump on the date of sampling and cannot be added directly to the mass balance inventory. However, these data provide additional information to be included with previous reactor building basement sample analyses. Evaluation of the solid material depth in the basement is discussed in more depth in Reference C-2.

Reactor Coolant Drain Tank. The Reactor Coolant Drain Tank (RCDT) receives water from the pressurizer when the PORV releases pressure in the reactor system. (The RCDT location is shown in Figure 12 in the main body of this report.) During the first 3 d following the accident, an estimated 1.0 E+9 mL of primary coolant escaped from the reactor coolant system (RCS) through the pressurizer to the RCDT. The RCDT rupture disk burst, allowing this coolant to flow to the reactor building basement. Samples from the RCDT were collected to determine the quantity of fission products retained in this portion of the flow path.

Major reactor coolant flow to the RCDT, except for leakage and cycling of the block valve for 13 h, was stopped when the block valve was closed 2 h-20 min into the accident. Leakage continued until July 1982, when the RCS was depressurized. The total volume passed through the RCDT during this period was estimated at 7 E+8 mL. From December 1982 until July 1983, the reactor system was again pressurized, resulting in additional leakage to the RCDT of approximately 2 E+8 mL. The total volume of liquid passed through the RCDT was 1.9 E+9 mL, which represents 69 tank volumes passing through the tank before sampling of the tank.

The first sample of the RCDT was obtained in December 1983 and is representative only of the water that was passed from RCS leakage through the RCDT to the reactor building basement during early 1983 after the RCS was pressurized to 60 psig. Solid material that was sampled may have been introduced into the tank at any time during the various periods of flow through the tank.

The RCDT samples were collected by inserting a sampler directly into the tank through a hole cut in the overflow line. Liquids and solids were drawn into an evacuated glass container through a hollow needle. The sampler was similar to that used to collect some of the reactor building basement samples. Two samples were taken; one from a point 12 in. above the bottom of the tank to measure the radionuclide concentration in the liquid, and one from the bottom of the tank to measure radionuclide retention in the sediment that had collected there.

The volume of liquid and mass of solids in the tank at the time of sampling was estimated to be 2.74 E+7 mL and 2.6 E+4 kg, respectively. The liquid volume was based on the design dimensions of the tank, and a 20% uncertainty is assumed. The mass of solids was estimated from visual observation of solids depth by CCTV in one portion of the tank and from the density of materials measured in the sample collected from the bottom of the tank. For calculational purposes, the sediment on the bottom surface of the tank is assumed to be 0.16 cm (1/16 in.) thick and uniformly covers one-eighth of the inner surface of the tank. The total volume of solids is calculated to be approximately 8.3 E+3 cm^3. Based on the elemental

Table C-6. Radionuclide concentrations and fractions of core inventory retained in reactor building sump[a]

Radionuclide	Radionuclide Contentration		Fraction of Core Inventory	
	Solids (μCi/g)	Liquid (μCi/mL)	Solids	Liquid
^{54}Mn	1.1 ± 0.2 E-1	—[b]	—[b]	—[b]
^{60}Co	2.29 ± 0.08	—[b]	—[b]	—[b]
^{90}Sr	1.49 ± 0.06 E+2	6.0 ± 0.3	8.3 ± 0.9 E-7	9.0 ± 1.0 E-5
^{106}Ru	—[b]	—[b]	—[b]	—[b]
^{125}Sb	1.4 ± 0.1	—[b]	1.4 ± 0.2 E-7	—[b]
^{129}I	<3 E-5	—[b]	<5 E-7	—[b]
^{134}Cs	2.91 ± 0.07	5.07 ± 0.04	2.9 ± 0.3 E-7	1.4 ± 0.1 E-3
^{137}Cs	5.29 ± 0.03 E+1	9.40 ± 0.05 E+1	2.6 ± 0.3 E-7	1.3 ± 0.1 E-3
^{144}Ce	8.0 ± 2.0	—[b]	1.0 ± 0.3 E-7	—[b]

a. Data decay corrected to March 24, 1984.

b. Not detected.

analysis results for the RCDT solids sample, the density of the sediment is approximately 6.2 g/cm^3. It is assumed that one-half of the total sediment volume is water; and, therefore, the total mass of the solids in the RCDT is approximately 26 kg. The uncertainty in the total mass is high, estimated at ∿100%, mainly because of the uncertainty of the depth of the sediment. The radionuclide concentrations and estimated fractions of core inventory retained in the RCDT are shown in Table C-7.

The RCDT analyses indicate the presence of minimal fractions of the retained core inventory. In both liquid and solid sample fractions, Sr-90 is the radionuclide with the highest retention factor in the tank (∿10^{-4}), with the solid material having the highest retention. The samples are not representative of the soluble fission product content of the tank immediately after the accident, as many tank volumes of diluted reactor coolant have been transferred through the tank since that time. The measured solids content and radionuclide concentrations are not representative of immediate postaccident content either, as some portions of the solid material originally transferred to the tank were probably swept into the reactor building basement. An evaluation of the flow rate and path through the tank should be performed to determine what particle sizes could have been swept into the reactor building. This information may be useful in evaluating the character of solids which could have been released from the reactor to the remainder of the reactor system.

Table C-7. Radionuclide concentrations and fractions of core inventory retained in reactor coolant drain tank[a]

Radionuclide	Radionuclide Concentration		Fraction of Core Inventory	
	Solids (μCi/g)	Liquid (μCi/mL)	Solids	Liquid
^{3}H	—[b]	3.43 ± 0.07 E-2	—[b]	2.9 ± 0.06 E-4
^{60}Co	3.04 ± 0.05 E+1	1.0 ± 0.1 E-3	—[c]	—[c]
^{90}Sr	1.39 ± 0.07 E+4	2.49 ± 0.04 E0	5.0 ± 5.0 E-4	1.0 ± 0.2 E-4
^{106}Ru	6.5 ± 0.3 E+1	—[b]	2.0 ± 0.2 E-5	—[b]
^{125}Sb	1.60 ± 0.08 E+1	6.0 ± 1.0 E-3	1.0 ± 1.0 E-5	4.0 ± 1.0 E-6
^{129}I	5.2 ± 0.4 E-8	3.9 ± 0.2 E-7	6.0 ± 6.0 E-9	5.0 E+1.0 E-5
^{134}Cs	5.9 ± 0.4 E0	6.84 ± 0.05 E-2	4.0 ± 4.0 E-6	5.0 ± 1.0 E-5
^{137}Cs	9.7 ± 0.2 E+1	1.22 ± 0.01E0	3.0 ± 3.3 E-6	4.4 ± 0.9 E-5
^{144}Ce	1.0 ± 0.3 E+1	—[b]	1.0 ± 1.0 E-6	—[b]

a. Data decay corrected to March 1984.

b. Not detected.

c. Not a fission product.

Samples from the Reactor Coolant System

"A" Steam Generator Resistance Temperature Detector. In April 1984, a dual element resistance temperature detector (RTD) was removed from the "A" steam generator hot leg. This RTD is installed in the steam generator "candy cane" to measure the temperature of the reactor coolant entering the steam generator from the reactor core. The 15.2 cm^2 tip of the RTD thermowell exposed to the reactor coolant stream was subjected to accident conditions in the "A" hot leg. It is assumed, for calculational purposes, that the deposits on the RTD thermowell tip are representative of current deposits on RCS internal surfaces, excluding the reactor vessel.

The concentrations of radionuclides measured on the RTD surface are shown in Table C-8. The concentrations were determined by chemical removal (12 different decontamination steps) of the radionuclide content from the RTD thermowell tip and by dividing the total radionuclide content by the 15.2 cm^2 surface area of the tip. Approximately 2% of the total Cs-137 activity was retained on the RTD thermowell tip after decontamination.

To calculate the fraction of core inventory retained on the RCS surfaces, the surface area of the RCS minus the reactor vessel was calculated from system drawings, with an estimated uncertainty of 10%. The surface areas calculated for the hot legs, cold legs, and

Table C-8. Radionuclide surface concentrations on resistance temperature detector thermowell tip[a]

Radionuclide	Radionuclide Surface Concentration (μCi/cm^2)
^{54}Mn	2.2 ± 0.6 E-4
^{60}Co	1.4 ± 0.1 E-1
^{90}Sr	9.4 ± 0.2
^{125}Sb	1.36 ± 0.06 E-1
^{134}Cs	9.4 ± 0.06 E-1
^{137}Cs	2.05 ± 0.01 E+1
^{144}Ce	2.15 ± 0.06 E-1
^{129}I	8.0 ± 4.0 E-8

a. Data decay corrected to March 1984.

steam generators[a] are 9.7 E+5 cm^2, 9.8 E+5 cm^2, and 3.7 E+7 cm^2, respectively, resulting in a total RCS surface area of 3.9 ± 0.4 E+7 cm^2. This surface area does not include the pressurizer, reactor vessel, MUP system, or residual heat removal system.

The estimated fractions of core fission product inventory retained on RCS internal surfaces are shown in Table C-9. Total retention of fission products on RCS surfaces is similar (~0.01%) for all radionuclides measured except Ce-144, which is approximately two orders of magnitude less, suggesting less transport of this radionuclide to RCS surfaces. In any event, retention of fission products on RCS surfaces is minimal, suggesting that RCS surfaces outside the reactor vessel are not a significant repository for fission products. However, these data are based on analyses of the RTD thermowell tip, which constitutes only a very small fraction of the total RCS surface area (~10^{-5}%); the RTD is not representative of other portions of the RCS (e.g., horizontal surfaces, cold legs). No estimate of the total uncertainty is possible based on the small sample analyzed. Further sampling of surfaces in this system should be performed to better characterize the system.

a. S. R. Behling, private communication with S. T. Croney, EG&G Idaho, Inc., May 1, 1985.

Samples from Inside the Reactor Vessel. Samples of the control rod drive leadscrews and samples from the core debris bed were obtained from inside the reactor vessel and analyzed during 1984. A summation of these results is provided in the following section. More complete analysis results are to be published.[C-7,C-8]

Control Rod Drive Leadscrews. Radionuclide surface analysis was performed on two control rod drive leadscrews, which were removed from the

Table C-9. Radionuclide content and fraction of core inventory retained in reactor coolant system[a]

Radionuclide	Piping Surface Activity[b] (Ci)	Fraction of Core Inventory
^{54}Mn	8.6 ± 0.3 E-3	—[c]
^{60}Co	5.4 ± 0.7 E+0	—[c]
^{90}Sr	3.7 ± 0.4 E+2	5.6 ± 0.6 E-4
^{125}Sb	5.3 ± 0.6 E+1	1.4 ± 0.2 E-3
^{129}I	3.3 ± 2 E-6	1.3 ± 0.9 E-3
^{134}Cs	3.7 ± 0.4 E+1	1.0 ± 0.1 E-3
^{137}Cs	8.0 ± 0.8 E+2	1.1 ± 0.1 E-3
^{144}Ce	1.1 ± 0.1 E+1	

a. Data decay corrected to March 1984.

b. Assumes a total surface area of 3.9 E+7 cm^2.

c. Not a fission product.

reactor head as part of the July 1982 television inspection of the damaged core. One leadscrew was removed from each of three different core positions: H8, at the center of the core; E9, at approximately mid-radius; and B8, near the outer edge (see Figure 4 of main report). The E9 leadscrew was not characterized for radionuclide content.

Each leadscrew is approximately 7.3 m long, and during removal from the reactor vessel, GPU Nuclear cut them into 5 ft sections. Each section was bagged in polyethylene sleeving, inserted into a polyvinyl chloride (PVC) tube, and put into a shipping container.

Leadscrew sections from H8 and B8 were shipped to and examined at the Idaho National Engineering Laboratory (INEL). Three short sections of the H8 leadscrew from near the top of the plenum assembly were examined by Pacific Northwest Laboratory (PNL), Babcock & Wilcox (B&W), and GPU Nuclear. The objectives of the H8 and B8 examinations at INEL were to determine the extent and nature of the radionuclide deposition on the leadscrew surfaces and to determine the temperatures experienced by the leadscrews.

Figure 5 of the main report shows the H8 leadscrew sections and the portions sent to the various laboratories for radionuclide analysis. The surface deposits on the lower 3.17 m of the H8 leadscrew and the B8 leadscrew were analyzed at the INEL. These deposits were removed by brushing the loose debris, followed by acid etching of the tightly adherent material. The total radionuclide surface concentrations measured are listed in Table C-10. The results presented are from the EG&G analysis (Reference C-8) and are comparable to those reported by the other laboratories.

An axial gradient in surface radionuclide concentrations was observed, with the highest concentration found on samples from nearer the top of the plenum assembly (colder). It may be expected that a similar gradient will be found on other plenum surfaces.

Uncertainties in the concentrations listed in Table C-10 are assumed to be ∿50%, as an unknown quantity of loose material was lost during handling, cutting, and analysis of the leadscrews, which could bias the measured concentrations.

It is assumed, for purposes of calculation, that the deposits on the leadscrews are representative of those on other plenum assembly surfaces. The surface area for the plenum was estimated by NUS Corporation and TMI-2 site personnel.[C-9] Surfaces other than plenum surfaces, such as the vessel outlet nozzles, baffle plate, and leadscrew surfaces, are not included. The surface area for a number of plenum components, as estimated by NUS and TMI-2 personnel, are shown in Table C-11. The average of these two surface area estimates, 3.54 ± 0.71 E+6 cm^2, is used for calculations in this report.

The fraction of core inventory retained on the plenum assembly surfaces is shown in Table C-12. The data suggest that the plenum surfaces did not function as a major repository for radionuclides (<1% of core inventory); however, the analyses were performed ∿5 y after the accident, and loose surface deposition may have been affected by washout during that period of time. Based on CCTV surveys of the plenum, deposition appears to be greater on surfaces higher in the plenum and farther from the core. In order to adequately characterize radionuclide deposition in the plenum, further examination of other plenum surfaces should be done.

Core-Debris Samples. Visual inspection of the physical condition of the core revealed a debris bed consisting of particles of various sizes. Insertion of a probe into the core material through control rod locations indicated that the debris bed is as deep as 37 in. The probe could not be driven below this level, leaving about 5 ft of the core condition unknown.

The first samples of reactor core material were taken in September 1983. At this time, six debris samples from the bed were collected by lowering sampling devices through two leadscrew openings, locations H8 (center) and E9 (mid-radius) shown on Figure 4 of the main report. Core-debris samples were obtained from three depths: the surface of the bed, 3 in. below the surface, and 22 in. below the surface. Figure 7 shows the location in the debris bed of each sample and Figure C-1 shows the type of sampling devices used for the surface and sub-surface samples.

The core-debris samples contained particles of cladding and other core materials of a wide range of sizes. Table C-13 shows the average radionuclide concentration for the first series of core-debris samples. To obtain these results, ∿30% of each bulk sample was separated and dissolved for analysis. The I-129 analysis was not possible by the dissolution method, so these concentrations were calculated based on samples from individual particles and particle-size aliquots obtained from each sample. Further, the Sr-90 analysis results of the bulk dissolution samples were not available at the time of this report, so only the results of individual

Table C-10. Radionuclide surface concentrations on leadscrews H8 and B8[a] (μCi/cm^2)

Radionuclide	H8 Bottom	H8 Top	B8 Bottom	B8 Top
^{54}Mn	4.0 E-3	5.2 E-2	—[b]	—[b]
^{60}Co	9.0 E+2	3.9	5.6 E-1	7.5 E-1
^{90}Sr	2.0	4.6 E+1	1.7	1.4 E+1
^{106}Ru	2.2 E-1	1.1 E+1	3.2 E-1	1.5
^{110m}Ag	2.8 E-2	5.1 E-2	—[b]	—[b]
^{125}Sb	2.0 E-1	1.2	6.4 E-1	1.8 E+1
^{129}I	3.4 E-6	6.8 E-5	3.4 E-6	1.3 E-4
^{134}Cs	4.4 E-1	2.8	1.8	3.1 E+1
^{137}Cs	7.4	5.6 E+1	3.4 E+1	5.5 E+2
^{144}Ce	4.3 E-1	1.8 E+1	5.1 E+1	1.3

a. Sum of surface radionuclide concentrations from brush-off debris, leach solutions, and insoluble fractions. The estimated uncertainties are assumed to be 50%. Data decay corrected to March 1984.

b. Not detected.

particle and particle-size aliquots analysis are reported. With few exceptions, the concentrations are consistent, within a factor of 2, indicating that to the depth to which the bed was sampled, the fission product concentrations are relatively consistent.

The Cs-137 results were calculated from individual particles and particles-size aliquots and compared with the bulk dissolution sample analyses as a check on how well the particle samples represent the bulk. The ratio of particle size to bulk dissolution results are: Sample 1, 0.65; Sample 3, 0.42; Sample 4, 0.27; Sample 5, 0.28; and Sample 6, 0.59. There is a bias ~50% low in the particle-size results. This bias may be due to the nonrandom sample selection of particles greater than 1000 μm, which was done to better characterize nonrepresentative samples. The disagreement between the bulk dissolution sample analysis and individual particle and particle-size aliquot analysis for Cs-137 would suggest that there is a large uncertainty associated with the individual particle and aliquot analysis for I-129 as well.

Chemical analyses indicate that significant amounts of material other than fuel are present in the core-debris samples. Control rod materials (Ag-In-Cd) and structural materials were found in addition to uranium and zirconium in the majority of samples analyzed.[C-10] Structural material components measurable in the majority of the core-debris samples are iron (Fe), chromium (Cr), nickel (Ni), manganese (Mn), aluminum (Al), silicon (Si), and tin (Sn). The original mass of components in the TMI-2 core[C-11] are:

Table C-11. Estimated retention surface areas of reactor plenum (ft^2)

Item	TMI-2 Site	NUS	
Outer surface	338.53	310	
Inner surface	329.84	300	
Hole edges	9.58	10	
CRDM guide tubes	828.78	1660	
Top plate (one side)	55.92	60	
Cover assembly	266.56	400	
Subtotal	1829	2740	(Average = 2280 ± 460)
CRDM guide tube inner surface	—[a]	1540	
Leadscrew surfaces	—[a]	290	
Total	3050[b]	4570	Average = [3810 ± 760 (3.54 ± 0.71 E6 cm^2)]

a. Not estimated.

b. Calculated from NUS total using ratio of NUS subtotal to TMI-2 site subtotal.

UO_2	=	9.3 E4 kg
Zr	=	2.3 E4 kg
Stainless steel	=	4.6 E3 kg
ZrO_2	=	3.3 E2 kg
Ag-In-Cd	=	2.7 E3 kg
Total		1.2 E5 kg

This total mass calculation is used to determine the radionuclide inventory retained in the reactor core. The fractions of the core fission product inventory based on the averaged sample results are shown in Table C-14 (which is the same as Table 7 of the main report). Because it has been estimated that only 20% of the core material is in the core debris bed, the fission product retention in the core is calculated with the debris samples representing both 20% and 100% of the core mass for comparison purposes. Based on this extrapolation, the radionuclide with the highest measured retention in the core is Ce-144, at 130% of the predicted concentration. This figure is within the range of concentration that may be expected from locations in the core with higher than average burnup. The estimated uncertainty in the fission product retention in the core may be as high as 30%.

The results for I-129 and Cs-137 indicate significant release from the core (70 to 75%). However, there is an asymmetric uncertainty[a] associated with I-129 analysis, possibly as large as +50%. Therefore, significantly more I-129 may have been retained in the core than is shown here. Further analyses of these samples are being performed to better define the fission product concentrations in the core debris bed.

The fractions of core inventory retained, extrapolated to the entire core, are based on the radionuclide concentration from core debris bed samples and may not accurately represent the fission product concentrations in lower regions of the core that have not been sampled. The uncertainty introduced by the

a. More likely to be low than high, due to possible incomplete recovery of all I from sample.

Table C-12. Radionuclide inventories and fractions of core inventory retained on the reactor plenum and associated surfaces[a]

Radionuclide	Radionuclide Inventories (Ci)	Fraction of Core Inventory
^{90}Sr	5.9 E+1	9.0 ± 7.0 E-5
^{106}Ru	1.2 E+1	1.0 ± 0.9 E-4
^{125}Sb	3.0 E+1	8.0 ± 5.0 E-4
^{129}I	1.8 E-4	8.0 ± 4.0 E-4
^{134}Cs	3.3 E+1	9.0 ± 7.0 E-4
^{137}Cs	6.1 E+2	8.0 ± 6.0 E-4
^{144}Ce	1.9 E+1	7.0 ± 4.0 E-5

a. Assume 3.54 ± 0.71 E6 cm^2 surface area from Reference 12.

unknown radionuclide concentrations below the debris bed are expected to be reduced by further sampling of the lower unexposed portion of the core and the lower plenum. However, it should be noted that the core has been exposed to reactor coolant for 5 y, and leaching may have significantly affected the radionuclide distribution in the core material. Increases of Sr-90 in the coolant have been observed that are related to leaching.

Samples From the Auxiliary Building

Makeup and Purification Demineralizers. During normal operation, the makeup and purification system receives reactor coolant from the steam generator cold leg for filtration and demineralization. This system operated only intermittently during the accident. The system contains two ion-exchange resin beds that remove radionuclides from the RCS. Resin samples were obtained for analysis from both demineralizers, and a liquid sample was taken from the "B" demineralizer in March/April 1983.

The demineralizer vessels are located on the 305-ft elevation of the auxiliary building and are part of the makeup and purification system. Each demineralizer vessel was charged initially with a 50 ft^3 quantity of Amberlite IRN 217 mixed resin—a 3:2 mixture of strongly acidic cation resin IRN-77, and a strongly basic anion resin IRN-78. This initial resin charge weighs about 2650 lb and swells to about 57 ft^3 when water is added to the vessel. The resins consist of polystyrene beads copolymerized with divinylbenzene to create beads with large surface areas containing many ion-exchange sites. The resultant resin bed consists of about 40% by volume voids and 54% by volume water.

For 2 to 3 months before March 28, 1979, the demineralizer vessels were in operation processing reactor coolant at normal flow rates of between 40 and 78 gpm. At the time of the turbine trip, the system was operating at 40 gpm with one filter and demineralizer train in operation. After the trip, flow was secured for about 5 min, then reestablished and stabilized at 71 gpm, where it remained for several hours. By 16:30 on the date of the accident, flow began to fluctuate from lows of 40 gpm to highs of 150 gpm until flow was lost at 22:34:23, apparently because of plugging of the letdown block orifice. By 06:31 on March 29, 1979, a flow of 25 gpm had been established with all the system filters and the demineralizers bypassed.

The GPU Nuclear Corporation has estimated that between the time of core damage and system flow loss (∿16 h-25 min), the MUP system processed about 46,000 gal of water from the reactor coolant system.[C-12] Physical measurements of both demineralizers and visual observations of the "A" demineralizer during sampling indicate that present bed volumes are reduced. Calculations of volume reduction indicate that the present volumes are approximately(Reference C-12):

- "A" Demineralizer—17 ft^3
- "B" Demineralizer—15 ft^3.

This compares with an original bed volume of 50 ft^3 and mass of about 2650 lb (1.2 E6 g) for each demineralizer; the actual present mass of the resin is not known. The resin was severely degraded by radiation and high temperature water during the accident, and the density of resin samples taken in March and April have not been reported. The fission product inventory determinations computed

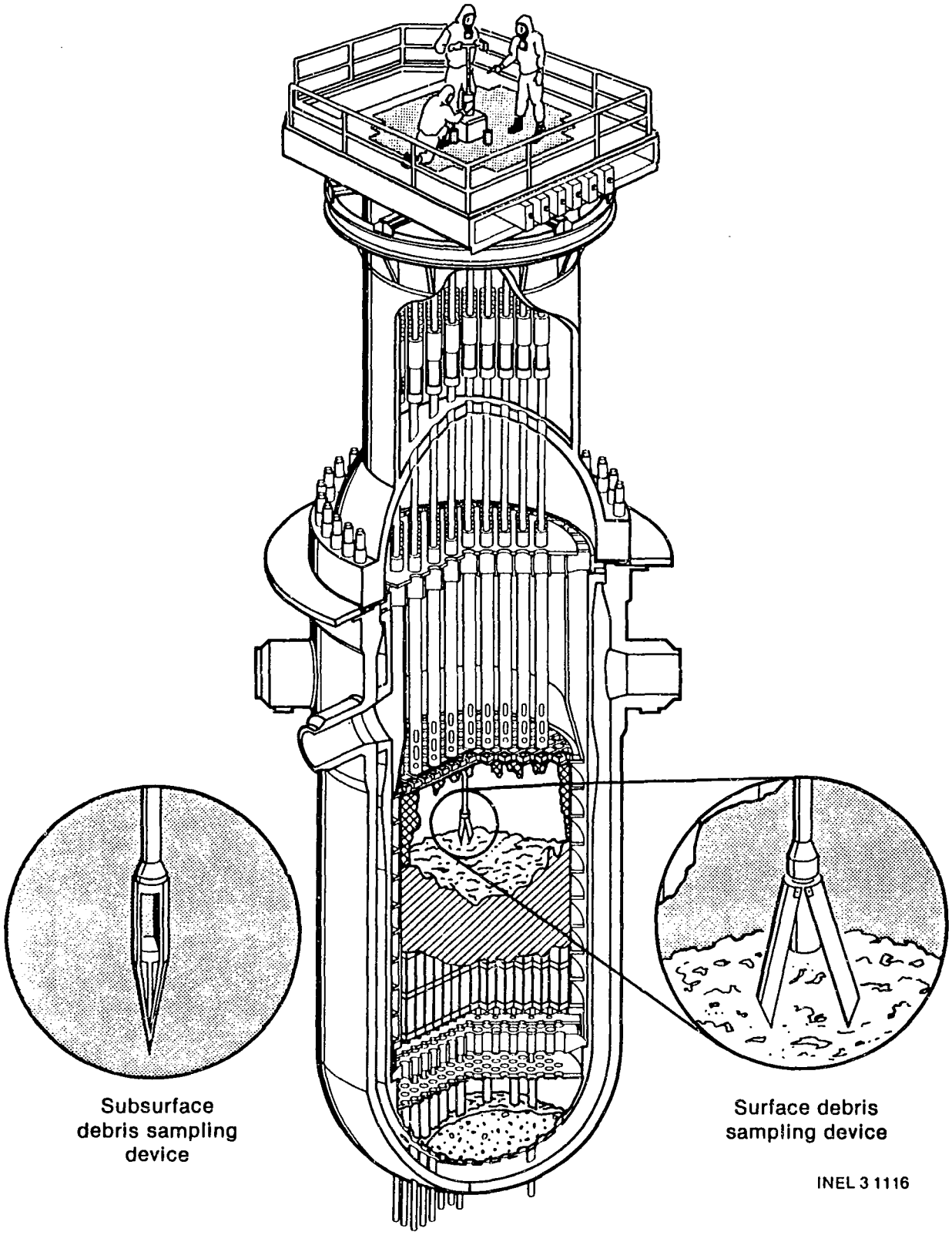

Figure C-1. TMI-2 core debris sampling schematic.

Table C-13. Average radionuclide concentrations in core debris samples[a] (μCi/cm^2)

Radionuclide	Average Radionuclide Concentration				
	Sample No. 1 H8-Surface (23.6 g)	Sample No. 3 H8-22 Inches (50.10 g)	Sample No. 4 E9-Surface (5.1 g)	Sample No. 5 E9-3 Inches (16.6 g)	Sample No. 6 E9-22 Inches (44.43 g)
^{60}Co	5.0 ± 0.1 E+1	2.1 ± 0.08 E+1	5.7 ± 0.1 E+1	4.7 ± 0.1 E+1	3.9 ± 0.1 E+1
^{90}Sr[b]	2.1 E+3	4.3 E+3	4.5 E+3	3.1 E+3	6.0 E+2
^{106}Ru	4.9 ± 0.1 E+2	8.7 ± 2 E+2	7.1 ± 0.1 E+2	1.01 ± 0.02 E+3	5.7 ± 0.2 E+2
^{125}Sb	1.19 ± 0.03 E+2	1.27 ± 0.03 E+2	8.2 ± 0.2 E+1	8.8 ± 0.2 E+1	1.04 ± 0.04 E+2
^{129}I[b]	5.6 E-4	3.8 E-4	2.4 E-4	5.9 E-4	4.2 E-4
^{134}Cs	6.7 ± 0.1 E+1	6.0 ± 0.1 E+1	2.44 ± 0.06 E+1	1.10 ± 0.02 E+2	8.9 ± 0.2 E+1
^{137}Cs	1.35 ± 0.01 E+3	1.44 ± 0.01 E+3	4.79 ± 0.02 E+2	2.45 ± 0.02 E+3	2.19 ± 0.01 E+3
^{144}Cd	2.9 ± 0.2 E+3	3.0 ± 2.0 E+3	3.6 ± 0.1 E+3	3.06 ± 0.02 E+3	2.43 ± 0.02 E+3
^{154}Eu	5.4 ± 0.2 E+1	5.4 ± 0.2 E+1	5.5 ± 0.3 E+1	4.9 ± 0.3 E+1	3.0 ± 0.2 E+1

a. Data decay corrected to March 1984. Errors reflect counting statistics only.

b. ^{90}Sr and ^{129}I analysis data obtained from a sample weighted data evaluation of individual particle and aliquot results.

from analytical results and presented here assume that volume and mass reductions of each resin bed are equal. However, there could be a 50% uncertainty in the calculations of the density and volume of the resin.

Radionuclide inventory estimates are based on resin radionuclide concentrations, physical dimensions of the demineralizers, visual inspection of the "A" demineralizer during sampling, and measurements of bed dimensions obtained during sampling. Radionuclide concentrations of resin and liquid samples are shown in Table C-15. Uncertainties are not reported for radionuclide concentrations of the demineralizer samples, but a standard deviation of the two samples from the "B" demineralizers is used. The estimated radionuclide inventory for the demineralizers is shown in Table C-16; Table C-17 shows the estimated fraction of core inventory retained.

The radionuclide calculated to be the most significantly retained by the MUP demineralizers was I-129, at 2% of core inventory. One percent (1%) of the Cs-137 inventory was retained. The retention of some radionuclides by the demineralizers is based on only one sample of demineralizer resin, and further sampling of the resin and of the elution effluent obtained when the demineralizers were being backwashed to remove the fission product content is recommended to better define fission product retention by this system.

Table C-14. Fractions of core inventory retained in core debris bed[a]

Radionuclide	Average Radionuclide Concentrations in Core[b] (μCi/g)	Sample Weighted[c] Radionuclide Concentrations (μCi/g)	Fraction of Core Inventory Retained	
			In Entire Core	In Debris Bed[d]
^{90}Sr	5.30 E+3	3.0 ± 1.0 E+3[e]	6.0 ± 2.0 E-1	1.2 ± 0.4 E-1
^{106}Ru	9.20 E+2	7.0 ± 2.0 E+2	8.0 ± 2.0 E-1	1.6 ± 0.4 E-1
^{125}Sb	2.96 E+2	1.1 ± 0.2 E+2	3.8 ± 0.7 E-1	8.0 ± 1.0 E-2
^{129}I	1.83 E-2	4.0 ± 1.0 E-4[f]	2.4 ± 0.6 E-1	5.0 ± 1.0 E-2
^{134}Cs	2.96 E+2	8.0 ± 3.0 E-1	2.5 ± 0.9 E-1	5.0 ± 2.0 E-2
^{137}Cs	6.08 E+3	1.8 ± 0.7 E+3	3.0 ± 1.0 E-1	6.0 ± 2.0 E-2
^{144}Ce	2.20 E+3	2.8 ± 0.4 E+3	1.3 ± 0.2	2.6 ± 0.4 E-1
^{154}Eu	5.10 E+1	4.6 ± 0.9 E+1	9.0 ± 2.0 E-1	1.8 ± 0.4 E-1

a. Data decay corrected to March 1984.

b. Calculated from initial core inventory decayed to March 1, 1984. The inventory has been divided by the mass of the core (1.25×10^5 kg) to provide an average concentration per gram of core.

c. The sample weighted concentrations in column 3 are assumed to be representative of the entire core.

d. The debris bed is assumed to account for 20% of the core.

e. Preliminary estimate to be revised based upon bulk dissolution sample analysis results that were unavailable at the time of this report.

f. Estimate based upon individual particle and particle-size aliquots. The result may be low by as much as 50%.

Table C-15. Radionuclide concentrations in makeup and purification demineralizers[a] (μCi/cm^2)

	"A" Demineralizer	"B" Demineralizer[b]	
Radionuclide	Resin	Liquid	Resin
^{60}Co	1.8	—[c]	—[c]
^{90}Sr	2.0 E+2	1.2 ± 0.3 E+1	7.0 ± 3.0 E+2
^{125}Sb	6.0	—[c]	—[c]
^{129}I	1.7 E-2	—[c]	—[c]
^{134}Cs	1.1 E+1	1.1 ± 0.4 E+2	7.0 ± 2.0 E+2
^{137}Cs	2.2 E+2	2.1 ± 0.8 E+3	1.4 ± 0.4 E+4
^{144}Ce	4.7	—[c]	—[c]

a. Data decay corrected to March 1984.

b. Uncertainties are standard deviation of two measurements.

c. Not detected.

Table C-16. Radionuclide inventories in makeup and purification demineralizers[a] (Ci)

Radionuclide	"A" Demineralizer Resin[b]	"B" Demineralizer Liquid[c]	"B" Demineralizer Resin[d]	Total
^{60}Co	7.0 ± 4.0 E-1	—[e]	—[e]	—[e]
^{90}Sr	8.0 ± 4.0 E+1	7.0 ± 3.0	3.0 ± 2.0 E+2	4.0 ± 2.0 E+2
^{125}Sb	3.0 ± 2.0	—[e]	—[e]	—[e]
^{129}I	7.0 ± 4.0 E-3	—[e]	—[e]	—[e]
^{134}Cs	5.0 ± 3.0	6.0 ± 3.0 E+1	3.0 ± 2 E+2	4.0 ± 2.0 E+2
^{137}Cs	9.0 ± 5.0 E+1	1.1 ± 0.6 E+3	5.0 ± 3.0 E+3	6.0 ± 3.0 E+3
^{144}Ce	2.0 ± 1.0	—[e]	—[e]	—[e]

a. Data decay corrected to March 1984.

b. Assume 4.1 E+5 g of resin with a 50% uncertainty.

c. Assume 3.56 E+5 g of water above the resin and a void volume of 1.87 E+5 cm^3 (35% as in new resin).

d. Assume 3.6 E+5 g of resin with a 50% uncertainty.

e. Not measured.

Table C-17. Fraction of core inventory retained in the makeup and purification demineralizers[a] (Ci)

Radionuclide	"A" Demineralizer Resin	"B" Demineralizer Liquid and Resin	Total
^{90}Sr	1.2 ± 0.6 E-4	4.6 ± 0.3 E-4	6.0 ± 3.0 E-4
^{125}Sb	8.1 ± 3.0 E-5	—[b]	7.0 ± 3.0 E-5[c]
^{129}I	3.0 ± 1.0 E-2	—[b]	2.0 ± 1.0 E-2[c]
^{134}Cs	1.4 ± 0.5 E-4	1.0 ± 0.6 E-2	1.0 ± 0.5 E-2
^{137}Cs	1.2 ± 0.6 E-4	8.6 ± 5.0 E-3	8.0 ± 5 E-3
^{144}Ce	7.3 ± 4.0 E-6	—[b]	7.0 ± 4.0 E-6[c]

a. Data decay corrected to March 1984.

b. Not measured.

c. Total based on "A" demineralizer results only.

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