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INFORMAL REPORT

TMI-2 ACCIDENT EVALUATION PROGRAM SAMPLE ACQUISITION AND EXAMINATION PLAN

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EG&G Idaho

Work performed under DOE Contract No. DE-AC07-76ID01570

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1. INTRODUCTION

1.1 Purpose and Intent

The purpose of the TMI-2 Accident Evaluation Program Sample Acquisition and Examination (TMI-2 AEP SA&E) program is to develop and implement a test and inspection plan that completes the current-condition characterization of (a) the TMI-2 equipment that may have been damaged by the core damage events and (b) the TMI-2 core fission product inventory. The characterization program includes both sample acquisitions and examinations and in situ measurements. Fission product characterization involves locating the fission products as well as determining their chemical form and determining material association.

The intent of the TMI-2 AEP SA&E Plan documentation is to describe the TMI-2 Sample Acquisition and Examination Plan in a manner that provides sufficient information for "stand alone" comprehensiveness. The SA&E Plan description is furnished in two versions, an abridged version (Executive Summary) for external distribution, and this detailed unabridged version primarily for internal use as a reference manual.

1.2 Project Genesis

The TMI-2 Sample Acquisition and Examination will be accomplished in accordance with United States Department of Energy contractor business practices. These practices require rigorous project planning, control, and reporting to assure that government-funded research programs are accomplished in a way that maximizes research results and the effective utilization of program resources. The TMI-2 AEP SA&E Plan will provide those assurances.

This Plan is part of the EG&G Idaho, Inc. TMI-2 Programs project which is described in the EG&G Idaho, Inc. TMI-2 Programs Division Master Plan, Revision 4, dated October 31, 1985. Included in this Master Plan is an outline of the EG&G Idaho, Inc. TMI-2 Programs Work Breakdown Structure (WBS). The SA&E program is composed of two (Level 4) elements; Sample Acquisition (WBS No. 751400000) and Sample Examination (WBS No. 755400000). These two elements are within the (Level 2 WBS No. 75B000000) TMI-2 Accident Evaluation Program.

The TMI-2 Accident Evaluation Program will accomplish the Department of Energy's program objectives of understanding the TMI-2 accident, disseminating this knowledge to the nuclear industry, and aiding in the resolution of severe accident and source term issues. The program's work is divided into four elements:

1. Examination Requirements and Systems Evaluation

2. Sample Acquisition and Examination

3. Data Reduction and Qualification[a]

4. Information and Industry Coordination.

The Examination Requirements and Systems Evaluations element is responsible for defining program scope and technical objectives, defining sample acquisition and examination data requirements, determining the accident scenario, and providing a standard problem and applying the research results to aid in the resolution of the severe accident source term issues. The Sample Acquisition and Examination element is responsible for obtaining the samples specified by the Examination Requirements and Systems Evaluation element from the TMI site, for examination of the samples, and for reporting the examination results. Data Reduction and Qualification is responsible

a. Analytical and Experimental Support in Revision 4 of the Master Plan.

for developing and maintaining the TMI-2 data base and for evaluating and qualifying online instrumentation and recorded data. Information and Industry Coordination is responsible for information transfer, coordination of review and consulting groups, interface with other source term research programs, and coordination of the TMI-2 standard problem exercise.

The tasks within the four work elements are designed to accomplish the following technical objectives:

- Identify and quantify the parameters and processes which controlled the progression of core damage and damage to the lower core support assembly, instrument penetration nozzles and guide tubes, and possibly to the reactor vessel lower head,

- Determine the plant-wide fission product behavior (source term), concentrating on release from the fuel and transport and retention in the primary cooling system,

- Provide a data base that contains the examination (and analysis) results,

- Provide a standard problem of the TMI-2 accident that includes the examination results and against which the severe accident analysis codes and methodologies can be benchmarked,

- Apply the TMI-2 accident evaluation research toward resolution of severe accident source term technical issues.

The Sample Acquisition and Examination element is specifically responsible for the collection of sample materials from the TMI-2 plant, the examination of those samples (to provide the data specified by the Examination Requirements and Systems Evaluation element), the interpretation and reporting of the examination results, and the coordination of examination activities at other laboratories. This program element is also responsible for providing engineering support for the sampling activities and for sample shipment.

1.3 Background and History

Although the March 28, 1979 accident at Three Mile Island Unit 2 (TMI-2) involved severe damage to the core of the reactor, it had minimal effects on the health and safety of the public in the area.[1] That such a severe core disruption accident would have no consequent health or safety effects has resulted in the questioning of numerous aspects of light water reactor (LWR) safety. In an effort to resolve these questions, several major research programs have been initiated by a variety of organizations concerned with nuclear power safety. The U.S. Nuclear Regulatory Commission (NRC) has embarked on a thorough review of reactor safety issues, particularly the causes and effects of core damage accidents. Industrial organizations are conducting the Industry Degraded Core Rulemaking (IDCOR) program. The U.S. Department of Energy (DOE) has established the TMI-2 Program to develop technology for recovery from a serious reactor accident and to conduct relevant research and development that will substantially enhance nuclear power plant safety.

Immediately after the TMI-2 accident, four organizations with interests in both plant recovery and accident data acquisition formally agreed to cooperate in these areas. These organizations, commonly referred to as the GEND Group--General Public Utilities, Electric Power Research Institute, Nuclear Regulatory Commission, and Department of Energy--are presently actively involved in reactor recovery and accident research. At present, DOE is providing a portion of the funds for reactor recovery (in those areas where accident recovery knowledge will be of generic benefit to the U.S. light water reactor industry) as well as the preponderance of funds for severe accident technical data acquisition (such as the examination of the damaged core). However, the core examination, rather than being an open-ended program of scientific inquiry, must be well planned and executed and must be designed to meet specific technical objectives.

The EG&G involvement with the TMI-2 accident has been continuous, initially providing technical support and consultation from the Idaho National Engineering Laboratory (INEL). In 1979 EG&G received an assignment from DOE to collect, analyze, distribute, and preserve significant technical information available from TMI-2. In 1981, the technical information assignment was expanded to include conducting research and development activities intended to effectively exploit the generic research and development challenges at TMI-2. In conjunction with this expanded assignment, an organization element for Offsite Core Examination was developed. This evolution continued, and in January 1985 DOE agreed to expand the EG&G involvement to include an evaluation of the TMI-2 accident that would develop an understanding of the accident sequence-of-events in the area of core damage and escape of core radionuclides (fission products) and materials. The TMI-2 Accident Evaluation Program document, which will be published at a later date, implements the January 1985 agreement, defines the program required to understand the accident, and contains the guidelines and requirements for TMI-2 sample acquisition and examination.

The TMI-2 AEP SA&E Plan evolved from the requirements set forth in the TMI-2 Accident Evaluation Program document. The program description provides the guidelines for the post-accident core condition and fission product inventory characterization. The SA&E program has been underway since the TMI-2 accident. Examination requirements documents written previously include the GEND Planning Report 001[2] and the TMI-2 Core Examination Plan.[3] The current program description document is an extension of the preceding examination requirements documents with appropriate additions and changes to account for our enhanced understanding of the TMI-2 accident and the resultant refinements in sample and examination requirements.

The already-completed portion of this SA&E program includes in situ measurements and sample acquisition and examinations involving private organizations and state and federal agencies. It has provided the post-accident core and fission product end-state data that indicate the following:

1. Large regions of the core exceeded cladding melting (~2200 K), and significant fuel liquefaction by molten zircaloy and some fuel melting occurred with temperatures up to at least 3100 K.

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The already-completed portion of this SA&E program includes in situ measurements and sample acquisition and examinations involving private organizations and state and federal agencies. It has provided the post-accident core and fission product end-state data that indicate the following:

1. Large regions of the core exceeded cladding melting (~2200 K), and significant fuel liquefaction by molten zircaloy and some fuel melting occurred with temperatures up to at least 3100 K.

2. Core materials relocated into the reactor vessel lower plenum region from the core, leaving a void in the upper core region equivalent to approximately 26% of the original core volume. Between two and twenty metric tons of core and structural materials now reside in the space between the reactor vessel bottom head and the elliptical flow distributor.

3. Fission product retention in core materials is significant, and the retention of fission products outside the core was primarily in reactor cooling system (RCS) water, water in the basement, and in basement sediment.

Significant consequences resulting from these findings include (a) increased technical interest in the TMI-2 accident because it represents a severe core damage (SCD) event in full-scale and provides evidence of a large inconsistency in the understanding of SCD event offsite radiation release, (b) a reconsideration of the plans and equipment for defueling the TMI-2 reactor, and (c) an expansion in the TMI-2 accident examination plan to determine the consequences of high temperature interactions between core materials and reactor vessel lower plenum structural and pressure boundary components and to determine the release from the fuel of the lower volatility fission products.

Section 2 of this report contains an overview of the guidelines and requirements set forth in the TMI-2 Accident Evaluation Program document, continuing with a description of what would be required to meet these guidelines and requirements, and concluding with a proposal for sample acquisition and examination tasks that can be accomplished within the available resources. Sections 3, 4, and 5 contain details of the proposed SA&E tasks. Section 6 summarizes the technical and administrative support for management of the SA&E Program. Section 7 is a summary containing the cost and schedules for the proposed SA&E Program and the summary description of how the authorizing of the performance of work further subdivides the work breakdown structure and provides controls during the work accomplishment.

2. OVERVIEW

2.1 Overview of SA&E Requirements from the Accident Evaluation Program Document

The TMI-2 Accident Evaluation Program document states that substantial contributions can be made to the resolution of severe core damage (SCD) accident technical issues by developing an understanding of the TMI-2 accident sequence and consequences. These issues were combined into three broad technical areas: reactor system thermal hydraulics, core damage progression and reactor vessel failure, and fission product release and transport.

Table 1 in the Accident Evaluation Program document lists the technical issues to be addressed in TMI research. To ensure optimum results from the available program resources, the technical issues were prioritized as shown in Table 1 below. Two prioritization criteria were used. The first criterion is the potential of the TMI-2 sample examination data to directly enhance the understanding of each issue. Issues that could be addressed directly using data that can be obtained from TMI were prioritized as high. Low or medium priority was assigned to issues that could not be directly addressed using TMI-2 data. The second prioritization criterion is based on the relative importance of each issue to enhance the understanding of severe accident source terms. These second priorities were obtained from recommended priorities from independent industry research and from engineering judgment of the relationship of the technical issues to the environmental source term.

The sample acquisition and examination tasks will provide data to identify and quantify the mechanisms controlling core damage progression and fission product release, transport, and retention. The basic data needs, associated samples from the plant, and the overall priority of the acquisition and examination tasks are summarized in Table 2. The relative priority of the acquisition tasks is based on a subjective weighting of the associated technical issues, applicability of the TMI-2 data to the issues,

TABLE 1. PRIORITIZED LIST OF TECHNICAL ISSUES TO BE ADDRESSED VIA TMI RESEARCH

	Application of Data to Issue	Priority
Reactor System Thermal Hydraulics		
1. Coupling between core degradation, reactor vessel hydraulics, and fission product behavior (Integrated severe accident code)	Direct	High
2. Reactor system natural convection	Indirect	Medium
Core Damage Progression and Reactor Vessel Failure		
1. Damage progression in core	Direct	High
2. Core slump and collapse	Direct	High
3. Reactor vessel failure modes	Direct	High
4. Hydrogen generation after core disruption	Indirect	Medium
5. Alpha mode containment failure[a]	Direct	High
Fission Product Release and Transport		
1. Release of low-volatility fission products during fuel degradation	Direct, Indirect	High
2. Chemical reactions affecting fission product transport	Indirect	High
3. Tellurium behavior	Indirect	High
4. Fission product and aerosol deposition in the reactor cooling system	Indirect	Low
5. Release of control rod materials	Direct	High
6. Aerosol generation mechanisms	Direct, Indirect	High
7. Revaporization of fission products in the upper plenum	Indirect	Low
8. Core-concrete interaction	Indirect	Medium

a. Steam-explosion-accelerated missile penetration of reactor building wall.

TABLE 2. PRIORITIZED LIST OF TMI DATA NEEDS AND SAMPLE ACQUISITION TASKS

Primary Data Needs from TMI-2	Sample Data Acquisition Tasks	Prioritization Criteria: Technical Issue(s) Priority[a]	Prioritization Criteria: Data Applicability to Issue	Prioritization Criteria: Data Applicability for Establishing Consistent Accident Scenario	Overall Priority of Acquisition Task	Comments
1. Gross structure of core, core support structures, instrument structures, RV lower head.	a. Video probe data through core bore channels (core and lower plenum).	High	High	High	High	a. Video inspections are high priority information needs.
	b. Topography of core and lower plenum regions.	High	High	High	High	b. Acoustic characterization of hardpan below debris bed is planned.
	c. Acquisition of core bores.	High	High	High	High	c. Qualitative data from core boring will provide valuable insights into damage.
2. Peak temperature, core and core support materials interactions, and core boundary structures.	a. Distinct fuel assembly samples.	High	High	High	High	a. Will provide data on core boundary conditions (radially), control and poison rod behavior, and fuel degradation.
	b. Core bore samples plus video characterization to correlate with examination results.	High	High	High	High	b. Core bores are primary samples for determining temperatures, materials, and fission products vs location in the core and lower plenum.
	c. Large volume samples of core and lower plenum debris.	High	High	High	High	c. Necessary for extrapolating smaller sample material and fission product data and for debris bed characterization.
	d. Core former wall samples.	High	Medium	Medium	Medium-high	d. May not be required if intact.
	e. Core support assembly samples.	High	High	High	High	e. Extent of damage (chemical and thermal interactions) needs to be determined.
	f. Instrument structures samples.	High	High	High	High	f. Very important to assess vessel failure modes.
	g. Reactor vessel wall samples.	High	Medium	Medium	Medium-High	g. May not be required if undamaged.
	h. Fuel assembly upper grid and/or end boxes.	High	Medium	Medium	Medium	h. Judged to be important in establishing core boundary conditions.
	i. Fuel rod segments from upper core region.	High	Medium	Low	Medium	i. Important for fission product release, local oxidation.

TABLE 2. (continued)

Primary Data Needs from TMI-2	Sample Data Acquisition Tasks	Prioritization Criteria: Technical Issue(s) Priority[a]	Prioritization Criteria: Data Applicability to Issue	Prioritization Criteria: Data Applicability for Establishing Consistent Accident Scenario	Overall Priority of Acquisition Task	Comments
3. Fission Product Release and Transport						
A. Retained fission products in core materials.	a. Distinct fuel assembly samples.	High	High	High	High	a. Sufficient examinations are required for characterizing the retained fission products (important high and low volatility species).
	b. Core bore samples.	High	High	High	High	b. Core bore samples are primary sources of data from core and lower plenum.
	c. Large volume samples of core and lower plenum debris.	High	High	High	High	c. Large volume samples necessary to increase detectability limit for some important radioisotopes.
B. Retained fission products on primary cooling system surfaces.	a. Upper plenum surface samples.	Medium-High[c]	Medium-Low	Medium	Medium	a. Surface deposition is important; however, only undissolvable component remains and is known to be very small. Additional data on horizontal surfaces would be used for evaluating separate effects experiments.
	b. Primary cooling surface samples. • Access covers from steam generators and pressurizer. • Sediment from steam generators and pressurizer. • RTD thermowells.	Medium-High[c]	Low	Medium	Medium	b. Surface deposition is important; however, only undissolvable component remains and is known to be very small. Samples from accessible locations will complete RCS inventory. Sample locations include A- and B- loop steam generators, manhole access covers (surface deposits and any accessible sediment), pressurizer, and hot leg RTD thermowells.
C. Retained fission products in containment basement.	a. Sludge samples.	High[b]	Low[b]	High	High-Medium	a. Major final fission product repositories are known to be the reactor vessel and the containment basement. Uncertainty in containment inventory is still large.
	b. Basement concrete wall samples.	High[b]	Low[b]	High	High-Medium	b. Major final fission product repositories are known to be the reactor vessel and the containment basement. Uncertainty in containment inventory is still large.
D. Retained fission products in transport pathway outside the reactor cooling system (RCS) excluding the containment basement.	None specified.[e]	High[b]	Low[b]	Medium	Low[d]	a. These examinations and data are primarily for definition of the accident scenario. The existing data requires more evaluation to 1) integrate the information into the accident scenario and 2) determine the need for additional samples/data.

TABLE 2. (continued)

Primary Data Needs from TMI-2	Sample Data Acquisition Tasks	Prioritization Criteria: Technical Issue(s) Priority[a]	Prioritization Criteria: Data Applicability to Issue	Prioritization Criteria: Data Applicability for Establishing Consistent Accident Scenario	Overall Priority of Acquisition Task	Comments
E. Fission product chemical form	a. Fission product chemical form from all core material samples.	High	Medium	Medium	Medium-High	a. Applicability of data obtained to date to fission product chemical form during the accident needs confirmatory evaluation.
4. Reactor system natural convection	a. Upper plenum temperature distribution	Medium	Medium	Low	Medium-Low	a. Reactor system natural convection heating was low in TMI. The confounding effect of B pump transient will make it difficult to evaluate natural convection cells in the reactor vessel.
5. In-vessel coupling of core degradation, thermal hydraulics, and fission product deposition	Data acquisition tasks 2a, 2b, 2c, 2d, 2h	High	Medium	Medium	Medium-High	a. End-state characterization data will have to be coupled with qualified online plant data and reactor systems models to define consistent accident scenarios. Coupled phenomena can only be estimated from code sensitivity calculations.

a. The priority in general applies to the technical issue grouping from Table 9 of the September 1985 draft TMI-2 Accident Evaluation Program document.

b. Fission product retention in containment is a very high priority severe accident issue, but primarily for accidents where the core has penetrated the reactor vessel and there is significant interaction between the concrete and the concrete and the molten core, with vaporization or aerosol formation directly into the containment atmosphere. The TMI-2 accident did not progress to that stage.

c. This specific technical issue is rated as medium priority for all severe accidents except the interfacing systems LOCA or "V" sequence, for which it is rated high.

d. Ranking reflects our knowledge that highest concentrations of fission products are probably in the core material and the containment basement. Also, much of this portion of the fission product pathway has already been sampled.

e. This portion of the fission product transport pathway has been extensively sampled. Additional samples are not requested until a definite need is established.

and applicability of the data for establishing a consistent understanding of the accident. The prioritization process produced a list that assigns highest priority to samples and examinations that will provide data that directly characterize core damage progression and fission product release from the fuel. Next in relative importance are data that will characterize retained fission products in the containment basement, fission product chemical form, and structural damage within the lower plenum. The lowest priority data are those related to fission product retention in the primary cooling system and structural peak temperatures. Additional data to characterize the retention of fission products in the containment (excluding the basement) and auxiliary building transport pathways are not required at this time.

The sample acquisition tasks are listed in Table 3. This listing reflects the prioritization established in Table 2 as well as the availability of samples and the sequential need for the data to provide a consistent understanding of the accident. For instance, the core bore and associated video and acoustic information will provide data relevant to core damage progression and fission product retention in the core materials; therefore, these samples are listed before samples of the core support assembly (CSA) and lower plenum structures. Also, the CSA and lower plenum structural samples will not be available until the core has been removed from above the CSA.

The basic data/measurements listed in Table 2 consist of peak temperatures, physical and chemical state of the core and structural materials, physical and chemical interactions between the fission products, core, and structural materials, the chemical form and concentrations of the retained fission products in the core and reactor coolant system, and the fission product transport pathway within the containment and auxiliary building. The measurements are required in sufficient number to map the distribution of the characteristic being measured. The data/measurements needs are reviewed including prior TMI-2 Core Examination Plan accomplishments in the following paragraphs. The items are discussed in the order of priority listed in Table 3.

TABLE 3. SUMMARY OF PRIORITIZED SAMPLE ACQUISITION TASKS

1. Central core bore to the lower core support plate, and visual examination.

2. Central core bore to the lower head, and visual examination.

3. Large volume sample from the upper debris bed.

4. Topography of the crust below the debris bed.

5. Mid-radius core bores to the lower plenum (3 bores).

6. Local large volume samples of debris from the core support assembly region.

7. Local large volume samples of the debris resting in the bottom of the reactor vessel.

8. Two intact, part length fuel assemblies from control rod and poison rod locations.

9. Outer radius core bore to the lower core support plate.

10. Basement sediment samples.

11. Concrete samples from the containment basement walls and floor.

12. Reactor cooling system surface and sediment samples from A- and B-loop steam generators, pressurizer, hot leg RTD thermowells, and steam generator manway and handhole covers.

13. Samples of the interaction zone between core materials and the lower core support assembly.

14. Samples of the interaction zone between the instrument guide tube structures and core materials.

15. Samples of the interaction zone between the reactor vessel lower head surface and the lower core debris materials.

16. Samples of the interaction zone between the core former wall and the core.

17. Fission product retention on surfaces in the upper plenum.

18. Upper plenum leadscrews.

19. Upper end boxes, control rod spiders, and holddown springs from the top of the core.

20. Fuel rod segments from the debris bed.

Core Bore Samples (Table 3, Tasks 1, 2, 5, and 9). Core material samples are required that will allow multidimensional (axial, radial, azimuthal) interpretation of the core damage; i.e., cladding melting, fuel liquefaction and relocation, freezing of the molten core materials, and subsequent remelting and slumping of the core materials. This requirement necessitates a number of continuous axial samples of core materials through the core and lower plenum regions. Thirty core bore samples are identified: ten high, ten medium, and ten low priority samples.

The core bore removal will provide access into the lower core and plenum regions for closed-circuit television (CCTV) video probes. Acquisition of the core bores will provide access for insertion of the CCTV video camera into the center of the core and lower plenum. The CCTV will provide visual examinations of the extent of damage and guidance to possibly modify further core bore locations. The video data must be carefully keyed to reactor vessel position, and sufficient data must be taken to provide global views of the extent of damage and closeup views of the damaged core materials.

Core Debris Grab Samples (Table 3, Tasks 3, 6, 7). Grab samples from the upper core debris have been obtained and analyzed.[4] These small samples have provided significant physiochemical data to evaluate material interactions and fission product behavior. Eleven samples were retrieved, representing only about 0.005% of the estimated debris volume. The samples were generally quite homogeneous, but the relatively small concentration of some fission products has resulted in relatively large uncertainties in the measured concentrations. Additional larger volume samples are required from the upper core debris region to better quantify the retained fission products, particularly tellurium, and their physical and chemical state.

Debris samples (both small localized samples and larger volume samples) will also be obtained from the loose core material resting on the reactor vessel lower head and possibly from the lower core and/or core support regions (depending on the damage conditions). This material may vary significantly from the upper debris in physical and chemical composition and structure, particle size, and retained fission product. The physical and chemical properties of these materials in the various unique zones will be characterized. Large volume samples are required to increase the detectability of the fission products with low concentrations due to decay since the accident.

Topography of the Crust Below the Debris Bed (Table 3, Task 4). Visual and ultrasonic topography data will help characterize the frozen crust (previously molten core material) which is postulated to exist under the upper debris bed. Ultrasonic techniques similar to those used for mapping the upper core cavity will be used if practical.

Fuel Rod Segments From Distinct Fuel Assemblies (Table 3, Task 8). Examination of fuel rod segments from part length, relatively intact fuel assemblies from the core periphery will provide information on the radial progression of core damage as well as fission product retention over a wide range of fuel rod damage. Assemblies from control and poison rod positions are needed for examination. Intact rod segments will be extracted from the retrieved assemblies for detailed examination. These examinations will provide information on peak fuel rod temperature, materials interactions, retained fission products, and fission product chemical form. The core damage represented by these assemblies is representative of the damage gradient between the molten core and the relatively undamaged core former wall. Also, data on the effect on core damage of silver from control rod assemblies and of alumina from burnable poison rod assemblies will be available.

Retained Fission Products in Containment--Basement Sludge, Concrete Samples (Table 3, Tasks 10, 11). The primary remaining repositories for fission products at TMI-2 are thought to be the reactor vessel (primarily core materials) and the containment basement, particularly the sludge and the concrete walls. Sufficient samples of the basement sludge are needed to estimate the total inventory in the sludge and to characterize the fission products and the materials they are associated with. The current radioactivity in the basement and sludge samples suggests significant retention and activity from the basement concrete walls. Independent experiments have confirmed that the concrete is an efficient absorber of Cs. Sufficient samples of the basement walls and floor are necessary to estimate total fission product retention in the basement.

Fission Product Retention in Ex-Vessel Release Pathways (Table 3, Task 12). All present experience in characterizing the plant indicates relatively small fission product inventories remain in or on the surfaces of all pathways external to the reactor vessel. Additional examinations of samples from readily accessible locations are suggested to confirm these results. These include:

1. Manway/handhole covers for both A- and B-loop steam generators and sediment samples (if possible).

2. Resistance temperature detector (RTD) thermowells in the hot leg and sediment from the pressurizer.

Examinations on these samples will quantify the retained fission products, fission product chemical form, and the irreversible retention mechanisms, either physical or chemical.

Core Support Assembly Samples (Table 3, Task 13). The extent of CSA damage will be determined from visual inspection of the lower plenum and core support assembly regions through the core bore channels as well as from selected samples of the CSA obtained during defueling. Samples of the core support assembly are needed to determine peak temperatures and the important interactions between the core materials and the stainless steel structures. Sample selection will be based on knowledge gained from the core bores and the follow-up video examination data.

Reactor Vessel Samples (Table 3, Tasks 14, 15). The current understanding of the interactions between molten core materials and the reactor vessel suggests that the mode of vessel failure would be melting of the instrument penetration nozzles. Samples of the instrument penetration nozzles are required to determine the extent of damage to these structures and to estimate the margin to failure of the vessel. Samples from the instrumentation penetration nozzles at the vessel center and mid-radius locations should be sufficient.

The condition of the reactor vessel is not known, and our understanding of thermal/hydraulic/mechanical details of the core melt progression and ultimate attack on the vessel walls is not complete. These data requirements will be further substantiated as defueling progresses and examination data becomes available, i.e., data from the core bores, and lower plenum volume samples. Visual examination of the vessel wall after defueling is desirable to obtain samples of the reactor vessel wall at locations other than the instrument penetrations. These data needs will be further refined from the vessel failure models as these models are developed.

Core Former Wall (Table 3, Task 16). The core former wall appears to be basically intact in the upper regions of the core. However, below the core mid-plane the extent of damage is not known. If severe damage to the core former walls becomes evident during core defueling, detailed video and acoustic mapping of the damage zones will be necessary, and samples of the walls will be needed to determine the mode of damage and the material interactions. Sample locations will be specified when the severe damage is evident.

Upper Plenum Surface Temperatures and Deposition (Table 3, Tasks 17, 18). The upper plenum surface temperatures are necessary to assess the relative importance and effect of natural convection and multidimensional flow patterns within the reactor vessel on core heatup and fission product transport/retention within the RCS. Previous examinations of two control rod leadscrews indicate axial temperature differences of approximately 500 K (top to bottom) and radial temperature differences (i.e., core center to periphery) of approximately 250 K. These data, in conjunction with the damage profile of the upper core support plate and structure of the debris bed, are probably sufficient to address the technical issues associated with reactor vessel natural circulation. However, additional samples of structural surfaces are needed to complete characterization of the retained fission products. The upper plenum is probably not a significant repository for fission products, so these samples and examinations are judged to be of lower priority.

2.2 Development of Sample Acquisition and Examination Plan

Table 4 is a summary of the in situ measurements and sample acquisitions and examinations that satisfy the technical information needs identified in the TMI-2 Accident Evaluation Program document and listed in Table 2. Table 4 includes prior year sample acquisitions and examinations and in situ measurements for completeness. The Sample Acquisition and Examination Plan includes:

1. Acquisition of all samples, distinct components, and in situ measurements listed in the Future Additional Samples column under Quantity.

2. Sample examination and in situ measurement analysis of those items listed in the Proposed Future Exams column. Only the high priority tasks can be accomplished within the allocated resources. Selection was made using the examination priority list shown in Table 3.

The plans for sample acquisition and in situ measurements were developed based on the policy of retrieving samples and making in situ measurements in conjunction with the GPU Nuclear decontamination and defueling program for the TMI-2 facility. Some decontamination and defueling program plans are currently uncertain, primarily because of budget and/or technical uncertainties. The technical uncertainties include the methods and procedures for removal of the fused core and structural materials from the core and reactor vessel lower plenum regions. The GPU Nuclear TMI-2 decontamination and defueling program includes the following:

1. An auxiliary and fuel handling building decontamination program.

TABLE 4. TMI-2 ACCIDENT EVALUATION IN SITU MEASUREMENTS AND SAMPLE ACQUISITIONS AND EXAMINATIONS

Measurement/Examination Activity	Quantity: Completed Exams	Quantity: Future Additional Samples	Quantity: Proposed Future Exams	Priority[a]	Examiner[a]	Justification/Information
A. Reactor vessel visual examination						Explain accident scenario and support sample selection.
1. Closed circuit television surveys	3 areas[a]	NA	1 area	1	REP/AEP	Determine lower core support structure ablation and approximate location and volume of internal cavities.
2. Periscope survey	0	NA	1 area	4	REP	Improved images of loose debris in core cavity region.
3. Sonar topography survey	1 area	NA	1 area	-	REP/AEP	Core cavity dimensions after loose debris and distinct core component removal.
B. Core bore samples of fused/joined core material						Determine condition and quantity of fused/joined core material under loose debris and between core and reactor vessel head.
1. Under loose debris	0	up to 12	3	1, 5, 9	AEP-INEL	Determine retained fission product concentration and chemical form.
2. Subcore	0	up to 18	5	2, 5, 9	NRC-[illegible][c]	
C. Core distinct components						
1. Upper core region						
a. 6-in. fuel rod segments from core cavity periphery	0	6	0	20	--[b]	Determine condition of unrelocated fuel rods in upper core region. In situ separation of segments. Reduce uncertainty in retained fission product inventory (especially tellurium) from previous grab sample examination.
b. Small grab samples from upper core debris	11	4	0	--		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 will be performed in INEL hot cell.
c. Large grab samples from upper core debris	0	2	1	3		
d. Fuel assembly upper section:						
(1) Fuel rod segments from core cavity periphery fuel assembly remnants	0	25	4	8	AEP-INEL[b]	
(2) Guidetube/burnable poison rod (BPR) segments	0	5	1	8	AEP-INEL[b]	

TABLE 4. (continued)

Measurement/Examination Activity	Quantity: Completed Exams	Quantity: Future Additional Samples	Quantity: Proposed Future Exams	Priority[e]	Examiner[a]	Justification/Information
(3) Guidetube/control rod segments	0	5	1	8	AEP-INEL[b]	
(4) Instr. tube/instr. string segments	0	3	0	19	--[b]	
(5) Instrument tube segments	0	3	0	19	--[b]	
(6) Spacer grids	0	9	0	19	--[b]	
(7) Upper end boxes	0	16	0	19	--[b]	
(8) Holddown springs	0	14	0	19	--[b]	
e. Burnable poison rod spiders	0	6	0	19	--[b]	
f. Control rod spiders	0	7	0	19	--[b]	
g. Axial power shaping rod (APSR) spider surface deposit	0	1	0	19	--[b]	
2. Lower core region						Additional data needed to complete selection.
a. Fuel rod segments	0	TBD	4	TBD	AEP-INEL	
b. Guide tube/BPR segments	0	TBD	1	TBD	AEP-INEL	
c. Guide tube/control rod segments	0	TBD	1	TBD	AEP-INEL	May provide information on thermocouple junction relocation.
d. Inst. tube/instr. string segments	0	TBD	0	19	--[b]	
e. Instrument tube segments	0	TBD	0	19	--[b]	
f. Spacer grids	0	TBD	0	19	--[b]	
g. Lower end boxes	0	TBD	0	19	--[b]	
D. Lower Vessel Debris						
1. Core material samples from lower head region						
a. Small	0	10	10	7	REP-INEL NRC-ANLE	From 2 azimuthal locations via downcomer access.
b. Large		1	1	7	REP-INEL NRC ANLE	
2. Reactor vessel lower region gamma scans through instrument strings	0	--	--	--	--[b]	Ion-chamber survey of any of 35 unsurveyed core instrument string calibration tubes. Data may be convertible to location of fuel and nonfuel materials.
3. Samples of loose debris in lower core support structure region	0	1	1	6	AEP-INEL	Character of loose debris in lower core support structure region.

TABLE 4. (continued)

Measurement/Examination Activity	Quantity: Completed Exams	Quantity: Future Additional Samples	Quantity: Proposed Future Exams	Priority[a]	Examiner[a]	Justification/Information
E. Reactor vessel internals examinations						
1. Control rod leadscrews	2	7	0	18	--[b]	Fission product transport path, temperature gradient, and reactor vessel natural recirculation routes.
2. Core former wall samples	0	TBD	4	16	AEP-PL	Data for isotherm maps and materials interactions at core periphery.
3. Leadscrew support tube lower section	1	0	0	Low	AEP-BLL	Characterization of surface deposits in reactor vessel dome region.
4. Core lower support structure plate samples	0	TBD	6	13	AEP-PL	Data for isotherm maps and materials interactions along core material relocation path. Fission product inventory and materials interactions.
5. Reactor vessel lower head samples	0	TBD	2	15	AEP-PL	Data for isotherm maps and materials interactions.
6. Lower plenum horizontal surface deposits	0	TBD	0	17	--[b]	Fission product inventory data.
7. Lower plenum instrument structures	0	TBD	6	14	AEP-PL	Materials interactions.
F. Reactor coolant system (RCS) characterization						
1. RCS Gamma Scans						Capability to convert data to radionuclide and uranium abundance & location uncertain.
a. A-loop steam generator (external)	7	N/A	0	Low	GPUN/AEP	
b. Pressurizer (external)	6	N/A	0	Low	GPUN/AEP	
c. Core flood tank B	9	N/A	0	Low	GPUN/AEP	
d. Steam generator inside	0	N/A	TBD	Low	GPUN/AEP	
e. Pressurizer inside	0	N/A	TBD	Low	GPUN/AEP	
f. Pressurizer surge line	0	N/A	TBD	Low	GPUN/AEP	
g. Decay heat removal line	0	N/A	TBD	Low	GPUN/AEP	
h. Pump volutes	0	N/A	TBD	Low	GPUN/AEP	
i. Hot legs	0	N/A	TBD	Low	GPUN/AEP	
2. RCS adherent surface deposits						Adherent fission product deposits.
a. A-loop RTD thermowell	1	0	0	12		
b. B-loop RTD thermowell	0	1	1	12	AEP-PL	
c. A-loop steam generator handhole cover liner	0	1	1	12	AEP-PL	

TABLE 4. (continued)

Measurement/Examination Activity	Quantity: Completed Exams	Quantity: Future Additional Samples	Quantity: Proposed Future Exams	Priority[e]	Examiner[a]	Justification/Information
d. B-loop steam generator manway cover backing plate	0	1	1	12	AEP-PL	
e. Pressurizer manway cover backing plate	0	1	1	12	AEP-PL	
3. RCS sediment						
a. Steam generator tube sheet top loose debris	0	2	2	12	AEP-PL	Character of sediment in both steam generator upper heads.
b. Steam generator lower head loose debris	0	2	2	12	AEP-PL	GPU Nuclear project. Character of sediment in both steam generator lower heads.
c. Pressurizer sediment	0	1	1	12	AEP-PL	Character of sediment in pressurizer lower head.
6. Ex-reactor-coolant-system characterization						
1. Reactor building						
a. Liquid						Basement liquid has been drained and decontaminated.
(1) Basement 305 ft el.	110 ml	0	0	Low	AEP-INEL	
(2) Basement 325 ft el.	120 ml	0	0	Low	AEP-INEL	
(3) Bottom open stairwell	45 ml	0	0	Low	AEP-INEL/HEDL	
(4) Basement sump pit	200 ml	0	0	Low	AEP-INEL/HEDL	
(5) Reactor coolant drain tank (RCDT)	120 ml	0	0	Low	AEP-INEL/HEDL	
b. Sediment						Sediment includes Susquehanna River silt as well as core fission products and materials.
(1) Basement 305 ft el.	108 g	0	0	10	AEP-INEL	
(2) Basement 325 ft el.	25 g	0	0	10	AEP-INEL	
(3) Bottom open stairwell	1 g	0	0	10	AEP-INEL/HEDL	
(4) Basement sump pit	72 g	0	0	10	AEP-INEL/HEDL	
(5) Reactor coolant drain tank	0.5 mg	0	0	10	AEP-INEL/HEDL	
(6) Basement floor (282 ft el.)						
(a) RCDT discharge area	0	3	3	10	AEP-PL	
(b) Leakage cooler room, RCDT room, inside D-ring, outside D-ring areas	0	10	10	10	AEP-PL	

TABLE 4. (continued)

Measurement/Examination Activity	Quantity: Completed Exams	Quantity: Future Additional Samples	Quantity: Proposed Future Exams	Priority[a]	Examiner[a]	Justification/Information
(c) Core instrument cable chase	0	2	2	10	AEP-PL	
c. Concrete bores						
(1) Floors: 347 ft el.	8	0	0	Low	GPUN/AEP	
305 ft el.	6	0	0	"	GPUN/AEP	
282 ft el.	0	10	13	"	AEP-PL	GPUN proposal, bore depth not specified, after floor dewatering and desludging.
(2) D-ring walls: 347 ft el.	1	0	0	Low	GPUN/AEP	
305 ft el.	2	0	0	"	GPUN/AEP	
flooded region	3	8	3	"	AEP-PL	GPUN proposal, bore depth not specified.
(3) 3000 psi (shield) wall (flooded region)	3	8	3	"	AEP-PL	GPUN proposal, bore depth not specified.
(4) Block (elevator/stairwell) walls (flooded region)	3	8	3	"	AEP-PL	GPUN proposal, bore depth not specified.
d. Adherent surface deposits						
(1) Air cooler panels	5	0	0	Low	AEP-INEL	
(2) Basement outer wall steel liner	0	TBD	TBD	Low	AEP-PL	Acquisition and examination plan under consideration.
2. Auxiliary and fuel handling buildings						All equipment in the auxiliary and fuel handling buildings has been fully or partially decontaminated by flushing, filter removal, water treatment, and resin removal or treatment.
a. Liquid						
(1) Reactor coolant bleed Tank A	125 ml	0	0	Low	AEP-INEL	
(2) Reactor coolant bleed Tank B	150 ml	0	0	Low	AEP-INEL	
(3) Reactor coolant bleed Tank C	150 ml	0	0	Low	AEP-INEL	
(4) Makeup and purification demineralizer B	40 ml	0	0	Low	AEP-ORNL	
b. Sediment						
(1) Reactor coolant bleed Tank A	60 g	0	0	Low	AEP-INEL/HEDL	
(2) Makeup and purification demineralizer A (resin)	10 g	0	0	Low	AEP-ORNL	
(3) Makeup and purification demineralizer B (resin)	40 ml	0	0	Low	AEP-ORNL	
c. Filter housing contents (filter paper, liquid, and collected solids)						

TABLE 4. (continued)

Measurement/Examination Activity	Quantity			Priority[e]	Examiner[a]	Justification/Information
	Completed Exams	Future Additional Samples	Proposed Future Exams			
(1) Makeup and purification system						
(a) Demineralizer prefilters	both	0	0	Low	AEP-INEL/ LANL, NRC-ANLE	
(b) Demineralizer after filters	both	0	0	Low	AEP-INEL/ LANL, NRC-ANLE	
(2) RC pump seal water injection system filters	both	0	0	Low	AEP-INEL/ LANL, NRC-ANLE	

a. Examination responsibility is shown with the funding organization (AEP, REP, NRC, and/or GPUN) shown first (xxx/xxx indicates joint funding and/or performance responsibility), and the sample examination location shown second. Names of funding organizations are abbreviated as follows: Accident Evaluation Program, AEP; Reactor Evaluation Program, REP; Nuclear Regulatory Commission, NRC; GPU Nuclear, GPUN. Names of examination locations are abbreviated as follows: Idaho National Engineering Laboratory, INEL; Argonne National Laboratory-East, ANLE; Battelle Columbus Laboratories, BCL; Hanford Engineering Development Laboratory, HEDL; Oak Ridge National Laboratory, ORNL; Los Alamos National Laboratory, LANL. PL indicates an outside private laboratory is expected to perform the examination.

b. Possible examination by foreign laboratory, including funding.

c. Possible examination of two core bores and lower plenum debris by ANL using NRC funding.

d. Completed reactor vessel CCTV surveys include the following areas: all sides of the upper core region cavity, core cavity region loose debris after dislodging core components from plenum assembly, plenum assembly, and accessible areas of the downcomer and reactor vessel bottom head periphery regions.

e. Priority values 1 through 20 are listed in Table 3.

2. A reactor building decontamination program.

3. A reactor building basement contamination characterization program (see K. J. Hofstetter letter to D. M. Lake, 4240-85-0227, Reactor Building Sludge and Core Bore Samples, June 6, 1985).

4. A RCS fuel locating program (see J. C. DeVine letter to R. L. Freemerman, 4500-84-0738, Ex-vessel Fuel Locating Samples Packages, August 27, 1984).

5. A reactor vessel data acquisition program (see GPU Nuclear document TPO/TMI-117, In-Vessel Data Acquisition, September 1984).

6. The defueling program (see GPU Nuclear news release 38-85N, TMI-2 Defueling Schedule Updated, April 30, 1985).

An important part of the DOE TMI-2 Program is the Reactor Evaluation Program (REP), which supports the TMI-2 defueling program in the following areas:

1. Funding for special defueling tools.

2. Defueling operations, which will include both sample retrieval from the reactor vessel and collection of in situ measurement data such as CCTV surveys and ultrasonic scanner topography.

The responsibility for funding the tasks outlined in Table 4 is indicated in the table and includes GPU Nuclear, the DOE Accident Evaluation Program (AEP), and the DOE Reactor Evaluation Program (REP). Examinations will be performed at the Idaho National Engineering Laboratory (INEL), Argonne National Laboratory-East (ANL-E), other DOE laboratories, or private laboratories (PL). Work plans were developed for the tasks summarized in Table 4 under the assumption that after the samples have been retrieved at TMI-2, the handling, packaging, and shipping activities to the INEL will be funded by the REP-supported defueling program.

The development of the TMI-2 AEP SA&E Plan included consideration of the following assumptions:

1. The total budget allowance including prior years is $20.6M from the Department of Energy (DOE) and $600K from and administered by the Nuclear Regulatory Commission (NRC).

2. Sample retrieval and in situ measurements will be accomplished in conjunction with GPU Nuclear's TMI-2 recovery program and with support from the DOE TMI-2 Reactor Evaluation Program in the development of special defueling tools and the collection of defueling-operation-related samples and in situ measurements.

3. Prioritization of the information needs from the sample acquisition and examination tasks is as shown in Table 3. This prioritization is based on technical needs identified and discussed in the TMI-2 Accident Evaluation Program document. These are shown in Table 2.

4. The portions of the total budget to be allocated to laboratory examination of samples is: $918K to other DOE laboratories, $1.38M to private domestic laboratories, and $2.9M to EG&G laboratories. In addition, NRC will fund about 600K for other DOE laboratory examinations.

The proposed exam plan for the core bores includes examination of three upper core bores and five lower core bores. Examination of these eight core bore samples will yield information on the condition and quantity of the fused core materials beneath the loose debris and in the lower plenum. Data will also be obtained to determine fission product concentration and chemical form. However, with only three core locations being examined, only the axial and radial variation in these parameters will be determined. Measurement of azimuthal variation would require that more samples be examined.

Four fuel rod segments, two each from a part-length peripheral control rod assembly and a part-length peripheral burnable poison rod assembly, will be examined. One of the fuel rod segments will be obtained from a location near a control rod position, and one from a location not near a control rod position. The control rod remnant will also be obtained. Examination of these three (two fuel rods, one control rod) rod segments will help determine the effect of the failure of the control rod on the adjacent fuel rods. The examination of two fuel rods and one burnable poison rod remnant will be structured in a similar manner. Fuel rod segments from a burnable poison rod and a control rod assembly in the lower core region will also be obtained and examined, if possible.

The large debris sample from the debris bed below the upper cavity will help reduce the uncertainty in the retained fission products (especially tellurium) that was measured from the 11 grab samples already examined. Analysis of this large sample will also help determine the homogeneity of the upper debris bed and therefore the applicability of the data from the 11 small samples to the entire debris bed.

Eleven other small debris samples have been obtained from the lower vessel debris bed. Examination of these samples will indicate the fission product retention in a mixture of materials that probably contains more structural material than the the upper core debris bed. A large sample of this lower vessel debris will also be obtained and examined to determine homogeneity. Also, a large sample of loose debris will be obtained from the lower core support structure region if possible.

In order to determine fission product chemical form and fission product and aerosol interaction with structural materials, samples will be obtained from both the reactor coolant system and the EX-RCS. Samples of high priority in the EX-RCS are sediment samples and concrete samples from the containment building basement walls and floor. Samples of high priority in the reactor coolant system are adherent surface deposits on the B-loop RTD thermowell, the A-loop steam generator handhole cover liner, the B-loop steam generator manway cover backing plate, and the pressurizer manway cover backing plate. Sediment will be obtained for examination from the steam generator lower head, the top of the steam generator tube sheet, and the bottom of the pressurizer.

The proposed TMI-2 AEP Sample Acquisition and Examination work plan is divided into four work package categories as follows:

1. Reactor vessel, which includes the reactor vessel, its internal structures, and the core.

2. RCS fission product inventory, which includes the core materials and fission products now residing in the ex-vessel portion of the RCS, including the core flood tanks.

3. EX-RCS fission product inventory, which includes the core materials and fission products now residing in areas, buildings, and equipment external to the RCS.

4. Program management support, which includes personnel and services to plan, direct, and control the sample acquisition and examination program.

The three sample acquisition and examination implementation work package categories (1, 2, and 3 above) are further subdivided into sample acquisition and sample examination work packages because of the geographical separation of the respective support personnel and operations. The individual work packages provide the detailed scope of work, assumptions, products/deliverables, milestones, and prerequisites statements, logic diagrams (activity lists and schedules), and resource (labor and material) tabulations. The subdivision of the TMI-2 AEP SA&E Plan into the three TMI-2 nuclear power plant regions--reactor vessel, reactor coolant system, and external to the reactor coolant system (EX-RCS)--was selected to coincide with the GPU Nuclear TMI-2 fuel location and characterization program and with the chronological separation of the core damage sequence and the offsite radiation hazard during the TMI-2 accident.

The TMI-2 Sample Acquisition and Examination Program work packages are in two sets as follows:

1. A set of work packages which covers the list of sample acquisitions and examinations proposed for FY-1986.

2. A set of work packages which extends the proposed sample acquisitions and examinations to completion (FY-1988).

Detailed discussions of the four sample acquisition and examination work plans are contained in the next four sections of this report.

3. RV SAMPLE ACQUISITION AND EXAMINATION WORK PLAN

3.1 Introduction

The reactor vessel sample acquisition and examination work plan includes the reactor vessel, the nuclear reactor core and its support structures, the core instrument strings, including their support and ex-vessel conduit structures, and other reactor vessel (RV) internals. A diagram of the reactor vessel arrangement as it appeared before the commencement of core damage events is shown in Figure 1. A typical incore instrument assembly, including the ex-vessel conduit arrangement, is shown in Figure 2.

The RV sample acquisition and examination work plan was developed by considering the types of data needed to help resolve the major issues discussed in Section 2. Some of the information pertinent to developing the data acquisition plan is discussed in the following paragraphs. This information includes (a) applicable details of the TMI-2 accident sequence, and (b) available information on the current damage state within the reactor vessel.

At accident initiation, the TMI-2 core was in the initial fuel cycle at 97% of full power with 3175 MWD/MTU average core burnup. The critical time period of the accident sequence contributing to core damage progression and fission product release is believed to be between 103 and 210 minutes after the reactor tripped. 103 minutes corresponds to the beginning of core uncovery following phase separation of the primary coolant, when the last of the reactor coolant pumps was turned off in the A-loop at 101 minutes. 210 minutes corresponds to the approximate time of core refill following the resumption of sustained high-pressure injection, which occurred at about 200 minutes and resulted for the most part in termination of core heatup. During this period, several events occurred in the sequence that are pertinent to the scope of this section. At 135 minutes, the reactor building air sample particulate monitor went off-scale, indicating some core damage. At 142 minutes, the operators closed the pilot-operated relief

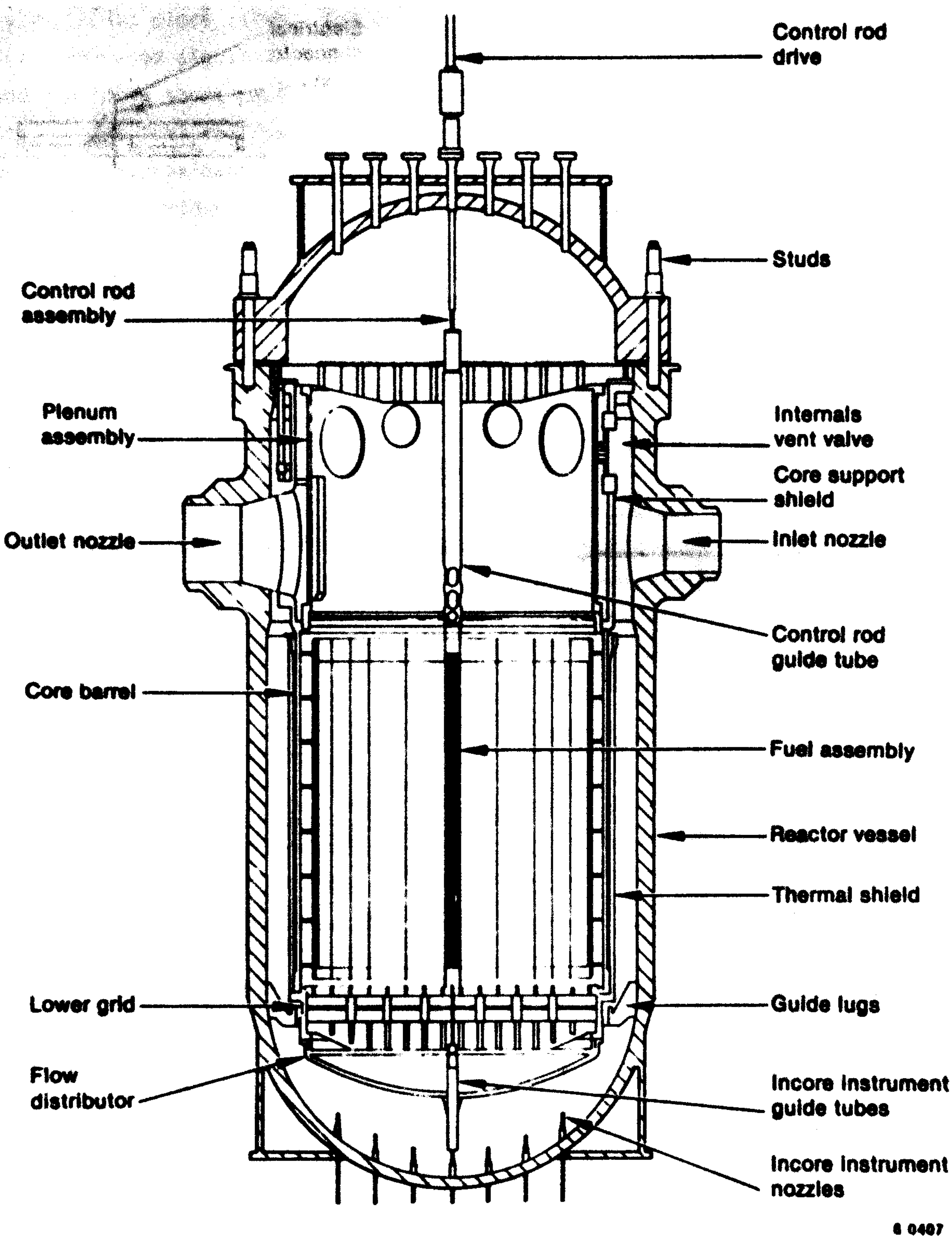


Figure 1. General arrangement of TMI-2 reactor vessel and internals.

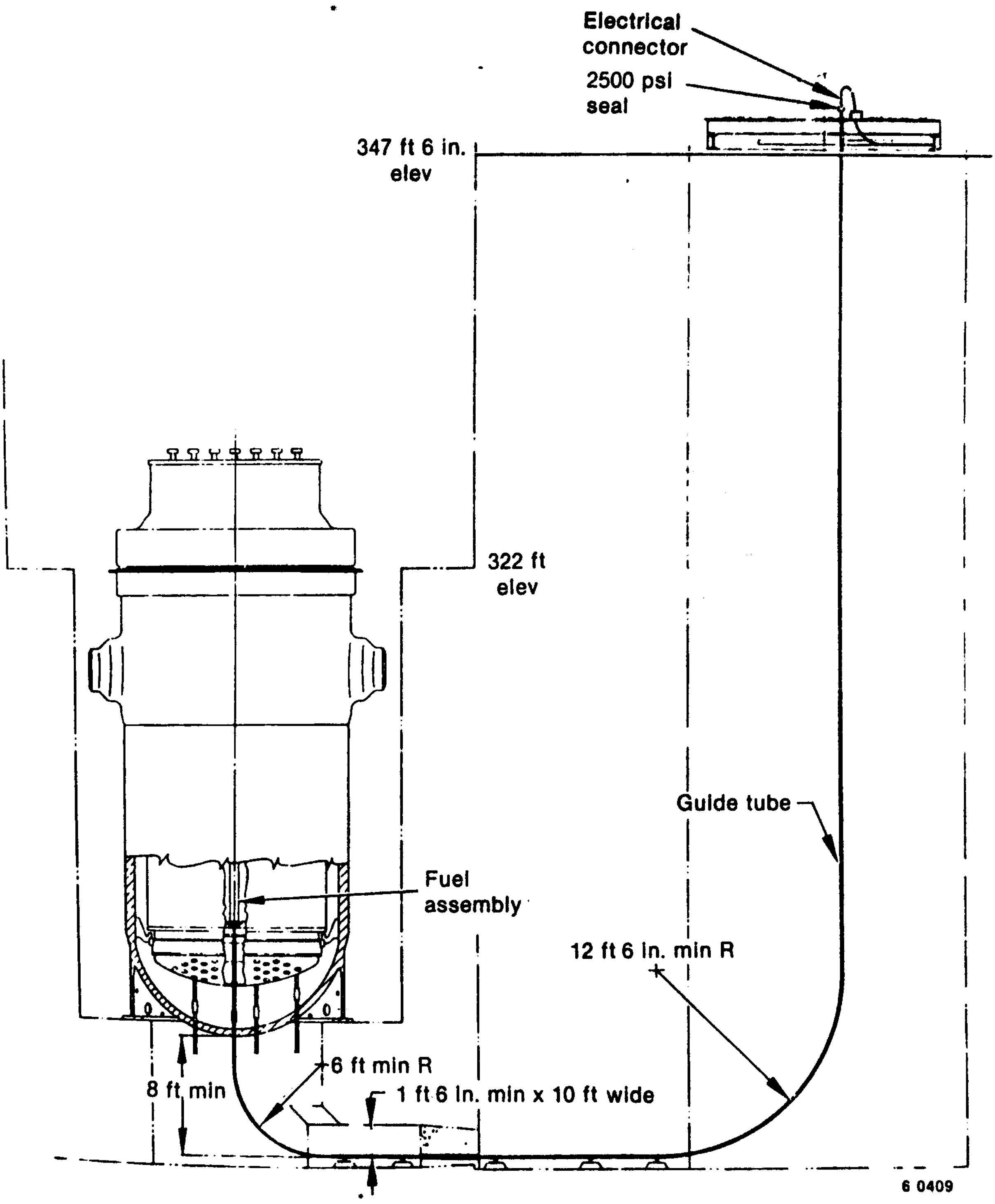


Figure 2. Schematic of typical incore instrument assembly.

valve (PORV) block valve. Following additional radiation detector responses that indicated significant core damage, reactor coolant pump 2B was started and run for a short period, forcing water through the core and causing significant fuel rod fracturing. The PORV block valve was reopened for a period of approximately 5 minutes at 192 minutes. This sequence of events defines the accident time period of interest here and identifies fission product escape pathways to the containment building.

The current state of the reactor core, support structures, and reactor vessel, as determined from various examinations and measurements, is shown in Figure 3. A void currently exists in the upper region of the core that encompasses approximately 1/3 of the total core volume and extends to the outermost fuel assemblies. Examinations of the control rod leadscrews indicate that upper plenum structural temperatures ranged from 700 K in the upper regions to 1255 K in the structures immediately above the core. The extent of damage to the bottom of the upper core support plate appears to be highly nonuniform (as determined from CCTV viewing during plenum removal), ranging from areas where the stainless steel was extensively oxidized and/or melted to areas with no significant damage. The damage appears to be limited to only a few inches above the core area.

A debris bed ranging from 0.6 to about 1.0 m deep is at the bottom of the cavity. Samples have been obtained from two locations near the center of the debris bed and examined. The core materials in the debris bed are, in general, highly oxidized, and some particles evidently reached peak temperatures near fuel melting at 3100 K. A hard (impenetrable) layer of material was detected at about 1.6 m from the bottom of the core, i.e., near the mid-core elevation, when the debris bed was mechanically probed. The extent of damage to the core below the hard layer is not known.

External gamma scans and internal video scans of the reactor vessel lower plenum indicate that as much as 20% of the core materials (fuel and cladding) now rest on the reactor vessel lower head. This is nearly 2.5 m below the bottom of the core. The material bears no resemblance to intact fuel rods. The particle size and apparent texture of the material in the

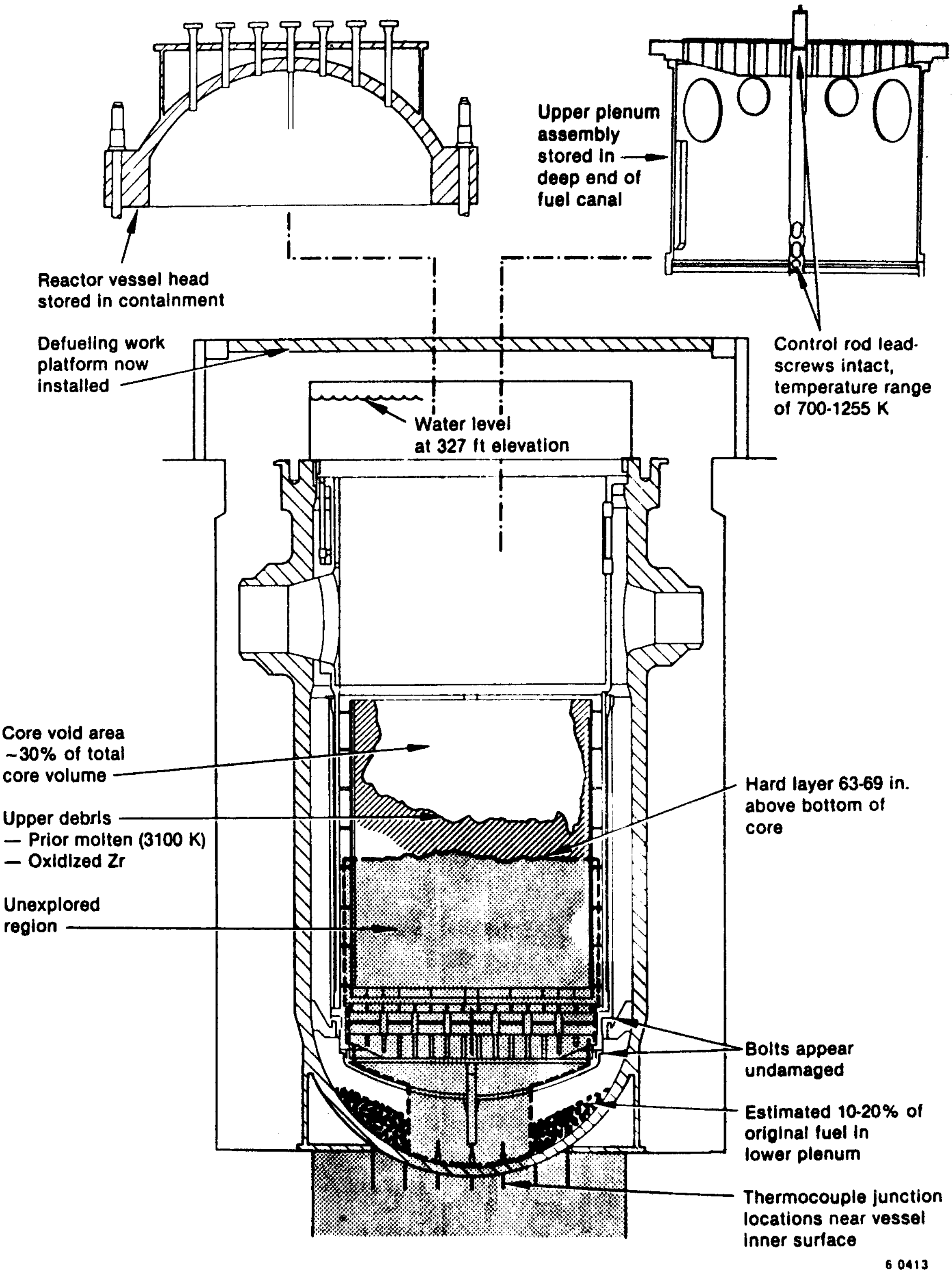


Figure 3. Known core and reactor vessel conditions.

lower plenum varies significantly, ranging from what appears to be pea-like gravel to large pieces of lava-like material at least 10 to 15 cm in diameter. Sample acquisition activities indicate that some of the debris in the lower plenum is loose, at least at the periphery nearer the reactor vessel wall. Possible damage to the core support assembly is not known, since the central regions of the lower plenum were not visible in the CCTV examinations that have been conducted to date. Also, based on the video data, damage to the reactor vessel lower head and instrument penetration is not evident.

3.2 Purpose

In addressing the data requirements recommended in the TMI-2 Accident Evaluation Program document, a scope of work has been formulated to support these data needs while recognizing certain limitations in data acquisition inherent in the TMI-2 defueling environment. As such, the purpose of the work plan is the acquisition and examination of samples of core and noncore material from the reactor vessel prior to and during defueling, along with video/acoustic documentation of the conditions of the TMI-2 core void after vacuum defueling and after bulk defueling. The scope of the sample acquisition plan includes obtaining the following:

1. Fuel rod segments from known locations in standing peripheral fuel assemblies.

2. Stratified core bore samples from the core region and from the lower head region below the core support plate.

3. Core distinct component specimens, such as fuel assembly end fittings and spacer grids, control and burnable poison rod segments, rod assembly spiders, and instrument string segments.

4. Samples of the loose debris from the lower head region below the elliptical flow distributor plate and from the lower plenum region below the core support plate.

5. Core support assembly and core former wall structural samples.

The specific reactor vessel sample examination objectives include the following:

1. Determination of peak temperatures of core and structural materials.

2. Extent of material oxidation and interaction between fuel rod components and other core and structural components.

3. Extent of control rod material relocation and interaction with fuel material.

4. Spatial distribution and physical and chemical characteristics of damaged core and structural materials.

5. Distribution and retention of fission products retained in the reactor vessel and in core materials, including their chemical form and the mechanism of retention.

6. Interaction of burnable poison rod materials with fuel rod materials and the effect on core heatup.

7. The extent and type of damage to the core support assembly, lower head, and instrument tube penetrations and amount of material relocation into the lower plenum.

3.3 Accomplishments

Since the TMI-2 accident, significant progress has been made toward gaining access to all the reactor building areas for defueling and plant decontamination. During these activities, extensive in situ data has been obtained via closed-circuit TV camera inspections of the reactor vessel internals. In addition, two sections of control rod leadscrew and a number of core debris grab samples have been obtained and examined. To date, a substantial amount of sampling tooling and equipment has been designed and fabricated to support the in situ examination and grab sample acquisition efforts. Several reports documenting the results of the completed examinations have been issued. These accomplishments are summarized in the following sections.

3.3.1 Data/Sample Acquisition

The most important early core examination task has been the continued closed-circuit television (CCTV) camera inspections of the core condition. These inspections have been performed by lowering a small-diameter camera down through vacated control rod drive mechanisms into the core void region. CCTV inspections have been conducted at three locations and have yielded a wealth of visual information, both direct and inferred, on damage to the core and reactor internals.

An ultrasonic core topography system was built and operated in the TMI-2 reactor vessel prior to head removal in order to measure the core topography before alterations occurred. A transducer/detector range-finding system was inserted into the core cavity through the leadscrew opening in the central (H8) position. Using a scanning system, the range finder was moved axially within the core cavity to measure the height, depth, and location of topographic features with an accuracy of a few centimeters.

CCTV videotapes were acquired of the following reactor vessel internal conditions:

1. The core cavity ceiling prior to the fuel assembly remnant dislodging.

2. The core cavity after fuel assembly remnant dislodging.

3. The plenum assembly outside and bottom surfaces after plenum assembly removal.

4. The outer region of the reactor vessel bottom head through two access pathways (vertically) through the downcomer.

Eleven samples of particulate debris from within the rubble bed have been obtained by lowering sampling devices through the H8 and E9 leadscrew openings. At position H8, samples were taken at the following depths into the debris bed: surface, 3, 11, 22, 27-1/2, and 30-1/2 inches. At position E9, the samples were taken at the surface, 3, 22, 29, and 37 inches into the debris bed.

The control rod drive leadscrews were obtained from the H8 and B8 locations in the reactor. Portions of the leadscrews were visually examined and metallurgically, chemically, and radiologically analyzed to estimate the maximum temperatures experienced along the length of the leadscrews and the extent of radionuclide deposit in the plenum assembly region. The H8 leadscrew support tube was also removed, and the lower 10-cm section was examined to determine surface deposition and peak temperature history.

Early attempts were made to insert the axial power shaping rods (APSRs) to determine whether the paths were obstructed. Some APSRs could not be inserted, indicating possible core damage extending out to the mid-radial locations. Ex-vessel neutron dosimetry was performed to estimate the amount of fissionable material present in the lower head area. These readings indicated that greater than two tons of uranium might be laying on the reactor vessel bottom. Thermoluminescent detector (TLD) strings were lowered into the upper plenum assembly to obtain radiation maps of the activity therein. The results confirmed the results of the leadscrew examinations, which indicated that there were higher concentrations of fission products deposited on surfaces in the upper portion of the upper plenum assembly than on lower portions of the assembly. More recently, the instrument tube wire probing was performed. Only one of 17 instrument calibration tubes was penetrated beyond the reactor vessel inner bottom. This probe penetrated to about 20 in. above the design core bottom at the L11 fuel assembly position.

3.3.2 Acquisition Equipment and Documentation

The reactor vessel sample acquisition program has provided the following equipment:

Reference	Description
	Core Boring Equipment:
Jensen Drilling Co.	Instrumented drilling machine
EGG Drawing 419931	Lead transfer cask
EGG Drawing 419932	Drill indexing platform structure assembly
EGG Drawing 420120	Lower casing clamp hydraulic assembly
EGG Drawing 420126	Drill indexing roller platform assembly
EGG Drawing 420155	Underwater structure assembly
EGG Drawing 420170	Cask roller platform assembly
EGG Drawing 420193	Underwater structure and tilting platform assembly
EGG Drawing 420234	Middle clamp and support assembly
EGG Drawing 420235	Hydraulic control assembly
EGG Drawing 420418	Underwater structure out-of-tolerance indicator
EGG Drawing 420430	Underwater cylinder and rod end clevis
EGG Drawing 420232	REES underwater video camera manipulator assembly
Wild-Heerborg	Computer-aided theodolite indexing system
	Core Topography Equipment:
	Black and white closed-circuit video system, including camera support and articulation tooling
	Enhanced still image videotape processor, including software
	Video-recording-to-enhanced-still-image hard copy processor, including software
GEND-INF-012	Multi-transducer searchlight-beam ultrasonic scanner system
EGG-TMI-6531	Loose Debris Collection Tooling:
EGG Drawing 417983	Clamshell-type loose debris collection tool
EGG Drawing 417984	Rotating-tube loose debris collection tool
EGG Drawing 418075	Loose-debris sample handling cask
	Core Boring Documentation:
PF-NME-84004	Requirements document for TMI-2 core stratification sample project

EGG-TMI-6824	TMI-2 core stratification sample project system design description
EDF-CSS-175	Equipment installation and removal procedure
EDF-CSS-189	Indexing system equipment installation and removal procedure
EDF-CSS-210	Operating procedure
EDF-CSS-213	Equipment staging procedure
EDF-CSS-229	Final acceptance test dummy fuel module
EDF-CSS-176 Rev. 2	System operational test procedure

3.3.3 Examination Reports/Records

The reactor vessel sample examination program has produced the following documentation:

Reference	Description
	Numerous videotape recordings of CCTV scans between 1982 and 1985. A listing of these tapes is given in Table 5
GEND-INF-012	Design and operation of the core topography data acquisition system (initial core cavity topographic mapping)
GEND-INF-031 (Vol I and II)	Preliminary report of TMI-2 incore instrument damage
Letter report	The FY-1983 Examination of the Lower 3.175 m Section of the H8 Leadscrew from TMI-2
EGG-TMI-6685	Draft report: Examination of H8 and B8 Leadscrew from Three Mile Island Unit 2 (TMI-2)
EGG-TMI-6531-1 Revision 1	TMI-2 Core Debris Grab Sample Quick Look Report
EGG-TMI-6630	TMI-2 Core Debris Sample--Analysis of First Group of Samples, Draft Preliminary Report
EGG-TMI-6697	TMI-2 Core Debris--Cesium/Settling Test--Draft Report
RDD:85:5097-01:01	TMI-2 H8A Core Debris Sample Examination Final Report

TABLE 5. LISTING OF VIDEOTAPE RECORDINGS OF CCTV SCANS OF TMI-2 REACTOR VESSEL INTERNALS AND CORE DEBRIS

Description/Title	Date
Quick Look Press Release (3/4 in. 60 min videocassette)	July 1982
Quick Look Tapes 1 and 2 (3/4 in. 60 min videocassette)	July 1982
Quick Look Tapes 3 and 4 (3/4 in. 60 min videocassette)	July 1982
Short (approximately 2 min) excerpts from the TMI-2 Incore CCTV Tapes (3/4 in. 20 min videocassette)	July 1982
TMI-2 Quick Look 3-Edited version dub (3/4 in. 60 min videocassette)	July 1982
Quick Look Number 2 Enhanced (3/4 in. 60 min videocassette)	July 1982
The Quick Look into the TMI Unit 2 narrator: Jack Devine (3/4 in. 20 min videocassette)	May 1984
TMI-2 Video Core Scans (from core centerline position H8, 3/4 in. 60 min videocassette):	April 1984
10° and 20° from vertical up	
30° and 40° from vertical up	
50°, 60°, and 70° from vertical up	
80° and 90° from vertical up	
100° and 110° (partial) from vertical up	
110° (partial) and 120° from vertical up	
130° and 140° (partial) from vertical up	
140° (partial), 150° and 160° (partial) from vertical up	
160° (partial) and 170° from vertical up	
Macro and "C"	
Core cavity ceiling prior to fuel assembly remnant dislodging from upper plenum	April 1985
Core cavity ceiling after fuel assembly remnant dislodging	April 1985
Plenum assembly outside and bottom surfaces during plenum removal	May 1985
Reactor vessel bottom head viewing via downcomer annulus (at two azimuthal locations near north and south vectors)	July 1985

3.3.4 Sample Examination Findings

The results of the in situ CCTV data and the sample examinations conducted to date are summarized in this section.

Core Debris Grab Samples. Examination and analysis of the eleven upper core loose debris grab samples has provided the following new knowledge of the TMI-2 accident:

- Some particles exceeded UO_2 melting (3100 K) during the accident.
- Loose debris extends downward about three feet to a hard object 4.5 ft above the original core bottom and outward to at least the next-to-outside ring of fuel assemblies (approximately 20% of the core volume).
- The hard-object upper surface is relatively flat but irregular and extends to near the core periphery.
- Significant radial mixing of core materials has occurred in the loose debris bed.
- The core material distribution in the loose debris indicates a depletion of lower melting temperature structural and poison materials.

Reactor Vessel Internals Documentation. The core topography data taken before head removal indicated that the void in the core region below the upper grid plate occupied 330 ft^3 (9.3 m^3) and extended radially into the peripheral row of fuel assemblies. Local variations in the nominal void radius ranged from exposed sections of core former wall to apparent standing fuel rods 12 to 14 in. inside the core former boundary. Significant quantities of core materials were suspended from the underside of the upper core support grid. This material was dislodged after plenum jacking to prepare for removal of the plenum from the reactor vessel and is now located on top of the core debris bed.

Review of the CCTV videotapes produced the following information about the core condition:

- Previous indications that 10 to 20 tons of previously-molten core material had relocated to the region between the flow distributor and reactor vessel bottom were confirmed.

- Previous acoustic topography indications of missing fuel assembly upper end fittings were confirmed.

- Ablation of the plenum assembly lower grid plate had occurred in two or more mid-radius areas.

- Downcomer and peripheral core support assembly structures appear to be undamaged.

Control Rod Leadscrew Examination. The principal findings of the leadscrew and leadscrew support tube examinations were:

- Less than two percent of any core radionuclide or material was deposited on metal surfaces in the plenum assembly, with the deposited core material depleted of control rod poison material.

- Upper plenum metal temperatures did not exceed the melting point (1700 K).

- Upper plenum metal temperatures ranged from 1255 K at the upper plenum inlet (center) to 755 K near the outlet.

- Previous indications that only small amounts of core radionuclides and material adhered to metal surfaces in the reactor vessel upper region were confirmed.

- Surface deposits on the leadscrew support tube consist of a tightly-adherent inner layer and loosely-adherent outer layer with a concentration of control rod poison material deposited on the inner adherent layer.

3.4 Detailed Work Plan

This section presents an overview of the work scope intended to provide the reactor vessel data recommended in the TMI-2 Accident Evaluation Program document. The detailed work packages that make up the reactor vessel sample acquisition and examination work plan are listed in the following table.

Work Package Number	Work Package Title
	Acquisition:
751420200	RV Internal Examination Acquisition and Handling
751420500	Fueled Rod Segments Acquisition
751420600	Core Bore Sample Acquisition
751421200	Core Distinct Component Acquisition and Handling
751420400	Lower RV Debris Acquisition and Handling
	Examination:
755421600	Lower RV Debris Examination
755420100	Debris Bed Sample Examination
755420200	RV Internal Examination Documentation
755420600	Core Bore Sample Examination
755420800	Control Rod Leadscrew Examination
755421200	Core Distinct Component Examination
	Equipment:
9M7830600	Core Topography Equipment (RCE)[a]
9M7840200	Core Bore Sample Acquisition Equipment (RCE)
9MA850100	Sample Handling Equipment (RCE)

a. Related Capital Equipment.

The reactor vessel sample examinations and in situ measurements currently funded in this work plan are summarized in Table 6. The table includes the AEP-designated sample priority, the quantity of samples to be

TABLE 6. SUMMARY OF CURRENTLY FUNDED REACTOR VESSEL IN SITU MEASUREMENTS AND SAMPLE EXAMINATIONS

Measurement/Sample Description	AEP Sample Priority[a]	Number of Samples Examined	TMI-2 Accident Information	Examination Methods[b]
1. Core bore samples			(All) Physical characteristics, surface texture	1, 13
a. Core region at K9	1	1	Sample weight, particle size	2, 3
b. Subcore region at K9	2	1	Total gamma emission, highest density region	4
c. Mid-radius core bore (core region and subcore region)	5	3	Fission product abundance and distribution	5, 10, 11
			Uranium abundance and distribution	8, 14, 9
			Oxygen and metallic element relative abundance, grain size, porosity, peak temperature	12, 6
d. Outer core bore (core region only)	9	1	Ductility, hardness	7
2. In situ data recordings				
a. Core cavity video/acoustic topography after vacuum defueling	4	--	(a) Extent and nature of visible deformation and surface deposits, dimensions of cavity, presence of fused core material or standing fuel rod stubs.	1
b. Video survey of lower core support structure	2	--	(b) Extent of CSA damage, presence of fused core material, rubble	1
c. Core cavity video/acoustic survey after bulk defueling	--	--	(c) Dimensions of cavity, CSA erosion, presence of fused core material.	1
3. Core debris samples			(All) Physical characteristics, surface texture	1, 13
a. Several samples from lower head debris	7	9-11	Sample weight, particle size	2, 3
			Total gamma emission, highest density region	4
b. Large volume sample from upper debris bed	3	1	Fission product abundance and distribution	5, 10, 11
			Uranium abundance and distribution	8, 14, 9
c. Large volume sample from CSA region	6	1	Oxygen and metallic element relative abundance, grain size, porosity, peak temperature	12, 6
			Material ductility, hardness	7
4. Rod segments from fuel assembly remnants	8		Rod Segments:	
			Physical characteristics, texture	1, 13
a. Fuel rod segments from core periphery ass'y in upper region		4	Gamma emitter distribution	4
			Specific radionuclide distribution and abundance	5, 8, 10, 11
			Material density distribution	11, 15
b. Guidetube/BPR segment from same ass'y as (a)		1	Material interaction, surface deposit thickness, prior temperature, oxidation and metal phase	12
c. Guidetube/control rod segment from same as (a)		1	Fuel Pellets/Fragments:	
			UO_2 stoichiometry	16
d. Fuel rod segment from core periphery ass'y in lower core region		4	Fission product relative abundance	5, 8
			I-129 and Sr-90 abundance	10, 11
			Metallic element relative abundance	6
e. Guidetube/BPR segment from same ass'y as (d)		1		
f. Guidetube/control rod segment from same ass'y as (d)		1		

TABLE 6. (continued)

Measurement/Sample Description	AEP Sample Priority[a]	Number of Samples Examined	TMI-2 Accident Information	Examination Methods[b]
5. RV structural components			(All) Metallic element relative abundance, prior peak temperature, grain size, oxygen distribution, surface deposits	12
a. Core support assembly plate samples from center region	13	6	Crystalline compound identification	16
b. Lower plenum instrument penetrations at RV head	14	6	Hardness, peak temperature, ductility	7
c. RV lower head samples	15	2	Physical characteristics, visible damage, and prior temperature	1, 13
d. Core former wall samples, axially distributed	16	4	Fission product adherents	5, 8

a. Priority values 1 through 20 are listed in Table 3.

b. Examination Methods:

1. Photography, video/acoustic surveys
2. Balance weighing
3. Sieving
4. Ion-chamber gamma detector (including scans)
5. Germanium-crystal gamma spectrometer
6. Inductively-coupled-plasma emission spectrometry
7. Compression, Rockwell Hardness
8. Scanning electron microscopy with energy dispersive x-ray
9. Delayed neutron radiochemistry
10. 129-I radiochemistry
11. 90-Sr radiochemistry
12. Metallography with Auger spectrometry
13. Immersion density
14. Sodium-iodide-crystal gamma spectrometry
15. Neutron radiography
16. X-ray diffraction

examined, the accident information expected from the sample examinations, and the examination technique that will be used.

As the TMI-2 defueling program progresses it is expected that "samples of opportunity" will present themselves. Acquisition of these serendipitous samples and occurrence of unexpected observations during sample examination will modify the currently planned work scope documented herein. The work package format used in the work plan will accommodate such modifications as they occur.

The following sections discuss the sample acquisition and examination work scope in more detail.

3.4.1 In Situ Data Recordings (WPs 751420200 and 755420200)

Detailed knowledge of the state of reactor vessel internal structures and of core relocation has come from careful documentation of the post-accident core topography using CCTV video probes and a specially designed acoustic probe system. Continued use of these in situ, nonintrusive data recording techniques at well-planned intervals during the defueling program will provide data from which (a) core debris volume measurements can be inferred, (b) visual indications of the extent of liquefaction and core material relocation to the lower plenum can be obtained, (c) confirmation of the degree of damage to peripheral core support structures, including the reactor vessel lower head and instrument guide tube penetrations, can be made, and (d) decision making for further incore sampling plans and bulk defueling can be carried out.

Substantial use of image-enhanced CCTV equipment is planned during the core stratification sample (core boring) acquisition activities. In addition, a newly designed core acoustic topography system (which now includes a video camera) will be used to map the underlying debris structure after the loose core debris has been vacuumed away. Use of the core video/acoustic topography system is also planned after all the fused debris and core components have been removed during the bulk defueling phase.

These in situ data will provide a basis of comparison with core heatup and relocation code models and core coolability models and will provide data input to the determination of system mass balance.

3.4.2 Core Bore Samples (WPs 751420600 and 755420600)

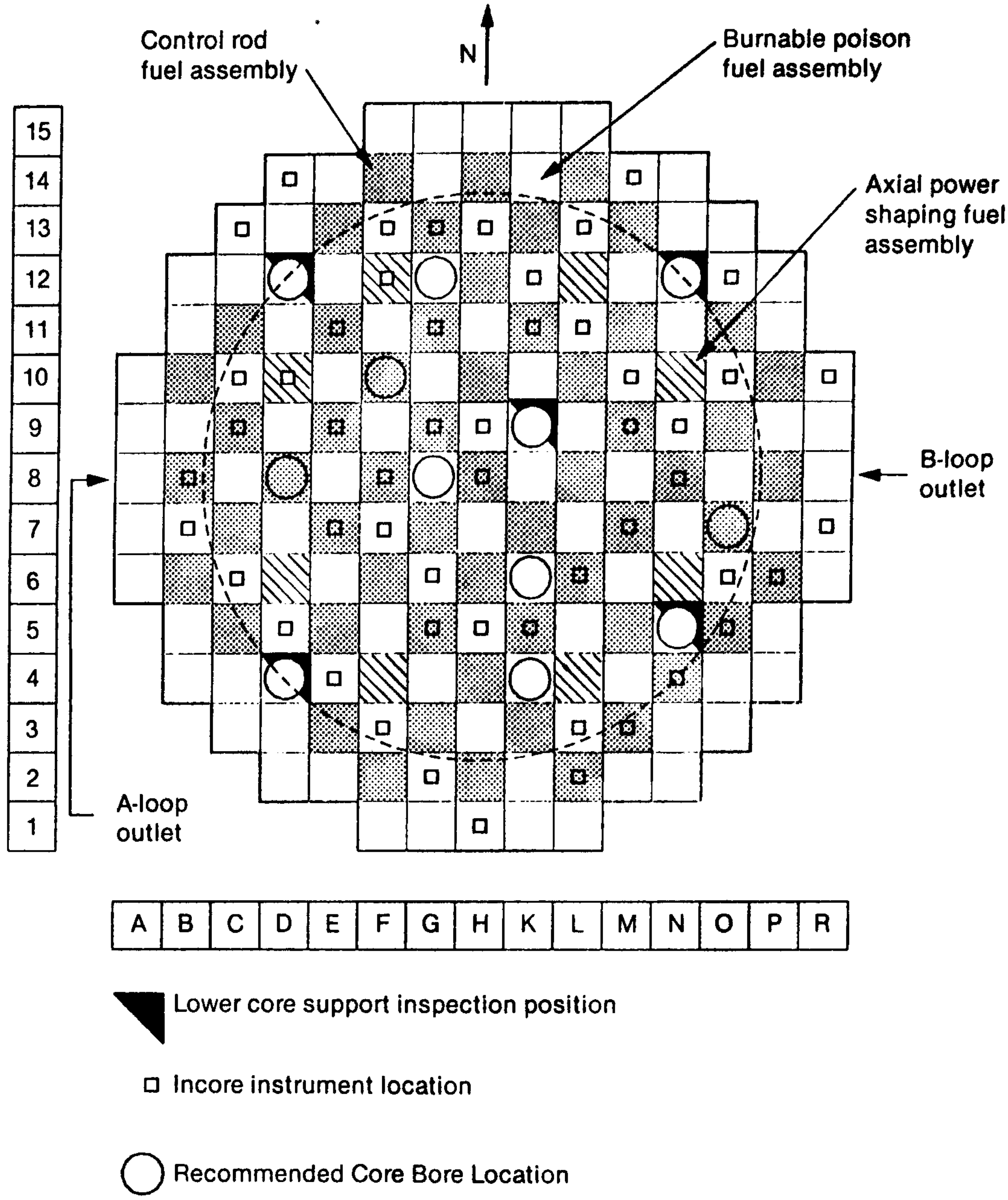
Core material samples are needed that will allow axial, radial, and azimuthal interpretation of the core damage progression. This includes cladding melting and relocation, fuel liquefaction and relocation, freezing of the molten core materials at the reactor coolant interface, and subsequent remelting and slumping of the core materials. This requirement necessitates a number of continuous axial samples of core materials through the core and lower plenum regions.

The current schedule for core boring provides for a sample acquisition "window" during the defueling activities after the loose core debris has been removed to allow a clear access to the crust layer. The core samples are to be extracted from the reactor core region using methods similar to those used for geological studies. A hydrostatically driven drill unit will drive a diamond-tipped core drill into the ceramic and metallic material that make up the crust and sub-crust regions. The core drill will penetrate the crust layer and enter a region where liquefied material interacted with partially intact fuel rods and assemblies, grid spacers, and control rods. Finally, the core drill will penetrate the lower fuel assembly endfitting. Once the lower endfitting is penetrated, the drill train with the enclosed core sample will be disconnected, extracted, and placed in a TMI-2 fuel canister. A second (lower-region) core sample may be taken from the lower core support and plenum spaces within the lower vessel head using the access path provided by the bore hole from the extracted core region sample.

Thirty core bore sample locations have been identified by the TMI-2 Accident Evaluation Program plan. In view of time and hardware limitations in containment, only a portion of the identified core bore samples will likely be acquired. The proposed core bore acquisition and examination plan will provide as much flexibility as possible, since the core bores will be taken from the unexplored region below the core cavity. The core bore acquisition plan is to obtain as many core bore samples as possible using the recommended locations and priorities shown on Figure 4. Each boring location will yield two or three samples (segments); one from the core region and one or two from the region beneath the core, depending on whether or not the lower flow distributor is encountered. The twelve bore locations shown on Figure 4 will provide for radial and azimuthal variations in core damage, characterize the differences between control and burnable poison rod assemblies, and indicate location, composition, and tensile properties of the core materials. The latter information will be derived from bore cutting tool data (cutting speed, tool location, cutter material, etc.) obtained during boring operations. Because of funding constraints, the examination plan includes only the segments (3 from the core region, 5 from the region beneath the core) from the three (K9, F10, and N5) high priority locations shown on Figure 4. Medium priority or contingency location segments will be examined if the higher priority location segments cannot be acquired. Examination of these eight core bore samples will yield information on the quantity and the physical and chemical state of fused core materials beneath the loose debris and in the lower plenum. These examinations will also provide data on fission product concentration and chemical form. However, with only three core locations being examined, only the axial and radial variation in these parameters will be determined. Measurement of azimuthal variation would require that more samples be examined.

The core bore removal will provide access into the lower core and plenum regions for CCTV video probes. As the core bores are removed, the video camera will provide visual examinations of the extent of damage and provide decision input for choosing further core bore locations. The video data will be carefully keyed to reactor vessel position, and sufficient data will be taken to provide global views of the extent of the damage and closeup views of the damaged core materials (as discussed in Section 3.4.1).

After the samples have been received at INEL, each core bore will be weighed, the upper portion of the split core sample tube removed, and the



High Priority	Medium Priority	Contingency
K9	K6	D4
F10	N12	G12
N5	D12	K4
	G8	O7
	D8	

6 3067

Figure 4. Recommended core bore locations.

contents photographed. Review of the information thus gained will then lead to a decision on how discrete samples of the stratified core bore should be extracted and will provide the necessary basis for the detailed examinations.

The detailed examinations proposed are based on the current understanding of the TMI-2 accident scenario and the postulated condition of the reactor core. Once actual data have been obtained through the initial examinations, it is anticipated that the proposed examinations will be modified to more efficiently and accurately meet the plan objectives. The two categories of examinations that will be performed on the samples are metallurgical and radiochemical. The metallurgical examinations will be performed to gather data relating to material, physical, and chemical conditions, the nature of material stratification and relocation, fuel/structural/control materials interactions, core coolant flow blockages and inventory, prior peak temperature, and the extent of fission product retention in the core material.

The radiochemical examinations address certain areas relating to material conditions, material stratification, and fission product retention. The radiochemical analyses to be performed on the core bore samples are based on previous examination plans, particularly the TMI-2 core debris examination plans. Although the material in the core bores may differ from the core debris samples, it is believed that the analyses used in those examinations are applicable to the current understanding of what the core bore samples will be like. The primary output of the radiochemical examinations will consist of data on radioisotope concentrations that can be scaled to the full core. The scaling factors are the sample weights, densities, surface areas, core drilling information, and photographic documentation.

Four different types of examinations will document the metallurgical properties of the materials. The first three (metallography, electron beam microanalysis, and x-ray analysis) give clues to the chemical and microstructural makeup of the material and thereby provide information concerning the type and extent of materials interactions. The fourth (crush testing) can yield information on mechanical properties and fracture release of fission products retained within the core materials. This information will be useful in the planning of the defueling operation.

Where original component geometry is preserved, studies will be performed on the intact cladding, fuel pellets, guide tubes, stainless steel encased control rods, and grid spacers. These studies will document phase transformations, grain growth, ballooning strains, wall thinning near ruptures, deformation, interactions, extents of oxidation, and mechanical properties such as the microhardness of the materials. Where geometry is not preserved, examinations will largely be limited to discrete fragments.

3.4.3 Core Loose Debris Samples (WPs 755421600, 755420100, and 751420400)

Larger volume debris samples (on the order of 2 kg) will be taken from both the upper core debris and lower vessel head debris beds to take advantage of improved analysis techniques for analyzing larger specimens of samples. In particular, the analysis for 129-I and Te has been improved and should be repeated (they were inconclusive on the earlier small "grab" samples from the upper debris bed). These analyses will provide needed information on fission product behavior in the reactor vessel during the accident.

Characterization of the sample material from the lower head will improve our understanding of the core material behavior during core melting and relocation into the lower plenum. The samples will be examined by metallurgical and chemical analysis and by radiochemical and gamma spectroscopic methods to determine peak core temperatures, retained fission products, the extent of oxidation, and average material composition. Various mechanical properties tests will be done on sample specimens to determine hardness, fracture toughness, etc. to provide early feedback for defueling tooling design.

3.4.4 Fuel Rod Segments (WPs 751420500 and 755421200)

As defueling progresses, fuel rod segments will be obtained from known locations in the remaining intact or partially intact fuel assembly remnants around the periphery of the core. The several-inch-long samples should come from the upper portion and lower portion of the fuel assemblies and at distributed azimuthal locations. The fuel rod segments should further represent the transition zones between the melted or shattered debris and the standing fuel rods, such that a gradation of damage is represented by the segments. In addition, control rod and burnable poison rod segments will be obtained from locations adjacent to the fuel rods samples in the fuel assembly remnants.

Examination of the fuel rod and poison rod segments will provide direct data on localized temperature, fission product retention, material composition, and extent of oxidation. Also to be inferred from the examination is the effect of the control rods and burnable poison rods on damage to adjacent fuel rods, the distribution of core peak temperatures, and some indication of time-dependent damage features such as rod fragmentation, liquid phase formation, and fuel liquefaction.

The rod segment examination techniques will include metallography, chemical analysis, radiochemistry, gamma scan, surface analysis, and visual interpretations of particle size, gross damage progression, and mechanical properties of the fuel cladding. Analysis of this data will provide a basis of comparison for benchmarking core heatup and fission product transport codes, checking estimates of hydrogen generation, and comparing source term calculations.

3.4.5 Reactor Vessel Structural Components (Activities for FY-1987 and Beyond)

The CCTV inspections of the reactor vessel to date have confirmed that significant amounts of previously molten core material passed through the core support assembly (CSA) into the lower plenum. The only portions of the CSA that were visible were around the periphery, and these appeared undamaged, as did the instrument penetrations that were visible. Other than these CCTV data, the current condition of the CSA is not known, and knowledge of the thermal and physiochemical interactions between the core materials and CSA are needed to understand the accident progression and the formation of a coolable configuration in the lower plenum. The following samples of structural components have been recommended by the TMI-2 Accident Evaluation Program for acquisition during and after defueling to provide data for determining extent of damage, temperature distribution, and materials interaction:

- Core former wall samples; four azimuthal samples at each of three axial elevations (to be specified during or after core defueling).

- Lower core support assembly samples to be specified based on further video examinations.

- Sections of fuel assembly upper end boxes available from the upper debris to establish the damage uniformity and peak temperatures gradients in the upper fuel assembly structures.

- Samples of the reactor vessel wall and instrument penetration nozzles and guide tubes at the center and mid-radius positions to determine the distribution of damage to the reactor vessel.

The reactor vessel structural components samples that are currently funded for acquisition and examination in the work plan are shown in Table 6.

3.4.6 Control Rod Leadscrews (WP 755420800)

The upper plenum and primary coolant system surface temperatures are needed to assess the importance of natural convection within the RCS and conditions that may lead to steam generator tube or other component failures. Examination of two control rod leadscrews to determine peak temperatures of structures and fission product retention on surfaces has already been performed. These results are summarized in Section 3.3.4. However, the data are insufficient to accurately quantify the peak temperature distribution. Examination of additional control rod leadscrews would confirm the upper plenum temperature distribution. Currently, there are no further leadscrew examination activities funded in the work plan, although several additional leadscrews will be acquired from TMI-2.

3.4.7 Core Distinct Components (WPs 751421200 and 755421200)

The initial CCTV inspection of the core void and the underside of the plenum revealed fuel assembly and control rod cluster components (cladding, control rods, spiders, spacer grids, end fittings, holddown spring, etc.) either hanging from the plenum or lying in the core bed. The condition of the components varies from basically intact to severely damaged. Although all components found hanging from the upper plenum have since been knocked down onto the debris bed, a number of fuel assembly upper end fittings and control rod spiders, as well as other fuel assembly components that exhibit a range of damage, will be obtained. Sample selection will be based on CCTV inspection as defueling proceeds.

The end fittings and spiders are stainless steel components originally located immediately above the fuel rods, although they may be found in a variety of locations in the core debris. The main damage to these components probably resulted from steam oxidation, although camera inspections have indicated that temperatures may have been high enough to produce localized melting. Metallography would be the main examination technique to document the oxidation, melting, and other reactions of these components. Oxide-thickness measurements could be used to estimate the amount of hydrogen released during steam oxidation of these components and thus their contribution to the total hydrogen generation. In addition, fission product plateout on these surfaces should be measured to assess their role in radionuclide retention in the core. Peak temperatures should also be determined to help profile the maximum temperatures experienced in the core region. A number of these artifacts will be obtained, as shown in Table 4, but currently there are no associated sample examinations funded in the work plan.

3.4.8 Product

The product of the RV sample acquisition and examination work plan in FY-1986 and beyond includes the following:

1. Special tools for in situ measurements, sample acquisition, and INEL sample handling and preparation.

2. Videocassette recordings of CCTV surveys.

3. Samples of core components, core materials, reactor vessel internal structure walls and plates, and the reactor vessel lower head wall.

4. CCTV survey videotape conversion to enhanced still-image videocassette recordings and hardcopy pictures.

5. Technical reports of sample examinations and in situ measurement data analysis.

A detailed list of the product items and target completion schedules is shown on Table 7.

3.5 Synopsis

The previous sections discussed the sample acquisition and examination work scope which meets the data requirements outlined in the AEP program document. However, not all of the desired examinations are currently funded, as indicated in Table 4 by the "zero" in the "proposed" column for certain examination activities.

The unfunded sample examinations can be grouped into four categories; (a) upper plenum horizontal surface samples, (b) additional leadscrews, (c) distinct core components such as upper end boxes and control rod spiders, and (d) additional fuel rod segments from known locations in

TABLE 7. REACTOR VESSEL SAMPLE ACQUISITION AND EXAMINATION WORK PLAN PRODUCT LIST

Work Package Number	Product Item	Target Completion Date
Special Tooling		
9M7840200	Core bore drilling equipment (at TMI)	November 1985
9M7830600	Phase II TMI-2 core topography system (at TMI)	November 1985
9MA850100	INEL handling/preparation equipment for core components and samples:	
	• Core barrel disassembly machine	December 1985
	• Laydown and lifting fixtures	December 1985
	• Sample handling equipment assembly	December 1985
	• Potting system assembly	December 1985
	• Examination fixture assembly	December 1985
	• Holddown spring removal press assembly	December 1985
	• Tools and support assemblies	December 1985
	• Transfer table assembly	December 1985
	• Gamma-scan container pallet adapter	December 1985
	• Electrical equipment and interconnection	December 1985
9MA850120	INEL gamma-ray measurement system	April 1986
CCTV Survey Videocassette Recordings		
REP	Predefueling cavity debris survey	November 1985
751420200	Post-vacuum-defueling core cavity walls and floor	TBD
751420200	Post-bulk-defueling core cavity walls and floor	TBD
Core Component and Material Samples		
751420400	Core debris from reactor vessel lower head peripheral region	October 1985
751420400	Core debris from reactor vessel lower head central region (2 samples)	December 1985
751420500	Six fuel rod segments	March 1986
751421200	Fuel assembly upper end boxes and control rod spiders (10 sets)	April 1986

TABLE 7. (continued)

Work Package Number	Product Item	Target Completion Date
751421200	Fuel assembly upper sections	April 1986
TBD	Larger volume samples from core cavity substrata loose debris	March 1986
751420600	Core and subcore bores (8 or less)	March 1986
751421200	Fuel assembly lower sections (6)	September 1987
TBD	Loose debris from lower core support assembly region	March 1986
751420800	Control rod leadscrews (7)	May 1988
TBD	Core former wall samples (4)	September 1988
TBD	Lower core support structure plate (6)	September 1988
TBD	Reactor vessel lower head samples (2)	September 1988
TBD	Core instrument reactor vessel penetration nozzle region (6)	September 1988
Videorecording Enhanced Still-Image Excerpts and Hardcopy Picture Albums		
755420200	Reactor vessel video-survey highlights (enhanced still-image excerpts)	September 1986
755420200	Reactor vessel video survey enhanced still-image pictures	September 1986
755420200	Reactor vessel video-survey highlights for FY-1986 and 1987 (enhanced still-image excerpts)	February 1988
755420200	Reactor vessel video survey enhanced still-image pictures for FY-1986 and 1987	February 1988
Technical Reports		
755420100	Final GEND-INF report on subsurface debris bed sample examination	March 1986
755420100	Core cavity substrata loose debris characterization final report	December 1986

TABLE 7. (continued)

Work Package Number	Product Item	Target Completion Date
755420200	Ultrasonic core cavity topography after vacuum defueling report	TBD
755420200	Ultrasonic core cavity topography after bulk defueling report	TBD
755420600	Core bore examination periodic progress reports	May 1986 thru FY-1987 at six month intervals
755420600	Core bore examinations final report	FY-1988
755421200	Rod (fuel, control, and burnable poison) segment examinations--preliminary report	April 1987
755421200	Rod (fuel, control, and burnable poison) segment examinations--final report	September 1988
755421600	Reactor vessel lower head loose debris examination report--draft	September 1986
TBD	Core former wall sample examination report	February 1989
TBD	Lower core support structure plate sample examination report	February 1989
TBD	Reactor vessel lower head sample examination report	February 1989
TBD	Core instrument reactor vessel penetration nozzle examination report	February 1989

standing peripheral fuel assemblies. These four categories correspond to the lowest four of twenty sample priorities identified in Table 11 of the AEP Program document and listed in Table 3 of this document.

The primary benefit to the program of examining samples from additional core locations is the resulting improvement in the sample statistics. The decrease in uncertainty of the data also increases the acceptability of the reported results to the technical community, thereby enhancing technology transfer. To date, analysis of the available samples has led to the observation that the accident produced very heterogeneous behavior throughout the core and reactor vessel. Examination of additional samples would provide a basis for either confirming the available observations or determining the extent of homogeneous behavior during the accident progression.

Examination of leadscrews from locations that received heavier damage (based on CCTV observations of the underside of the upper plenum assembly) would provide a much better peak temperature profile in the upper plenum. Determining the fission product deposition on a number of samples from upper plenum horizontal surfaces will provide data on transport and deposition behavior which is not yet available to the program. Any core region artifact samples and fuel rod segments that were at or near the edge of the fuel damage/melting front and that are still intact will provide data needed to define boundary conditions for damage progression. Such information may be useful for developing criteria for the computer code standard problem effort, a primary objective of the AEP.

The sample examinations which are funded in the current work plan reflect the availability of samples and the sequential need for the data to provide a consistent understanding of the accident. The prioritization of sample acquisition and examinations is intended to produce data relatively early that directly characterizes the core damage progression and fission product release. Lower in relative priority are data that will characterize structural damage in the CSA and lower plenum, followed by data needed for structural peak temperature distributions.

Accomplishing the examinations included in the reactor vessel sample acquisition and examination work plan will provide, as a minimum, the data needed to more fully develop the accident scenario, to identify the phenomena that controlled core degradation, and to contribute to the estimate of the end-state fission product distribution.

4. RCS SAMPLE ACQUISITION AND EXAMINATION WORK PLAN

4.1 Introduction

TMI-2 reactor coolant system piping and components are shown in Figure 5 and include the following:

- A reactor vessel containing the uranium fueled core. These are covered by a separate sample acquisition and examination work plan described in Section 3 above.

- Dual reactor cooling loops (A and B) consisting of the candy-cane-shaped hot legs from the reactor vessel upper plenum to the steam generator tops, two single-pass type steam generators, dual (four total) cold legs from the steam generator bottom back to the reactor vessel via the four reactor coolant pumps.

- A pressurizer connected to the cooling loops by a surge line from the A-loop hot leg to the pressurizer bottom and a spray line from the A-loop cold leg (downstream of pump RC-P-2A) to the pressurizer top.

- Dual core flood tanks connected to the reactor vessel.

During and after the TMI-2 accident sequence that lasted until natural circulation cooling commenced (approximately 30 days after accident initiation), many events occurred that affected the character and distribution of core materials and fission products which escaped from the reactor vessel to the reactor coolant system. The most significant events include the following:

- Fission product and a small uranium fraction release commenced in the reactor vessel at approximately 138 minutes after accident initiation when fuel rod rupture commenced. Reactor coolant pump operation had ceased, and the available escape paths were (a) through the A-loop hot leg, the surge line, and the

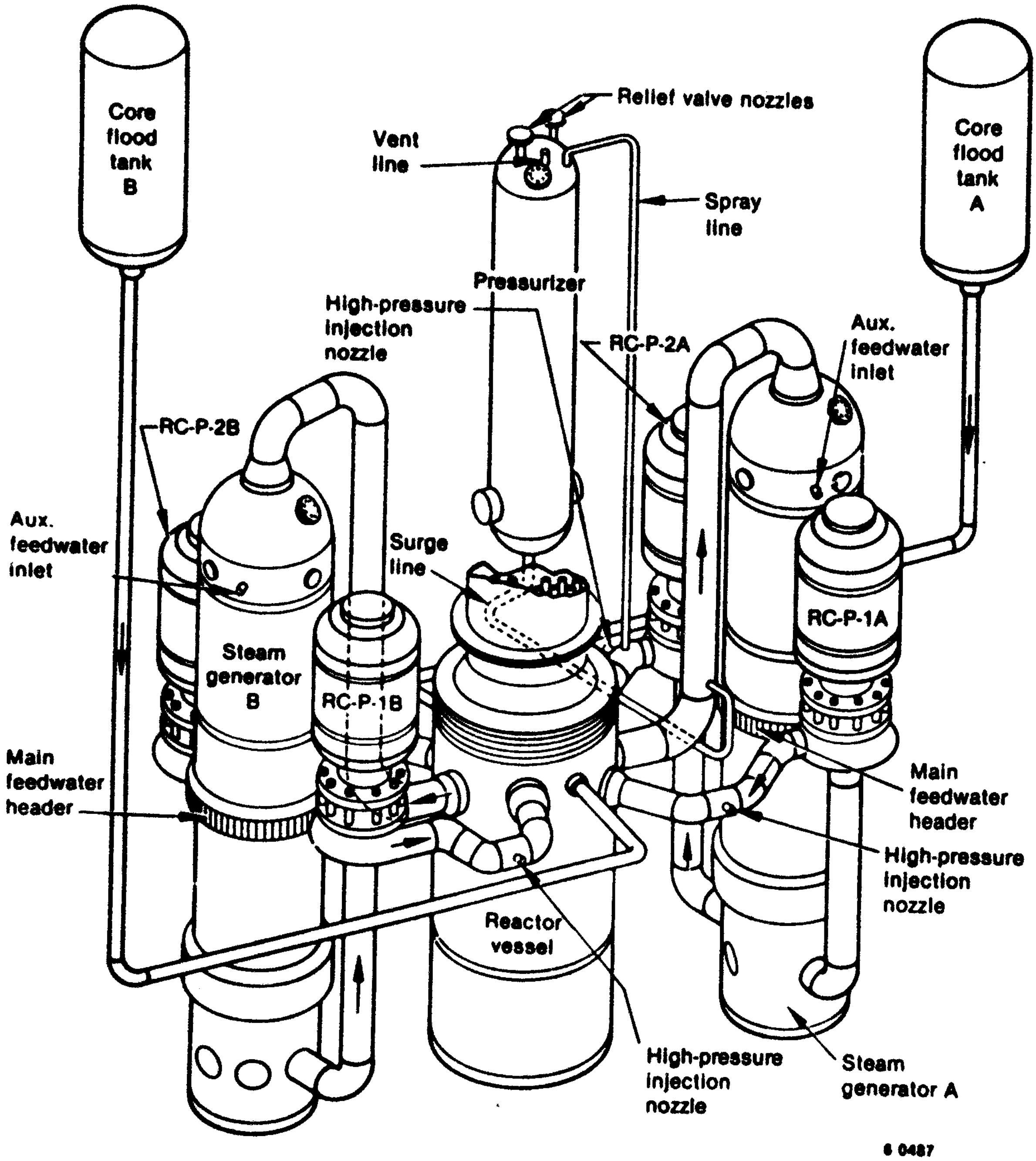


Figure 5. TMI-2 reactor coolant system piping and components.

pressurizer because the pilot operated relief valve (PORV) was stuck open, releasing reactor coolant to the reactor basement through the reactor coolant drain tank, and (b) through the A-loop cold leg to the letdown line (downstream of reactor coolant pump RCP-P-1A).

- Reactor coolant system temperatures exceeded the coolant saturation temperature from 136 minutes to approximately 16 hours after accident initiation in the hot legs and occasionally in the cold legs. Measured coolant temperatures did not exceed 725 K.

- The PORV/pressurizer escape path was closed at 142 minutes after accident initiation.

- Zircaloy-steam reaction became significant at 144 minutes, releasing hydrogen and other chemical reaction products into the coolant in the reactor vessel. Core material temperatures continued to rise and reached temperatures exceeding 2900 K, which could (a) generate aerosols from low volatility materials and chemical reactions and (b) accelerate the escape of fission products from the uranium dioxide.

- A reactor coolant sample taken at 163 minutes contained 140 μCi/ml gross activity.

- Reactor coolant pump RC-P-2B was energized from 174 to 192 minutes after accident initiation. This event is believed to have reflooded the over-heated core region, fragmenting most of the standing fuel in the upper core region and creating the upper core region cavity, and caused circulation of core material particles and fission products throughout the B-loop components.

- The PORV/pressurizer escape path was reopened from 192 to 197 minutes and from 220 to 318 minutes.

- At 227 minutes, a significant relocation of core material from the core region into the flooded reactor vessel lower plenum region occurred, which would likely increase the escape of core material and fission products to the letdown system escape path.

- A sustained high pressure injection period commenced at 267 minutes and continued to 544 minutes.

- A reactor coolant sample taken at 283 minutes contained >500 μCi/ml gross activity.

- The PORV/pressurizer escape path was cycled open repeatedly during the 340 to 458 minute period to prevent RCS over-pressurization and was also opened from 458 to 550, 565 to 589, 600 to 668, 756 to 767, and 772 to 780 minutes to depressurize the RCS for core flood injection.

- Core flood tank injection probably occurred from 511 to 550 minutes after accident initiation. This event is believed to have caused a back flow leak path to develop from the reactor coolant system to flood tank B due to incomplete check valve reseating.

- A reactor coolant system pressurization in the 840 to 900 minute period probably forced coolant and core material aerosols and volatile fission products from the reactor vessel into flood tank B.

- Forced circulation cooling of the reactor was resumed at 949 (15 hours 49 minutes) minutes through the A-loop with reactor coolant pump RC-P-1A.

- Letdown flow was lost from 18 hours 34 minutes to 26 hours 30 minutes.

- A reactor coolant sample taken at 36 hours and 15 minutes measured >1000 R/h on contact.

- Natural circulation cooling of the reactor commenced 30 days and 10 hours after accident initiation.

- Reactor coolant water cleanup using the SDS/EPICOR-II system commenced 2 years and 106 days (7-12-81) after accident initiation and included cleanup of an equivalent of four reactor coolant system volumes of reactor coolant water.

The RCS is currently liquid-full. In the last year, inadvertent injection of water with colloidal suspensions of ferrous oxide and high pH has introduced additional contamination into the RCS and probably caused increased buildup of surface and loose deposits. In addition aqueous chemistry changes may have changed the chemical form of some of the remaining fission products. Radiation surveys indicate radiation levels are higher in the vicinity of some B-loop components compared to the same A-loop locations, and access to the B-loop D-ring compartment is still restricted.

The above conditions have (a) prevented acquisition of surface or loose deposits from the RCS except the A-loop hot leg RDT, which was located at a system high point and (b) reduced the amount of TMI-2 accident sequence information that can be inferred from examining RCS specimens and in situ measurements.

4.2 Purpose

The purpose of the RCS sample acquisition and examination work plan is to retrieve and examine reactor coolant system adherent-surface and loose deposit samples and collect and reduce (conversion to hard copy graphs and tabulations) gamma-spectrometer-measured reactor coolant system gamma spectra data. The examination objectives are to determine the abundance, distribution, chemical form, and bonding characteristics of fission products and core materials deposited in the RCS and the extent to which the RCS can be decontaminated.

4.3 Accomplishments

4.3.1 Acquisition

Tooling. The RCS sample acquisition program has produced the following equipment:

Drawing/Report Number	Description/Title	Status
TBD	Germanium-crystal gamma spectrometer system, including computer software and point, pipe, and plane calibration sources	Complete
TBD	Sodium-iodide-crystal portable gamma spectrometer system, including a Davidson Model 4106 Multi-channel Analyzer and excluding the crystal detector proper	Complete

Data. The data (gamma spectra) acquisition program has produced a cassette tape containing gamma spectra data from the following RCS regions:

Region	Spectra Quantity
A-loop steam generator (external)	7(NaI crystal)
Pressurizer (external)	6(NaI crystal)
Core flood tank B	9(CdTe crystal)
Miscellaneous	24

Samples. The RCS sample acquisition program furnished the A-loop hot leg RTD thermowell in May 1984.

4.3.2 Examination

The RCS examination program has produced the following reports:

Report Number	Title	Status
H. M. Burton ltr to G. R. Eidam Hmb-268-84	Transmittal of Draft Report Analysis of TMI-2 'A' Steam Generator Hot Leg Resistance Thermal Detector	Transmitted Nov. 1984
EG&G Reactor Physics Branch letter STC-08-85	TMI Gamma Spectral Data from Primary System Scanning Measurements	Completed Sept. 1985

RCS examination activities performed by others has produced the following reports:

Report Number	Title	Status
GPU Nuclear TMI-2 Technical Planning Bulletin 84-5	OTSG "A" external measurements	Issued Dec. 1984
GPU Nuclear TMI-2 Technical Planning Bulletin 84-6	Ex-vessel fuel generic survey results	Dec. 1984
GPU Nuclear TMI-2 Technical Planning Bulletin 84-7	Fuel deposition in the "B" core flood tank system	Feb. 1985

4.3.3 Findings

The in situ measurements and sample examinations conducted to date indicate that the fractions of core materials and fission products deposited in the RCS are low, as follows:

Material/Fission Product	Estimated Abundance Fraction of Core Inventory
Uranium	Trace
Tritium	0.02
Kr-85	Negligible
Sr-90	0.01
Xe-133	Negligible
Ru-106	Negligible
Sb-125	0.001
I-129	0.012
I-131	0.11
Te-132	Negligible
Cs-134	0.008
Cs-137	0.008
Ce-144	0.0004
Plutonium	Negligible
Zirconium	Trace
Silver	Trace
Copper	Trace
Cadmium	None

Other examinations indicated that reactor coolant surfaces have an adherent surface deposit that will require removal by repeated application of decontamination solutions.

4.4 Detailed Work Plan

The RCS sample acquisition and examination program work plan details are contained in the following work packages:

Work Package Number	Work Package Title
751421000	RCS Fission Product Inventory Sample Acquisition and Handling
755421000	RCS Fission Product Inventory Sample Examination

Table 8 summarizes the in situ measurements (RCS gamma spectrometer scanning program) and sample (RCS adherent surface and loose deposits) acquisition and examinations which are included in this work plan. The table includes the AEP-designated sample priority (1-20), the quantity of

TABLE 8. RCS IN SITU MEASUREMENT AND SAMPLE ACQUISITION AND EXAMINATION PLAN SUMMARY

Measurement/Sample Description	Priority[a]	Sample Quantity	TMI-2 Accident Information	Examination Methods[b]
1. RCS Gamma Scans:	Not ranked		(All) Uranium abundance and distribution	17, 18
a. Steam generator inside		TBD	Fission product (Cs-137) abundance	17, 18
b. Pressurizer inside and outside		TBD	and distribution	
c. Pressurizer surge line		TBD		
d. Decay heat removal line		TBD		
e. Pump volutes		TBD		
f. Hot legs		TBD		
2. RCS Adherent Surface Deposits:	12		(All) Color, surface texture	1
			Total radioactivity and distribution	4
a. B-loop RTD thermowell		1	Fission product abundance and	
b. A-loop steam generator handhole cover liner		1	distribution:	
			Mn-54, Co-60, Ru-106, Ag-110, Sb-125, Cs-134/137, Ce-144, Eu-154/155	5, 12
			I-129	5, 10
c. B-loop steam generator manway cover backing plate		1	Sr-90	11
			Te	6
			Core material abundance and distribution:	
d. Pressurizer manway cover backing plate		1	Zr, Fe, Ni, Ag, In, Cd, Cr, Sn, Al, Mn, Si, Cu, Gd, Mg, Mo, Nb, B	6, 7, 8, 12
			U (includes U-235)	6, 8, 9, 12
			O	13
			Most abundant core material chemical form	15
			Decontaminatibility	14
3. RCS Sediment:	12		(All) Volume/weight	2, 16
			Particle size (transportability)	3
a. Steam generator tube sheet top loose debris		2	Color, surface texture, shape	1
			Total radioactivity	4
b. Steam generator lower head loose debris		2	Fission product abundance and distribution:	
c. Pressurizer lower head loose debris		1	Mn-54, Co-60, Ru-106, Ag-110, Sb-125, Cs-134/137, Ce-144, Eu-154/155	5, 12
			I-129	5, 10
			Sr-90	11
			Te	6
			Core material abundance and distribution:	
			Zr, Fe, Ni, Ag, In, Cd, Cr, Sn, Al, Mn, Si, Cu, Gd, Mg, Mo, Nb	6, 7, 8, 12

TABLE 8. (continued)

Measurement/Sample Description	Priority[a]	Sample Quantity	TMI-2 Accident Information	Examination Methods[b]
			U (includes U-235)	6, 8, 9, 12
			O	13
			Most abundance core material chemical form	15

a. Priority values 1 through 20 are listed in Table 3.

b. Examination methods:

1. Photography
2. Balance weighing
3. Sieving
4. Ion-chamber gamma detection (including scans)
5. Germanium-crystal gamma spectrometry
6. Inductively-coupled-plasma emission spectrometry
7. Spark source mass spectrometry
8. Scanning electron microscopy with energy dispersive x-ray
9. Delayed neutron radiochemistry
10. I-129 radiochemistry
11. Sr-90 radiochemistry
12. Metallography
13. Metallography with Auger spectrometry
14. Acid solution decontamination tests
15. X-ray diffraction
16. Immersion density
17. Sodium-iodide-crystal gamma spectrometry
18. Cadmium-telluride-crystal gamma spectrometry

in situ measurements or samples, the TMI-2 accident information expected from the examination, and the examination techniques which will be used to obtain the information.

The product of the RCS sample acquisition and examination program work plan consists of samples of RCS surface and loose deposits and technical reports of sample examinations or in situ measurement data analysis, as follows:

Work Package Number	Work Package Title	Target Completion Date
751421000	a. B-loop hot leg RTD thermowell	October 1985
	b. RCS gamma-spectrometer data cassette-tape recordings from:	
	• A-loop hot leg and coolant pumps	October 1985
	• B-loop D-ring (general), steam generator (external, hot leg and coolant pumps	December 1985
	• Decay heat line	December 1985
	• Pressurizer (internal)	December 1985
	• A-loop steam generator (internal)	April 1986
	• B-loop steam generator (internal)	July 1986
	c. Pressurizer manway cover backing plate	December 1985
	d. Pressurizer lower head loose deposit sample	December 1985
	e. A-loop steam generator handhole cover liner	March 1986
	f. A-loop steam generator tube sheet top and lower head loose debris samples	March 1986
	g. B-loop steam generator manway cover backing plate	June 1986
	h. B-loop steam generator tube sheet top and lower head loose deposit samples	June 1986
755421000	a. B-loop hot leg RTD thermowell examination report draft	May 1986
	b. RCS gamma spectrometer data letter report	September 1986
	c. RCS adherent surface deposit examination final report	September 1987
	d. RCS loose deposit examination final report	January 1988

Additional reporting will be done by means of the test-and-inspection-services subcontractor's periodic progress reports and incorporation of progress-report examination data into the annual fission product inventory program updates to be prepared by the Examination Requirements and Systems Evaluation group.

4.5 Synopsis

This RCS in situ measurement and sample acquisition and examination plan is expected to satisfactorily characterize the abundance, distribution, and chemical form of the radionuclides (fission products) and core materials deposited in the RCS and the extent to which the RCS can be decontaminated. At present the partially completed gamma spectrometer surveys and A-loop hot leg RTD thermowell surface deposit examination results represent a substantially incomplete characterization of the fission products and core materials in the RCS. The estimates of fission products and core materials deposited in the RCS may increase by factors of two to five when the B-loop gamma surveys and sample examinations are completed because the B-loop is observed to be more radioactive than the A-loop.

Examination technique development is needed to yield conclusive information about fission product chemical forms and bonding characteristics either during the accident sequence or currently because of the low (part-per-million) abundance of the fission products, which prevents detection by state-of-the-art techniques such as X-ray diffraction and electron microscopy. A FY-1986 study is planned by the AEP Examination Requirements and System Evaluation group to determine whether techniques are available or possible for obtaining the high-priority fission product chemical characteristics information.

5. EX-RCS ACQUISITION AND EXAMINATION WORK PLAN

5.1 Introduction

The EX-RCS fission product inventory (FPI) sample acquisition and examination work plan includes the buildings and equipment outside the TMI-2 reactor coolant system that are believed to be either migration paths or destinations of core fission products or materials during and after the TMI-2 accident sequence. Figures 6 and 7 show the TMI-2 nuclear power plant site at Three Mile Island on the Susquehanna River in Middletown, Pennsylvania with its older-sister plant, TMI-1. The following site features are of special interest to the EX-RCS FPI SA&E planning:

1. Reactor Building (Figure 8). The reactor building consists of a steel-plate-lined, reinforced concrete, cylindrical-shaped vessel designed to contain the consequences of a large-break loss-of-coolant accident including internal pressure of 60 psig at 286°F. The reactor building contains the reactor coolant system and other auxiliary equipment and extends from the 282-ft (above sea-level) elevation basement floor to the 473-ft elevation at the dome top. The site grade level is 304 ft, and the normal Susquehanna River level is 290 ft.

2. Auxiliary and Fuel Handling Buildings (AFHB). A plan view of the interconnected concrete-walled buildings is shown in Figure 9. The buildings are designed for radiation emission control because their functions include reactor coolant purification and degasification and spent fuel storage. The basement floor of both buildings is at the 280-ft elevation, with the auxiliary building penthouse roof at the 376-ft elevation and the fuel handling building roof top at the 400-ft elevation.

3. Vent Stack. The steel pipe vent stack also shown in Figure 8 extends from the 331-ft elevation to 463 ft, where gas/vapor effluent from the TMI buildings, including the reactor building and AFHB, can be released to the atmosphere.

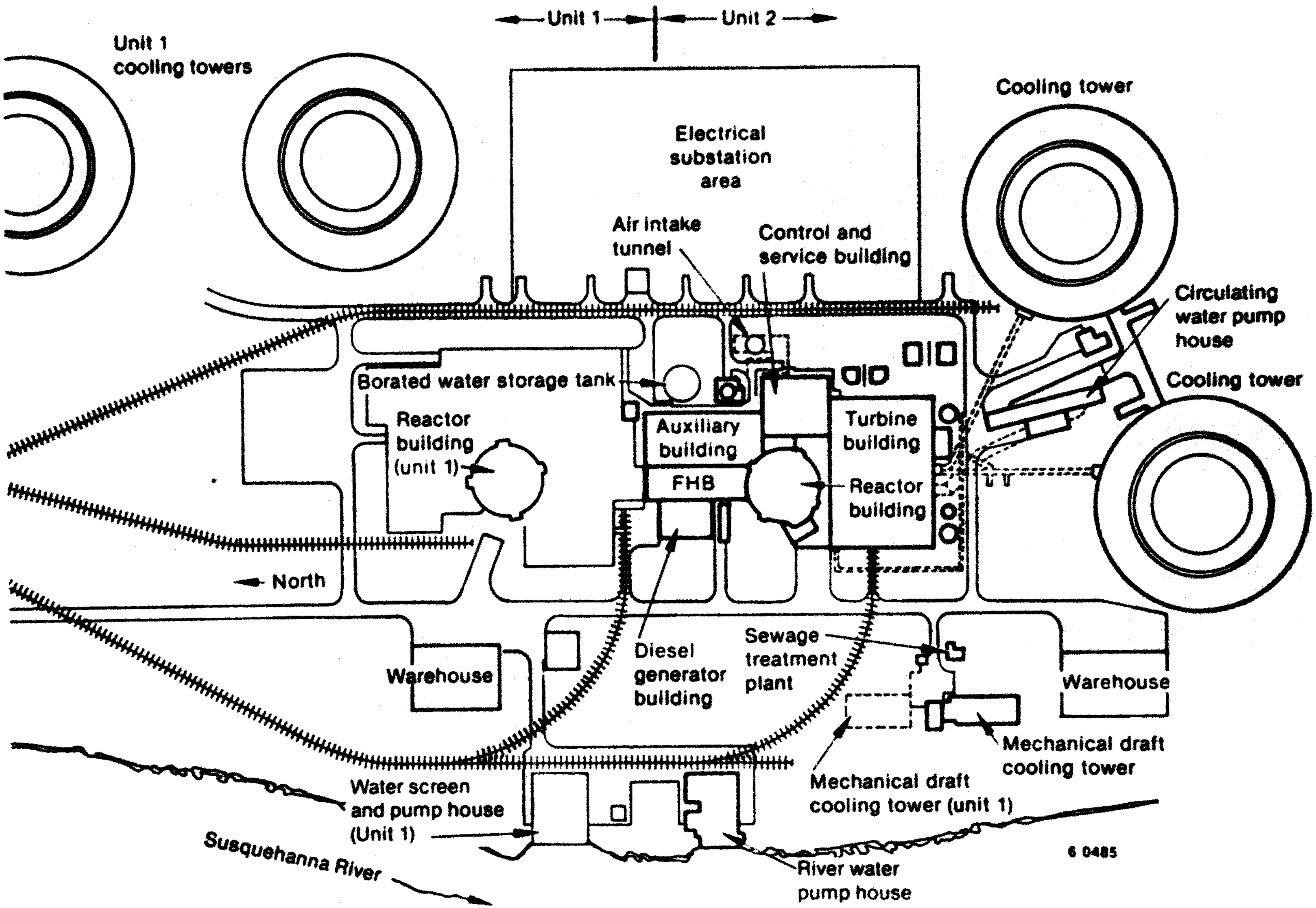


Figure 6. TMI-2 site plan.

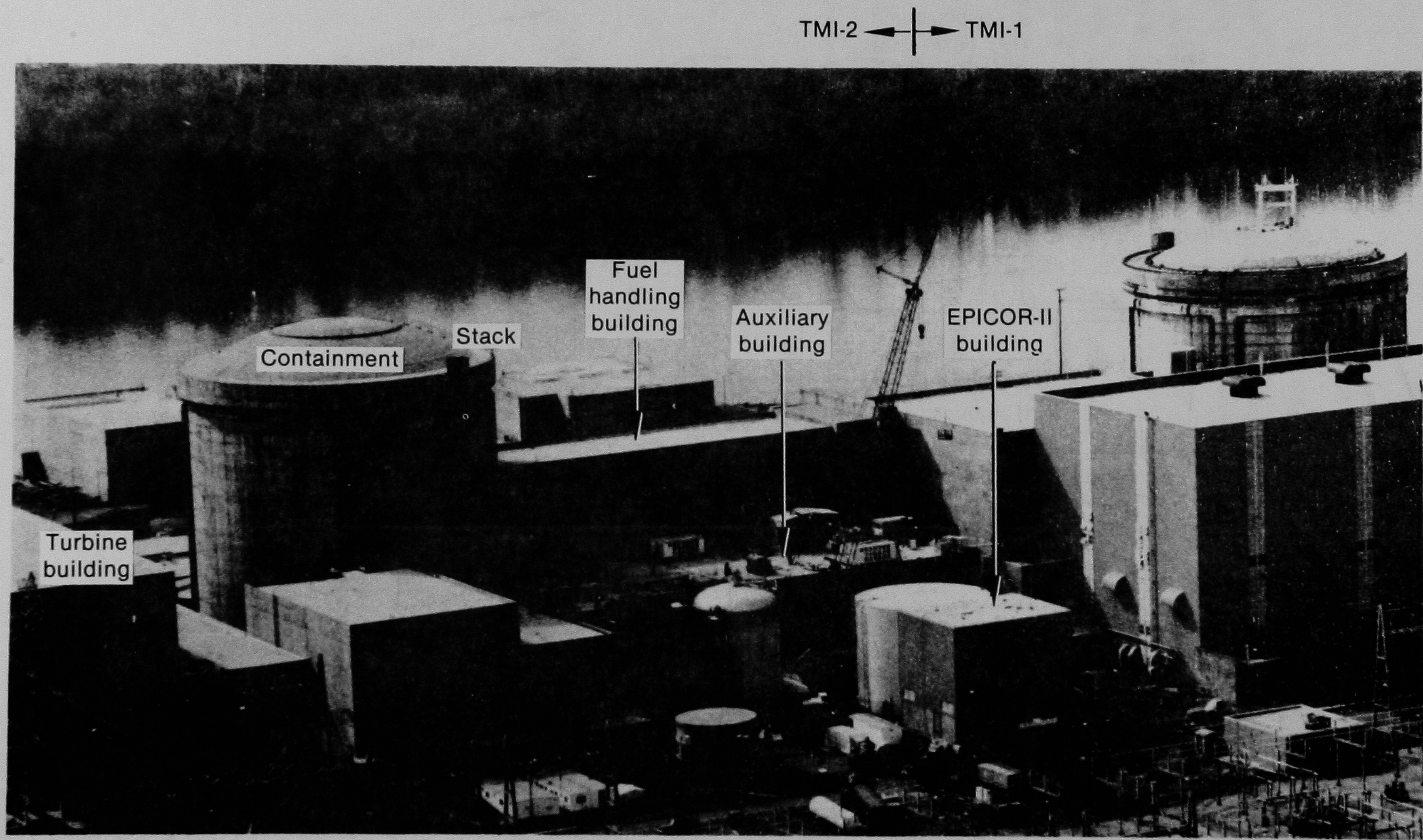


Figure 7. General building arrangement at TMI.

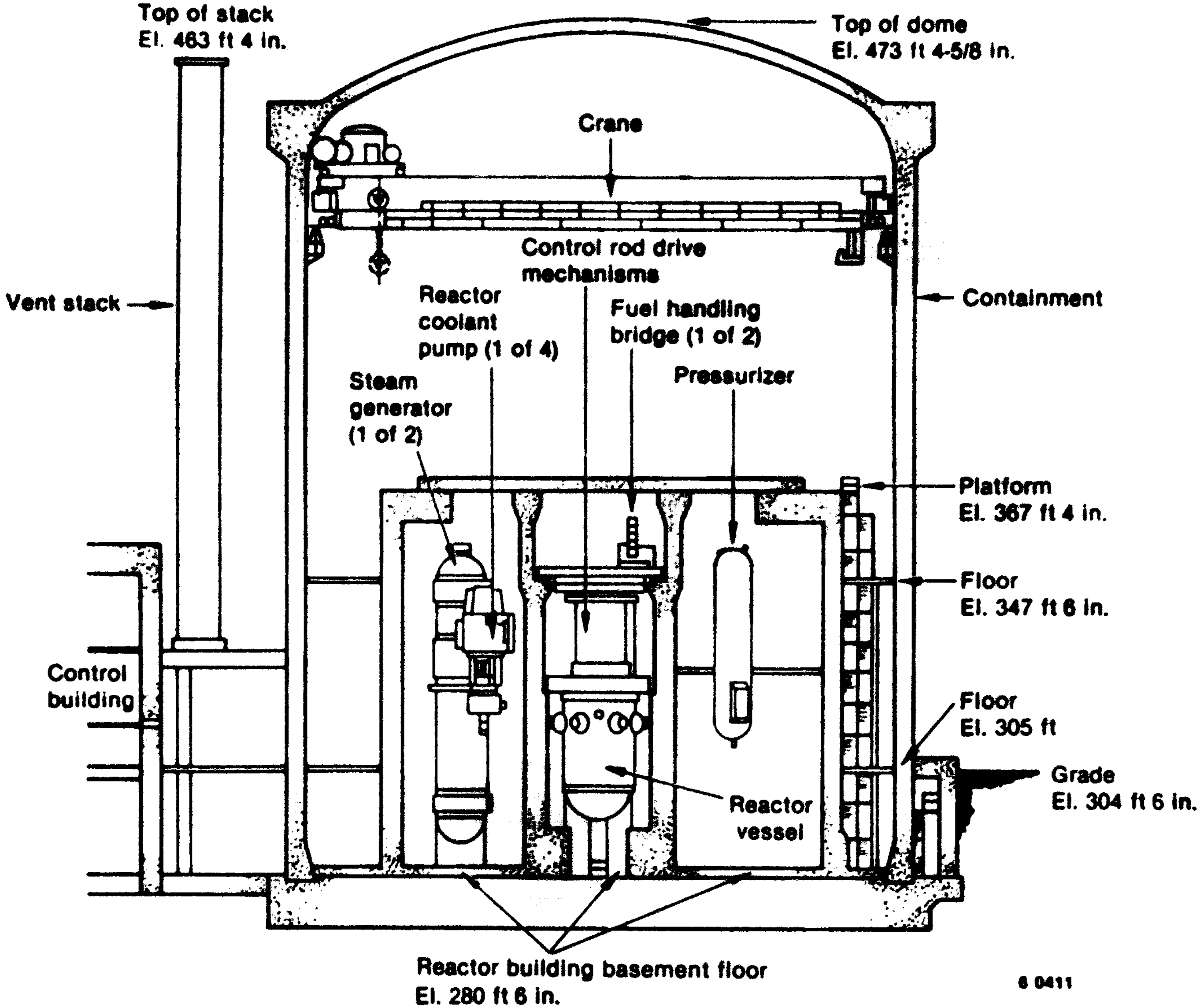


Figure 8. TMI-2 reactor building and major components of primary cooling system.

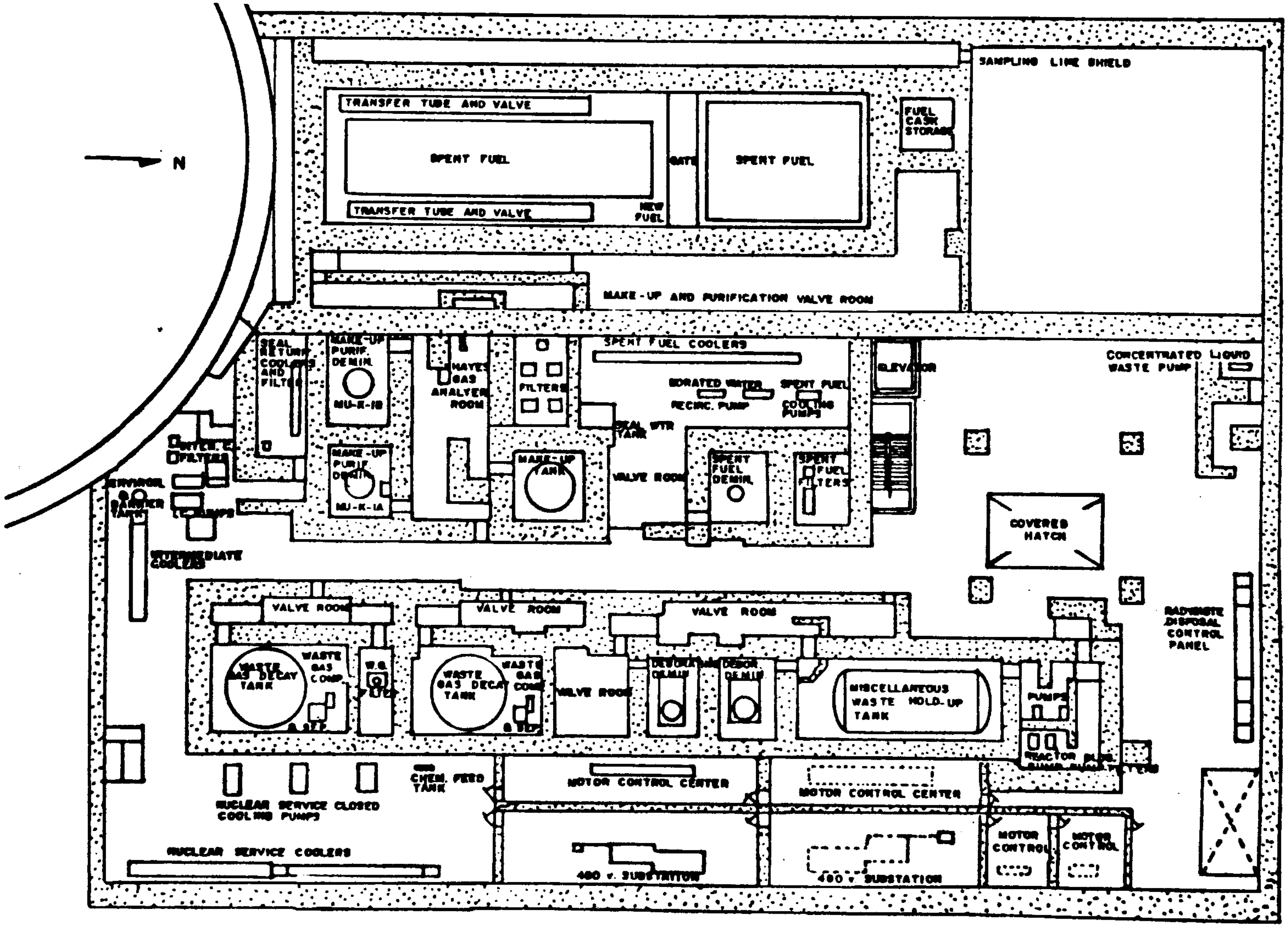


Figure 9. TMI-2 auxiliary and fuel handling buildings.

4. TMI-2 Control and Services Building. This building is connected to the AFHB by floor (liquid) drains and to the main steam system by sampling lines and extends from the 280-ft basement floor elevation to the 376-ft elevation roof top. Also, outside air is drawn in during circulation-mode ventilation of the control room.

5. TMI-1 Control and Services Building. This building is connected to the TMI-2 reactor coolant system through both reactor coolant and main steam system sampling lines. Also, outside air is drawn in during recirculation-mode ventilation of the control room.

6. Turbine Building. This building is connected to the reactor building and reactor coolant system by the main steam system and to both TMI-1 and TMI-2 control and services buildings by main steam system sampling lines.

7. TMI Industrial Waste Treatment System. This system filters and discharges waste water to the Susquehanna River.

TMI-2 accident studies have concluded that the fission product escape paths from the RCS during the accident sequence were as follows, in descending order of importance to the offsite radiation hazard:

1. Through the letdown system to the makeup and purification system, radwaste disposal liquid system, radwaste disposal gas vent and relief systems, AFHB free volume and air exhaust system, and the vent stack to the atmosphere. Contaminated air could then be drawn into the control rooms through the HVAC and could contaminate the control room atmosphere.

2. Through the PORV/RCDT rupture disc route to the reactor building basement floor and free volume.

3. Through the PORV/RCDT gas relief valve route to the radwaste disposal gas vent system, AFHB free volume and air exhaust system, and the vent stack to the atmosphere.

4. Through the RCS water sample line into the TMI-1 control and service building free volume and liquid drains and industrial waste treatment system to the Susquehanna River (believed to be very minor).

5. Through B-loop steam generator tube leaks to (a) the atmosphere via the main condenser, condenser vacuum system, the auxiliary building air exhaust discharge, and the vent stack and (b) the Susquehanna River via the main steam system sampling lines, both control and service buildings drains, and the industrial waste treatment system (believed to be very minor).

The reactor vessel bottom and core instrument cable chase regions have not been sufficiently explored to determine whether or not an escape path from the RCS to the reactor building free volume developed through the core instrument train tubes beneath the reactor vessel. Fission products did not escape to the auxiliary building by reactor building sump pump action because the escape path was closed prior to fuel rod rupture.

After the accident sequence concluded, with commencement of core cooling by natural circulation (April 27, 1979), all fission product escape paths were controlled, including (a) the venting of reactor building radioactive gases through filters and the vent stack to the atmosphere and (b) the transport to offsite repositories of filters and ion exchange resin from the water treatment/cleaning system cleanup and decontamination of the TMI-2 liquid that became contaminated during the accident sequence. The water cleanup systems included the following:

1. The already-installed EPICOR-I system at TMI-1 for water with less than 1 μCi/ml contamination.

2. The EPICOR-II system, which was specially installed for TMI-2 accident cleanup of water with 1 to 100 μCi/ml contamination.

3. The SDS, which was specially installed in the TMI-2 AFHB spent fuel storage pool for TMI-2 accident cleanup of water with greater than 100 μCi/ml contamination.

During and after the TMI-2 accident sequence, which lasted until natural circulation cooling commenced (30 days after accident initiation), many events occurred that affected the character and distribution of fission products and core materials that escaped from the reactor coolant system. The most significant events include the following:

- Fission product and a small uranium fraction release commenced in the reactor vessel at approximately 138 minutes after accident initiation, when fuel rod rupture commenced. Reactor coolant circulation had ceased, and the available escape paths from the RCS were through: (a) the stuck-open PORV to the RCDT where liquid could escape to the reactor building basement floor through the rupture disk and vapor could escape through vent lines to the radwaste disposal vent gas system in the auxiliary building and (b) the letdown line downstream of reactor coolant pump RCP-P-1A that led to either the makeup/purification or radwaste disposal systems in the auxiliary building.

- The PORV to RCDT escape path was closed 142 minutes after accident initiation.

- Zircaloy-steam reaction became significant at about 150 minutes, releasing hydrogen and other chemical reaction products into the RCS. Core material temperatures eventually reached or exceeded 3100 K, which could (a) generate aerosols from low volatility materials and chemical reactions and (b) accelerate the escape of fission products from the uranium dioxide. Sufficient damage to the core instrument string calibration tubes probably occurred, allowing coolant to enter the calibration tubes, which extend to a "seal table" at the reactor building 347 ft elevation.

- A TMI-2 reactor coolant sample (140 µCi/ml gross activity) was taken (163 minutes) at the TMI-1 control and service building sampling station, introducing contaminated liquid into the liquid drains.

- Reactor coolant pump RC-P-2B was energized from 174 to 192 minutes after accident initiation, and this event is believed to have reflooded the overheated core region, fragmented most of the standing fuel in the upper core region, and caused circulation of core material particles and fission products throughout the RCS.

- The B-loop main steam isolation valves were opened for seven seconds at 176 minutes, which allowed secondary coolant contaminated by primary coolant leakage through suspected B-loop steam generator tube cracks to migrate to the condenser.

- The PORV to RCDT escape path was reopened from 192 to 197 and 220 to 318 minutes.

- A significant relocation of core material from the core region to the flooded reactor vessel lower region occurred at 227 minutes, which likely increased the escape of core material and fission products to the letdown system.

- At 234 minutes plus, a B-loop steam generator secondary side water sample was drawn at the TMI-2 control and services building sampling station, introducing contaminated liquid to the building sump, from where it later migrated to the Susquehanna River through the industrial waste treatment system.

- The radioactive gas escape path to the radwaste disposal gas vent system through the RCDT vent was closed at 236 minutes during reactor building isolation.

- Overpressure in the reactor coolant makeup tank lifted the 80-psi-set-point liquid relief valve at 266 minutes and discharged contaminated RCS liquid to the reactor coolant bleed holdup tanks (RCBHTs), which also overflowed and overpressured. The RCBHT overpressure lifted the 20-psi-set-point relief valves and allowed unfiltered vapor to escape to the atmosphere, via the radwaste disposal gas relief header and the vent stack. It is also believed that liquid entered the radwaste disposal gas vent header, where it would be separated and drained to the auxiliary building sump.

- A sustained high pressure injection period commenced at 267 minutes and continued to 544 minutes.

- A TMI-2 reactor coolant sample (>500 μCi/ml gross activity) was taken at 283 minutes from the TMI-1 sampling station, introducing contaminated liquid into the liquid drains.

- The PORV to RCDT escape path was reopened repeatedly from 340 to 458 minutes to prevent RCS overpressurization and opened from 458 to 550, 565 to 589, 600 to 668, 756 to 767, and 772 to 780 minutes to depressurize the RCS for core flood injection.

- TMI-2 control room air became contaminated (both particulate and noble gas channel alarms) at 370 minutes, requiring the use of personnel face masks and particulate filters until 670 minutes.

- A hydrogen burn occurred in the reactor building at 590 minutes causing a 28 psig peak pressure and actuating the reactor building spray, which injected chemically-treated (boron and sodium hydroxide) water into the reactor building for six minutes.

- Forced circulation cooling of the reactor was resumed at 949 minutes (15 hours 49 minutes) through the A-loop with reactor coolant pump RC-P-1A.

- Letdown flow was lost from 18 hours 34 minutes to 26 hours 30 minutes.

- Overpressure in the letdown system lifted the 130-psi-set-point relief valve MU-R-3 around midnight (20 hours and 30 minutes), allowing reactor coolant escape to the RCBHT. The RCBHT relief valves are believed to have also lifted, allowing unfiltered vapor to escape to the atmosphere, and probably allowing liquid to enter the auxiliary building sump through the radwaste disposal gas vent header. This condition lasted longer than 40 minutes.

- TMI-2 control room air became contaminated (particulate channel alarm) at 22 hours 11 minutes, requiring use of personnel face masks and particulate filters for 64 minutes.

- An escape path was created at 24 hours 35 minutes by opening the makeup tank vent valve MU-V-13 to the radwaste disposal gas vent header. This pathway was reopened periodically for the next several days.

- A helicopter measured 3 R/h beta gamma and 410 mR/h gamma at 15 ft above the TMI-2 vent stack at 34 hours 10 minutes after accident initiation.

- A 100 ml TMI-2 reactor coolant sample was taken (36 hours 15 minutes) at the TMI-1 control and services building sampling station, introducing contaminated liquid into the liquid drains. The sample radiation emission was >1000 R/h at contact.

- Natural circulation cooling of the reactor commenced 30 days and 10 hours (April 27, 1979) after accident initiation.

- Auxiliary building decontamination commenced 30 days (April 27, 1979) after accident initiation.

- Supplemental filters for auxiliary building venting commenced operation on May 1, 1979.

- The vent stack was capped on May 20, 1979.

- EPICOR-II cleanup of medium contamination water commenced October 1979.

- Reactor building gas cleanup and venting commenced July 28, 1980 and included reopening of the vent stack.

- SDS/EPICOR-II cleanup of the high-contamination water commenced July 12, 1981, and included cleanup of an equivalent of four reactor coolant system volumes of reactor coolant water. Reactor building basement water cleanup was completed in May 1982.

- Reactor building decontamination commenced in March 1982.

An estimated 643,000 gal of contaminated water collected in the reactor building basement between accident initiation and September 1981, when SDS cleanup of the water commenced. The steadily increasing depth of water in the basement at key accident-sequence events was as follows:

Time After Accident Initiation	Event	Basement Water Depth[a]
227 minutes	Major core material relocation to reactor vessel lower plenum region	10 inches
15 hours 40 minutes	Commence sustained forced-circulation cooling of core	2 ft 8 in.
30 days 10 hours	Commence natural circulation cooling of core	4 ft 3 in.
910 days (9-23-81)	Commence SDS cleanup of RB basement	8 ft 6 in.

a. Assumes linear relationship of gallons of water to water depth and 643,000 gallons equals 8 ft 6 in. water depth.

The basement water is believed to have been composed of the following sources on 9-23-81:[1]

Water Source		Percent
Reactor Coolant System:	First 72 hours of accident	41
	Next 907 days	28
Reactor Building Spray System		3
Susquehanna River		28

The spray system water contained boron and sodium hydroxide chemicals, and the river water (from leaks in the river water cooling system) silt was composed of the following major elements in order of concentration: Fe, Si, Mn, Pb, Ca, K, S, Al, Ba, Na, and Ti.

The event sequence shows a chronological separation of the core damage events and the offsite radiation release. The core damage probably ended about 4 hours and 30 minutes after accident initiation, when the high pressure injection refill of the RCS commenced. The probable initiation of the offsite radiation hazard coincident with the measurement of TMI-2 control room air contamination was 6 hours and 10 minutes after accident initiation. The control room air is believed to have been contaminated by the outside air. The offsite radiation release continued for several days until the makeup tank venting through valve MU-V-13 was no longer necessary.

The measurements of the offsite radiation source characteristics showed that noble gases were the dominating contributor to the offsite source-term and that cesium and iodine contribution was negligible. This observation indicates that effectively all of the nongaseous fission products (cesium, iodine, strontium, etc.) inventory was retained by the TMI-2 buildings and equipment during the TMI-2 accident sequence.

The TMI-2 EX-RCS buildings and equipment are still being decontaminated. The decontamination process commenced April 27, 1979

30 days after accident initiation. All fluid systems have been flushed, fluid and gas filters removed, fluid treatment resin beds removed or decontaminated, and TMI-2 accident liquid effluent decontaminated. The decontamination has not yet reduced radiation to personnel-entry levels in the following areas:

1. The reactor building basement, which includes the letdown coolers, the RCDT, sediment containing fission products and core materials, and concrete, which has absorbed fission-product and core-material contaminated liquid.

2. The reactor building D-ring compartment, which contains the RCS B-loop.

3. The fuel handling building makeup and purification valve room, which contain the letdown system block orifice and piping.

The above conditions create a condition where (a) samples that are representative of or traceable to conditions which existed during the accident are no longer numerous and (b) sample acquisition from contaminated personnel exclusion areas is limited to what can be obtained with remote-operated hand tools and robots.

5.2 Purpose

The purpose of the EX-RCS sample acquisition and examination program is the retrieval and examination of reactor building basement sediment and absorber (concrete) samples. The examination objectives are to complete the EX-RCS search program for fission products and core materials which escaped from the RCS during and following the TMI-2 accident. The specific examination objectives are to determine the following:

- Abundance and distribution of fission products and core materials in EX-RCS buildings and equipment which are judged to be inadequately surveyed.

- Current condition of the fission products and core materials which are found.

5.3 Accomplishments

5.3.1 Introduction

The EX-RCS search program for the escaped radionuclides (fission products) and core materials has been a continuous effort since and including the day (March 28, 1979) of the accident. The expansion of the TMI-2 Core Examination Plan to a TMI-2 Accident Evaluation Program has resulted in resumption of an EX-RCS sample acquisition and examination work (search program) plan. The approach to developing a productive search program was to evaluate the current completeness of the search program by locating buildings and equipment which had not yet or only partially been inventoried for fission products. The evaluation developed the following:

1. A preliminary map (Figure 10) showing schematically the equipment, buildings, and areas where fission products may be present.

2. A preliminary matrix chart (Table 9) showing the extent of the already completed TMI-2 accident fission product search program.

3. Knowledge that many other organizations have participated in the planning and performance of the EX-RCS fission product inventory program and that most building areas and equipment have been decontaminated so that samples that are representative of or traceable to conditions which existed during the accident are no longer numerous.

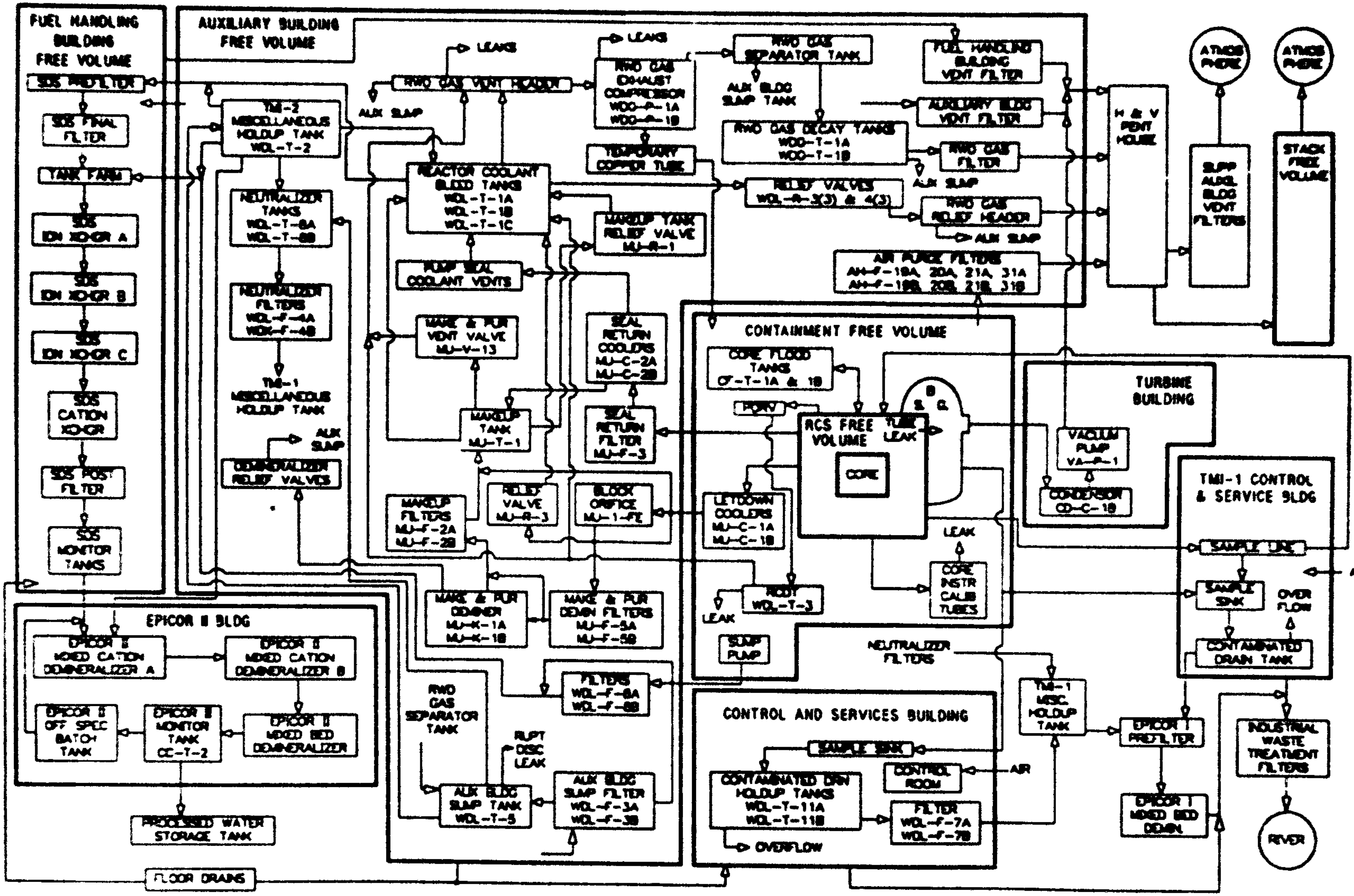


Figure 10. TMI-2 radioactive material location map.

TABLE 9. MATRIX TABLE OF COMPLETED FISSION PRODUCT INVENTORIES[b,c]

Location	Area Radiation Emission Mapping: γ and β	Area Radiation Emission Mapping: γ Spectra	Radiochemical Composition Examinations: Liquid	Radiochemical: Gas	Radiochemical: Solids and Sediment	Radiochemical: Surface Deposit	Radiochemical: Absorber	Chemical Composition Examinations: Liquid	Chemical: Gas	Chemical: Solids and Sediment	Chemical: Surface Deposit	Chemical: Absorber	Miscellaneous Information
Core and RV Lower Plenum	x	--	x	NA	x (0.2)	--	NA	x	NA	x (0.2)	--	NA	--
RV Upper Plenum	x	--	x	NA	x (0.5)	x (0.5)	NA	x	NA	x (0.5)	x (0.5)	NA	--[a]
Steam Generators	x	x	x	NA	--	--	NA	x	NA	--	--	NA	--[a]
Pressurizer	x	x	x	NA	--	--	NA	x	NA	--	--	NA	--[a]
RCS Piping, Pumps, and Valves (PP&V)	x	--	x	NA	--	x (Partial)	NA	--	NA	--	x (Partial)	NA	--[a]
Core Flood Tanks	x	--	--	--	--	--	NA	--	NA	--	--	NA	--[a]
Core Flood Piping	x	x	--	NA	--	--	NA	--	NA	--	--	NA	--
M&P Letdown Coolers	--	--	--	NA	--	--	NA	--	NA	--	--	NA	(One may be blocked)[a]
RCS Drain Tank	--	--	x	NA	x	--	NA	--	NA	x (Partial)	--	NA	--[a]
Containment Building Free Volume:													
1. 347 ft to Dome	x	x	NA	x	NA	x	x (Partial)	NA	x	NA	x	--	--
2. 305 ft to 347 ft	x	x	NA	x	NA	x	x (Partial)	NA	x	NA	--	--	(Partial)[a]
3. Bsmt. to 305 ft	--	--	x	x	x	x	--	x (Partial)	x (Partial)	--	--	--	10 in. water depth at [illegible] min
Core Instrument Tubes	x (Seal Table)	--	--	--	--	--	--	--	--	--	--	--	--
M&P Block Orifice	x	x	--	NA	--	--	NA	--	NA	--	--	NA	--[a]
M&P Demineralizer Filters (5A and [illegible])	1 of 2	x After Filter Removal	--	NA	--	1 of 2	NA	--	NA	--	--	NA	--[a]
M&P Demineralizers	x	--	x (Partial)	NA	x	--	NA	x (Partial)	NA	x	--	NA	--[a]
Makeup Filters (2A and [illegible])	1 of 2	x After Filter Removal	--	NA	x	--	NA	--	NA	x	--	NA	--[a]
Makeup Tank	Post Flush	x Post Flush	--	--	--	--	NA	--	--	--	--	NA	--[a]

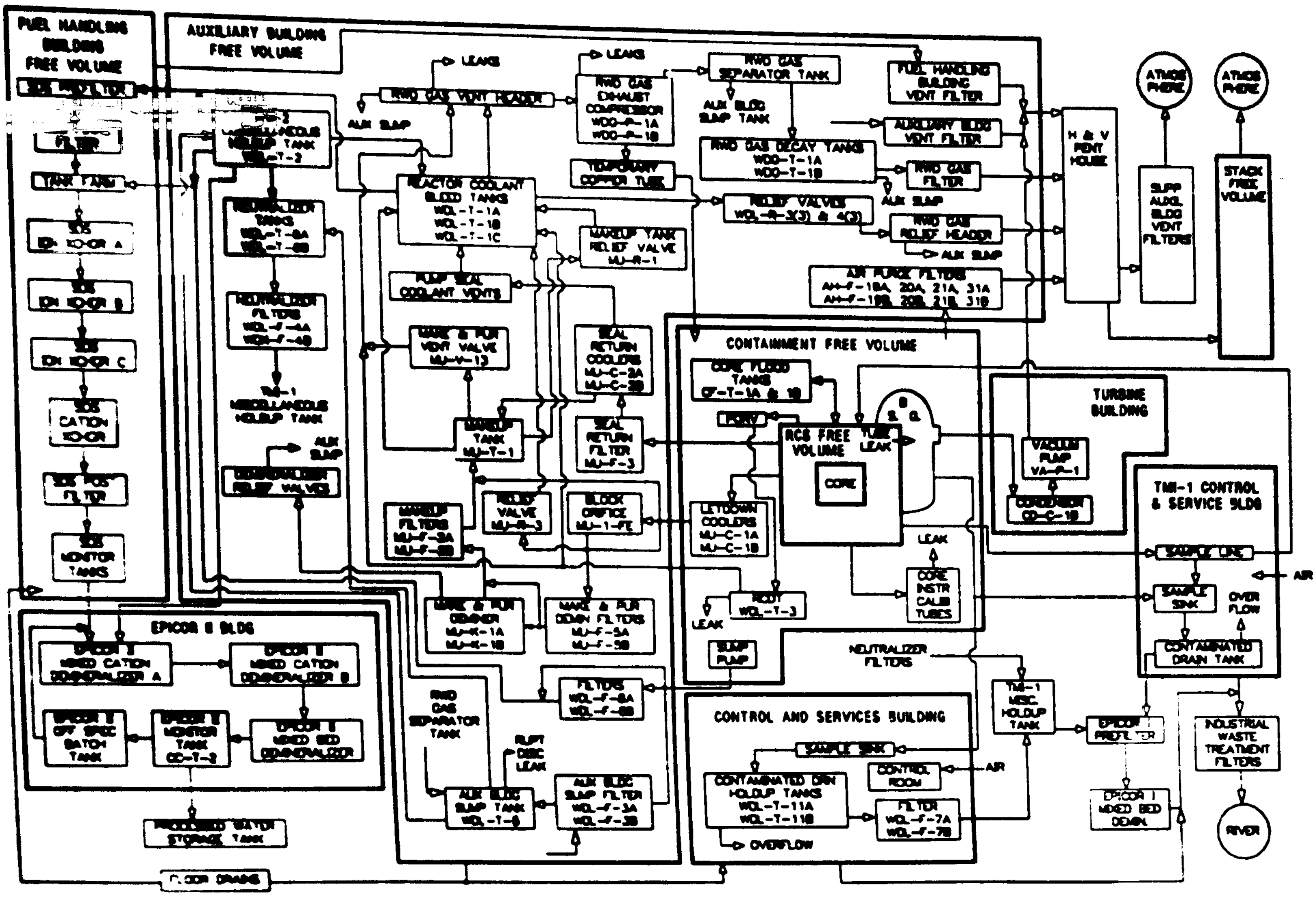


Figure 10. TMI-2 radioactive material location map.

TABLE 9. (continued)

Location	Area Radiation Emission Mapping: γ and β	Area Radiation Emission Mapping: γ Spectra	Radiochemical Composition Examinations: Liquid	Radiochemical: Gas	Radiochemical: Solids and Sediment	Radiochemical: Surface Deposit	Radiochemical: Absorber	Chemical Composition Examinations: Liquid	Chemical: Gas	Chemical: Solids and Sediment	Chemical: Surface Deposit	Chemical: Absorber	Miscellaneous Information
MAPS Pit	X (Partial) Post Flush	X (Partial) Post Flush	X	NA	--	--	NA	X	NA	--	--	NA	--[a]
Pump Seal Return Filter (F-3)	X	X	--	NA	--	--	NA	--	NA	--	--	NA	--[a]
Pump Seal Return Coolers	X	X	--	NA	--	--	NA	--	NA	--	--	NA	--[a]
Pump Seal Injection Filters (F-4a and 4b)	X	--	--	NA	X	--	NA	--	NA	X	--	NA	--[a]
Pump Seal PP&V	--	--	--	NA	--	--	NA	--	NA	--	--	NA	--[a]
Reactor Building Sump Filters (6A and 6B)	--	--	--	--	--	--	--	--	--	--	--	--	Pre-rod-burst contamination
RCS Liquid Waste PP&V													
1. Reactor Building	--	--	--	--	--	--	NA	--	--	--	--	NA	--
2. Auxiliary Building	--	--	--	--	--	--	NA	--	--	--	--	NA	--[a]
RCS Bleed Holdup Tanks													
1. WDL-T-1A	X	X	X 12/79	--	X	--	NA	X (Partial)	--	X	--	NA	Flushing began 8/20/81[a]
2. WDL-T-1B	X	--	X 1/80	--	X	--	NA	X (Partial)	--	X	--	NA	--[a]
3. WDL-T-1C	X	X	X 2/80	--	X	--	NA	X (Partial)	--	X	--	NA	[a]
Auxiliary Building Sump Filters (3A and 3B)	--	--	--	--	--	--	--	--	--	--	--	--	Post-core-damage contamination
Auxiliary Building Sump Tank	X	--	X 2/80	--	--	--	NA	X 2/80	--	--	--	NA	Post-core-damage contamination[a]
Miscellaneous Waste Hold-up Tanks	X	--	X	--	--	--	NA	X	--	--	--	NA	Post-core-damage contamination[a]
Neutralizer Tanks	--	--	--	--	--	--	--	--	--	--	--	--	Post-core-damage contamination[a]
Neutralizer Filter (4A and 4B)	X 9/25/81	--	X	--	--	--	--	X	--	--	--	--	Post-core-damage contamination

TABLE 9. (continued)

Location	Area Radiation Emission Mapping: γ and β	Area Radiation Emission Mapping: γ Spectra	Radiochemical Composition Examinations: Liquid	Radiochemical: Gas	Radiochemical: Solids and Sediment	Radiochemical: Surface Deposit	Radiochemical: Absorber	Chemical Composition Examinations: Liquid	Chemical: Gas	Chemical: Solids and Sediment	Chemical: Surface Deposit	Chemical: Absorber	Miscellaneous Information
Auxiliary Building Radwaste Disposal Systems P&PV	--	--	X	--	--	--	--	--	--	--	--	--	--
M&P Relief Valve Header	--	--	--	--	--	--	--	--	--	--	--	--	--
Reactor Coolant Process Gas Decay Tanks	--	--	--	X	--	--	NA	--	--	--	--	NA	--
Reactor Coolant Process Gas Exhaust Compressor	--	--	NA	--	--	--	NA	NA	--	--	--	NA	--
Reactor Coolant Process Gas Exhaust Filter	--	--	NA	NA	--	--	?	NA	NA	--	--	NA	--
Reactor Coolant Process Gas Ducting and Valves	--	--	NA	X	--	--	NA	NA	--	--	--	NA	--
Auxiliary Building Ventilation Filter	--	--	NA	X	--	--	?	NA	--	--	--	NA	--
Fuel Handling Building Ventilation Filter	--	--	NA	--	--	--	?	NA	--	--	--	NA	--
Auxiliary Building Ventilation Ducting, Valves, and Compressor	--	--	NA	X	--	--	NA	NA	--	--	--	NA	--
Reactor Building Air Purge Filters	--	--	NA	--	--	--	?	NA	--	--	--	NA	--
Reactor Building Air Purge Ducting, Valves, and Compressor	--	--	NA	--	--	--	NA	NA	--	--	--	NA	--
Auxiliary Building Free Volume													
1. 328 ft to [illegible]	--	--	--	X	--	--	--	--	--	--	--	--	--
2. 305 ft to 328	--	--	--	X	--	--	--	--	--	--	--	--	--
3. 281 ft to 30[illegible]	--	--	X	X	--	--	--	X	--	--	--	--	--

TABLE 9. (continued)

Location	Area Radiation Emission Mapping: γ and β	Area Radiation Emission Mapping: γ Spectra	Radiochemical Composition Examinations: Liquid	Radiochemical: Gas	Radiochemical: Solids and Sediment	Radiochemical: Surface Deposit	Radiochemical: Absorber	Chemical Composition Examinations: Liquid	Chemical: Gas	Chemical: Solids and Sediment	Chemical: Surface Deposit	Chemical: Absorber	Miscellaneous Information
Fuel Handling Building Free Volume	--	--	X	--	--	--	--	X	--	--	--	--	--
Process Gas Separator Tank	--	--	--	--	--	--	NA	--	--	--	--	NA	? NUREG-0600, pII-3-11
Vent Stack Free Volume	--	--	NA	X	--	--	--	NA	--	--	--	--	Capped 5/20/79 through [illegible]/28/80
Auxiliary Building Supplemental Filters	--	--	NA	--	--	--	?	NA	--	--	--	--	Utilized 5/1/79 through [illegible]/28/80
Contaminated Drain Tank	[illegible]	--	X	NA	--	--	NA	X	NA	--	--	NA	--[a]
Contaminated Drain Tank Filters	--	--	--	--	--	--	--	--	--	--	--	--	--
Control and Service Buildings Radwaste Disposal System PP&V	--	--	--	--	--	--	--	--	--	--	--	--	--
Reactor Coolant Sample Line and Valves	--	--	X[a]	--	--	--	--	--	--	--	--	--	--
TMI-1 Contaminated Drain Tank	--	--	--	--	--	--	--	--	--	--	--	--	Utilized until 6/17/80
TMI-1 Control and Services Building Free Volume	--	--	--	--	--	--	--	--	--	--	--	--	--
TMI-1 Miscellaneous Holdup Tanks	--	--	--	--	--	--	--	--	--	--	--	--	--
Industrial Waste Treatment Filters	--	--	--	--	--	--	--	--	--	--	--	--	--
Industrial Waste Treatment PP&V	--	--	X	--	--	--	--	--	--	--	--	--	--
EPICOR I Prefilter	--	--	--	--	--	--	--	--	--	--	--	--	--
EPICOR I Demineralizers	--	--	--	--	--	--	--	--	--	--	--	--	--
EPICOR I PP&V	--	--	--	--	--	--	--	--	--	--	--	--	--
EPICOR II Demineralizer A	--	--	--	--	--	--	--	--	--	--	--	--	--

TABLE 9. (continued)

	Area Radiation Emission Mapping		Radiochemical Composition Examinations					Chemical Composition Examinations					
Location	γ and β	γ Spectra	Liquid	Gas	Solids and Sediment	Surface Deposit	Absorber	Liquid	Gas	Solids and Sediment	Surface Deposit	Absorber	Miscellaneous Information
EPICOR II Demineralizer B	--	--	--	--	--	--	--	--	--	--	--	--	--
EPICOR II Mixed Bed Demineralizer	--	--	--	--	--	--	--	--	--	--	--	--	--
EPICOR II Monitor Tank	--	--	X?	--	--	--	--	--	--	--	--	--	--
EPICOR II Off-Spec Batch Tank	--	--	--	--	--	--	--	--	--	--	--	--	--
EPICOR II Piping, Pumps, and Valves	--	--	--	--	--	--	--	--	--	--	--	--	--
SDS Prefilter	--	--	--	--	X	--	--	--	--	X (TRU)	--	--	--
SDS Final Filter	--	--	--	--	X	--	--	--	--	X (TRU)	--	--	--
SDS Tank Farm	--	--	--	--	--	--	--	--	--	--	--	--	--
SDS Ion Exchanger A	--	--	--	--	X	--	--	--	--	X (TRU)	--	--	--
SDS Ion Exchanger B	--	--	--	--	X	--	--	--	--	X (TRU)	--	--	--
SDS Ion Exchanger C	--	--	--	--	X	--	--	--	--	X (TRU)	--	--	--
SDS Post Filters	--	--	--	--	--	--	--	--	--	--	--	--	--
SDS Monitor Tanks	--	--	X?	--	--	--	--	--	--	--	--	--	--
SDS Piping, Pumps, and Valves	--	--	--	--	--	--	--	--	--	--	--	--	--
Atmosphere	X	X	NA	X	NA	--	--	NA	--	NA	--	--	--
Susquehanna River	--	--	X?	--	--	--	--	--	--	--	--	--	--

a. Science Applications Inc. (SAI) history.

b. (X) indicates record exists of in situ measurement or sample examination.

c. (%X) indicates fraction of equipment, building, or area inventories.

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5.3.2 Acquisition

Tooling. The EX-RCS sample acquisition program has developed and provided the following sample acquisition tooling:

Drawing/Report Number	Description/Title	Status
TBD	Electrically-operated, vacuum-actuated, remote-operated liquid/sediment sampler	Complete

The gamma spectrometer equipment listed in Subsection 4.3.1 will also be used in the EX-RCS fission product inventory program.

Samples. The EX-RCS sample acquisition program has furnished the following fission product inventory samples to EG&G for examination:

TMI-2 Location	Sample Type	Quantity	Date Acquired
Reactor coolant bleed tank A	Liquid (filtered)	125 ml	Dec. 1979
Reactor coolant bleed tank B	Liquid (filtered)	150 ml	Jan. 1980
Reactor coolant bleed tank C	Liquid (filtered)	150 ml	Feb. 1980
Reactor coolant bleed tank A	Solids (sediment)	60 g	Aug. 1981
Makeup and purification demineralizer prefilter (MU-F-5B)	Solid debris Filter w/some filter paper remaining	2 g 204 g (filter paper, liquid, and collected solids)	Feb. 1981 1982
	Vacuum collected debris	small	Mar. 1982
Makeup and purification demineralizer prefilter (MU-F-5A)	Vacuum collected debris	small	Mar. 1982

Makeup and purification demineralizer after filter (MU-F-2A)	Filter	406 g (filter paper, liquid, and collected solids)	Mar. 1982
	Vacuum collected debris	436 g (filter paper, liquid, and collected solids)	Mar. 1982
Makeup and purification demineralizer after filter (MU-F-2B)	Filter	206 g (filter paper, liquid, and collected solids)	Feb. 1982
	Vacuum collected debris	small	Mar. 1982
Makeup and purification demineralizer A (MU-K-1A)	Solid (resin)	10 g	Apr. 1983
Makeup and purification demineralizer B (MU-K-1B)	Slurry (liquid and resin)	12 Samples (80 ml total w/40 ml solids)	Apr. 1983
Pump sealwater injection filter (MU-F-4A)	Filter	83 g (filter paper, liquid, and collected solids)	Mar. 1982
	Vacuum collected debris	80 g	Mar. 1982
Pump sealwater injection filter (MU-F-4B)	Filter	Not measured	Mar. 1982
	Vacuum collected debris	Small	Mar. 1982
Basement 305 ft floor elevation under south equipment hatch (entry 10)	Liquid and sediment	110 ml with 108 g filtered solids	May 1981
Basement 305 ft elevation in the open stairwell	Liquid and sediment	120 ml with 25 g filtered solids	Sept. 1981
Bottom of open stairwell	Slurry	45 ml with 1 g solids	June 1982
Basement sump pit	Liquid and sediment	200 ml with 72 g filtered solids	Aug. 1983

Reactor coolant drain tank (WDL-T-3)	Liquid and sediment	120 ml with 0.5 mg filtered solids	Dec. 1983
Reactor building air coolers	Access panels, 30 x 40 in.	5	Aug. 1983

Table 9 identifies the locations of many other in situ measurements and sample acquisitions and examinations which have been accomplished since 4 a.m. on March 28, 1979 to locate and characterize the fission products that escaped from the RCS during the accident.

5.3.3 Examination

The EG&G-controlled fission product inventory support program has produced the following reports:

Report Number	Description/Title	Status
GEND-INF-011	First Results of the TMI-2 Sump Samples Analyses Entry 10	Complete July 1981
GEND-INF-011 Vol. II	Reactor Building Basement Radionuclide Distribution Studies	Complete Oct. 1982
GEND-INF-011 Vol. III	Reactor Building Basement Radionuclide and Source Distribution Studies	Complete June 1983
GEND-INF-039	Final Analysis on TMI-2 Reactor Coolant System and Reactor Coolant Bleed Tank Samples	Issued June 1983
GEND-042	TMI-2 Reactor Building Source Term Measurements: Surface and Basement Water and Sediment	Complete Oct. 1984
EGG-TMI-6181	Interim Report on the TMI-2 Purification Filter Examination	Complete Feb. 1983
EGG-TMI-6580	TMI Particle Characterization Determined from Filter Examinations	Draft Complete Sept. 1984
GEND-INF-041	Radionuclide Mass Balance for the TMI Accident: Data Through 1979 and Preliminary Assessment of Uncertainties	Complete Nov. 1981

GEND-INF-054	Results of Analyses Performed on Concrete Cores Removed from Floors and D-Ring Walls of the TMI-2 Reactor Building	Issued June 1984
H. M. Burton (EG&G) ltr. to B. K. Kanga (GPU) Hmb-207-83	Purification Demineralizer Resin Samples	Issued June 22, 1983

Reports by others which describe and/or evaluate the fission product inventory investigation program include the following:

- SAI-139-82-14 RV, Characterization of Contaminants in TMI-2 Systems Interim Report, October 1982.

- NUREG 0600, Investigation into the March 28, 1979 Three Mile Island Accident by Office of Inspection and Enforcement, August 1979.

- NSAC-80-1, Analysis of Three Mile Island Unit 2 Accident, March 1980.

- NRC Special Inquiry Group (Rogovin), Three Mile Island, A Report to the Commissioners and to the Public.

- GEND-013, TMI-2 reactor building Purge--Kr-85 Venting, March 1981.

- GPU Nuclear TDR 055, Pathways for Transport of Radioactive Material Following the TMI-2 Accident, July 1981.

- GEND-031, Submerged Demineralizer System Processing of TMI-2 Accident Waste Water, February 1983.

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

- GPU TDP 85-10, Estimates of TMI-2 Letdown Demineralizer Resin Retained and Eluted Fission Products and Fuel, April 1985.

- GPU TPO/TMI-043 Rev. 4, Radioactive Waste Management Summary Review, August 1985.

A substantially complete list of reports of the EX-RCS fission product inventory program can be compiled using the reference lists from the reports listed above.

5.3.4 Findings

Estimates of TMI-2 accident fission products and core materials deposited in the EX-RCS buildings, as reported in the Fission Product Inventory Program FY-85 Status Report (EG&G 2407 draft to be published at a later date), are shown in Table 10. The estimates were derived from the FPI program in situ measurement and sample examination data. In general, low-volatility and water-insoluble core material (uranium) and fission products (strontium and antimony) did not escape from the RCS.

It is evident from the TMI-2 accident chronology that the offsite radiation release is not directly related in time to the core damage sequence phase, which occurred from 120 to 240 minutes after accident initiation. Instead, the offsite radiation release occurred during accident recovery phases after reactor coolant was replenished. The accident recovery phases include a sustained high-pressure injection period from 267 to 544 minutes and a forced-circulation (RC-P-1A operation) period commencing at 950 minutes (15 hours 50 minutes). It is believed that (a) the relatively stagnant RCS flow conditions during the core damage sequence probably confined medium-to-low-volatility fission products, such as cesium, iodine, and strontium to the reactor vessel region and (b) significant escape of the medium-to-low-volatility fission products from the reactor vessel occurred by leaching, suspension, and carryout by the reactor coolant during core cooling in accident recovery periods. As a

TABLE 10. LOCATION OF FISSION PRODUCTS INVENTORY IN PLANT BUILDINGS[b]

Location	Tritium	Kr-85	Fraction of Core Inventory											
			Sr-90	Xe-133	Ru-106	Sb-125	I-129	I-131	Te-132	Cs-134	Cs-137	Ce-144	U	Pu
1. Reactor Building	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
2. Reactor Coolant System[a]	0.02	--	0.01	--	--	0.001	0.012	0.11	--	0.008	0.008	4 E-04	--	--
3. Reactor Pressure Vessel	--	--	0.12	--	--	0.08	0.05	--	--	0.05	0.06	0.26	--	--
4. Auxiliary Building	0.04	--	--	--	--	7 E-05	0.02	--	--	0.01	0.008	7 E-06	--	--
5. Fuel Handling Building[c]	(0.62)[c]	--	(0.02)[c]	--	--	--	--	--	--	(0.46)[c]	(0.45)[c]	--	--	--
6. EPICOR II Building[c]	(0.042)[c]	--	(0.001)[c]	--	--	--	--	--	--	(0.034)[c]	(0.027)[c]	--	--	--
7. TMI-1 Buildings	--	--	--	--	--	--	--	--	--	--	--	--	--	--
8. Releases	4 E-04	--	8 E-10	0.07	--	--	--	1 E-06	--	--	7 E-12	--	--	--
Total	0.63	0.47[e]	0.15	0.35	--	0.08	0.30	0.32	--	0.49	0.49	0.26	--	--
Alternate Total[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. EGG-2407 draft, Fission Product Inventory Program FY-85 Status Report.

c. Not additive towards total inventory. Fraction collected by SDS or EPICOR-II water cleanup system.

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 was vented in April-June 1980, but activity was not released during the accident.

result, the core damage sequence-of-events and the offsite radiation release on which the EX-RCS fission product inventory program is based are weakly connected chronologically.

It appears that the greatest offsite radiation release occurred during the following periods:

- 20 to 92 hours after accident initiation, due to probable noble gas dominated fission product escape from the vent stack via the letdown and radwaste disposal gas vent and relief systems.

- 6 to 11 hours after accident initiation, due to probable noble gas dominated fission product escape from the vent stack via the letdown and/or radwaste disposal gas vent and relief systems.

Other findings include the following:

1. The reactor building sump to auxiliary building liquid escape path was closed prior to fission product escape from the fuel rods.

2. Most TMI-2 EX-RCS buildings and equipment have been completely or partially decontaminated by flushing, water treatment, contaminated filter removal, and water treatment resin removal.

5.4 Detailed Work Plan

The EX-RCS sample acquisition and examination program work plan details are contained in the following work packages:

Work Package Number	Work Package Title
751421300	Equipment, building characterization
755420300	EX-RCS fission product inventory sample examination

Table 11 summarizes the sample (reactor building basement sediment and concrete bores) acquisition and examinations which are included in this work plan. The table includes the AEP-designated sample priority (1-20), the number of samples, the TMI-2 accident information expected from the examination plan, and the examination techniques which will be used to obtain the information.

Other EX-RCS fission product sample examinations that were considered include the following:

Sample Description	AEP Priority	Sample Quantity
1. Reactor building basement sediment from the elevator and sump well floor depressions	10	2 one kg samples
2. RB basement wall liner adherent surface deposit	Low	2
3. Equipment internal deposits:	Low	
a. Reactor coolant drain tank:		
• Sediment (only 9 mg was collected and examined)		1
• Adherent surface deposit		1
b. Letdown coolers:		
• Sediment		2
• Adherent surface deposits		2
c. Letdown block orifice:		Entire orifice
• Sediment		
• Adherent surface deposits		

The impact of not examining these samples is judged to be minimal for the following reasons:

1. The other 12 reactor building basement floor sediment samples will provide sufficient data to assess the abundance of fission products and core materials in the basement sediment.

TABLE 11. EX-RCS SAMPLE ACQUISITION AND EXAMINATION PLAN SUMMARY

Sample Description	AEP Priority[a]	Number of Samples		TMI-2 Accident Information	Examination Methods[b]
1. RB basement sediment:	10	12		Volume/weight	2
a. Floor (282 El):			10	Particle size (transportability)	4
1. RCDT discharge area			3	Color, surface texture shape	1
2. Leakage cooler room, RCDT room, inside D-ring areas			7	Total radioactivity	11
				Fission product abundance and distribution:	
b. Core instrument cable chase			2	Mn-54, Co-60, Ru-106, Ag-110, Sb-125, Cs-134/137, Ce-144, Eu-154/155	6
				I-129	6,7
				Sr-90	8
				Te	9
				Core material abundance and distribution:	
				Zr, Fe, Ni, Ag, In, Cd, Cr, Sn, Al, Mn, Si, Cu, Co, Mg, Mo, Nb, Pb, Ca, K, S, Ba, Na, Ti	9
				U (includes U-235)	5,10
2. RB basement concrete absorption:	11	12		Surface condition (color, texture)	1
5000-psi (D-ring) wall bores			3	Concrete density	2,3
3000-psi (shield) wall bores			3	Fission product abundance and distribution in concrete:	
Block (elevator/stairwell) bores			3	Depth of fission product penetration	11,12,5
Floor bores			3	Fission product abundance and distribution:	
				Mn-54, Co-60, Ru-106, Ag-110, Sb-125, Cs-134/137, Ce-144, Eu-154/155	6
				I-129	6,7
				Sr-90	8
				Te	9
				Core material abundance and distribution:	
				Zr, Fe, Ni, Ag, In, Cd, Cr, Sn, Al, Mn, Si, Cu, B, Gd, Te, Mg, Mo, Nb, Pb, Ca, K, S, Ba, Na, Ti	9
				U (including U-235)	5,10

a. Priority values 1 through 20 are listed in Table 3.

b. Examination Methods: (1) Photography, (2) Balance weighing, (3) Dimensional (length and diameter) measurements, (4) Sieving, (5) Mill or grind concrete bore into eight powder samples and dissolve, (6) Germanium-crystal gamma spectrometry, (7) I-129 radiochemistry, (8) Sr-90 radiochemistry, (9) Inductively-coupled-plasma emission spectrometry, (10) Delayed neutron radiochemistry, (11) Ion-chamber gamma detector (including scans), (12) Autoradiograph maps (photographic paper in contact with outside surface).

2. The basement floor sump well was already sampled by collecting a liquid/suspended-solids sample during sump-pump-recirculation agitation of the sump contents, and only small quantities of fission products and core materials were found in the samples.

3. A prior reactor coolant drain tank sediment sample collection with remote-operated hand tools indicated the RCDT contains very little sediment, fission products, or core materials.

4. The letdown line sediment and adherent deposits are believed to be small due to continual flushing action during the accident sequence. If suspected plugging of one letdown cooler is confirmed, the importance of letdown cooler sediment samples will be reconsidered. A pin-hole-type gamma camera survey of the block orifice indicated the block orifice does not contain as much fission product contamination as the nearby bypass line plumbing, which is inconsistent with the suspicion of block orifice plugging that had been the basis for considering acquisition and examination of the block orifice.

5. The TMI-2 accident sequence history information is not obtainable from the letdown system retained fission product and core material characterization because of post-accident flushing and the inability to segregate the sediment chronologically. The solids, which became suspended by the forced circulation of reactor coolant through the reactor coolant system, which commenced about 16 hours after accident initiation, would dominate the deposits in the letdown system and would not be traceable to chronological details of the accident sequence of events.

6. The location and abundance of fission products and uranium in the letdown system and RCDT plumbing can be determined adequately using pin-hole-type gamma camera surveys, thermoluminescent detector strings, and portable gamma-spectrometer detectors.

The product of the EX-RCS sample acquisition and examination program work plan consists of (a) samples of reactor building basement floor loose deposits (sediment), wall and floor concrete, and outside wall adherent surface deposits, and (b) technical reports of sample examinations as follows:

Work Package Number	Work Package Title	Target Completion Date
751421300	a. Reactor building basement floor sediment samples:	
	• Impingement area (below air coolers)	October 1985
	• Inside A-loop D-ring	October 1985
	• Outside B-loop D-ring	October 1985
	• Outside A-loop D-ring	November 1985
	• RCDT room	November 1985
	• Inside B-loop D-ring	December 1985
	• RCDT discharge area	January 1986
	• Leakage cooler room	January 1986
	• Elevator depression	February 1986
	• Core instrument cable chase depression	March 1986
	• Sump pit	March 1986
	b. Reactor building basement wall and floor concrete bores:	
	• 5000 psi (D-ring) wall	1987
	• 3000 psi (shield) wall	1987
	• Block (elevator/stairwell) wall	1987
	• Floor (locations to be determined)	1988
	c. Reactor building basement outside wall adherent surface deposit sample (tentative)	TBD
755420300	a. Reactor building basement floor sediment examination report	February 1987
	b. Reactor building basement wall and floor concrete examination report	February 1989
	c. Reactor building basement outside wall adherent surface deposit sample examination report	TBD

Additional reporting will be done by means of the test-and-inspection-services subcontractor's periodic progress reports and incorporation of progress-report examination data into the annual fission product inventory program updates to be prepared by the Examination Requirements and Systems Evaluation Group.

5.5 Synopsis

The EX-RCS sample acquisition and examination plan is expected to satisfactorily complete the inventory of the TMI-2 accident fission products which escaped from the reactor coolant system and deposited in the TMI buildings and equipment. The reactor building basement sediment deposits are not expected to contain significant quantities of core materials, because only small-leak-type escape paths to the reactor basement existed for the solid core material. The reactor building basement concrete, which was submerged, is expected to be a repository for significant quantities of water-soluble fission products such as cesium or water-suspended fission product fines.

6. SAMPLE ACQUISITION AND EXAMINATION PROJECT MANAGEMENT SUPPORT WORK PLAN

6.1 Purpose

The TMI accident evaluation program sample acquisition and examination project management support provides the following:

a. Recruitment, maintenance, and supervision of a clerical and technical support staff.

b. Planning, technical direction, control, and documentation for the TMI-2 Accident Evaluation Program in situ measurements and sample acquisition and examinations.

c. Planning, technical direction, control, documentation, and maintenance of related support equipment (both hardware and software).

The documentation support includes periodic (weekly, monthly, annual) report contributions and formal status and technical presentations to EG&G, DOE, and special review and technical society groups.

6.2 Accomplishments

Visible products of the management support are the periodic status reports which have emanated from the project since the creation (1981) of the EG&G-operated TMI Unit 2 Technical Information and Examination Program and the following special reports:

Report Number	Description/Title	Status
EGG-TMI-6169	TMI-2 Core Examination Plan	Revised July 1984
PF-NME-84-005	Participating Laboratories Survey	Completed Sept. 1984

The deliverable products of the management support work plan are as follows:

Product	Target Completion Date
a. <u>TMI-2 Accident Evaluation Program Sample Acquisition and Examination Plan</u>:	
• First draft	Complete September 1985
• Second draft	Complete October 1985
• Executive summary	December 1985
• Final	December 1985
• Annual updates	October
b. TMI-2 accident-related reference document listing	February 1986

7. SUMMARY

The material presented in the previous sections is intended to accomplish the following:

1. Explain the development of the examination plan for the severe core damage accident issues set forth in the TMI-2 Accident Evaluation Program document from sample selection to final reporting of the sample examination results.

2. Provide a perspective of the status of the TMI-2 accident investigation by identifying the examination program accomplishments in prior years.

3. Be flexible to accommodate new findings, information, and knowledge that may become available from either this examination plan, the GPU Nuclear defueling program, or any SCD research program.

4. Develop a TMI-2 accident examination program manual which can be (1) revised annually as new findings cause redirection and (2) used for referenced by the analysts performing the studies needed to develop the understanding of the TMI-2 accident sequence and its radiological consequences.

The proposed financial plan for the SA&E plan is shown in Table 12, and the companion schedule of activities is shown in Table 13. The list of work package numbers and titles on Table 12 identifies the entire Work Breakdown Structure for the SA&E plan. In brief, the SA&E Plan Work Breakdown Structure provides the following:

1. Acquisition of the samples listed in Table 4 in the Future Additional Samples column. For FY-1986 this includes: as many core bores as possible from up to twelve locations during the 30-days scheduled for core boring, six approximately 6-in. long

TABLE 12. TMI-2 AEP SAMPLE ACQUISITION AND EXAMINATION WORK BREAKDOWN STRUCTURE AND FUNDING PLAN

Work Package Number	Description	Funding Plan ($ X 1000) FY-1985	FY-1986	FY-1987	FY-1988	FY-1989	Total
Reactor Vessel SA&E							
7514202	Reactor vessel internal (acq)	52	81	0	0	0	133
7514203	RTD thermowells (acq)	7	0	0	0	0	7
7514204	Lower Head Debris (acq)	70	0	0	0	0	70
7514205	Fueled rod segments (acq)	107	202	0	0	0	309
7514206	Stratification (core bore acq)	1679	1723	0	0	0	3402
7514208	Control rod leadscrew (acq)	16	0	0	0	0	16
7514212	Discrete core components (acq)	18	199	500	270	0	987
7554201	Debris bed sample (exam)	411	209	10	0	0	630
7554202	Reactor vessel internals documentation	52	237	0	0	0	289
7554205	Fuel rod segments (exam)	7	0	0	0	0	7
7554206	Stratification sample (exam)	8	1063	1207	190	0	2468
7554208	Control rod leadscrew (exam)	153	0	0	0	0	153
7554209	Leadscrew support tube (exam)	62	0	0	0	0	62
7554212	Core distinct component (exam)	8	144	334	406	0	892
7554216	Lower vessel debris examination	1	379	0	0	0	380
New	Core former wall examination	0	0	165	0	0	165
New	Core support assembly examination	0	0	0	250	0	250
New	RV instrument penetration examination	0	0	0	0	250	250
New	RV lower head examination	0	0	0	0	165	165
9MA8501	Sample handling equipment	455	369	0	0	0	824
9M78402	Core bore equipment	1710	0	0	0	0	1710
9M78306	Core topography system phase 2	377	170	0	0	0	547
9MA8404	Image Processing	259	0	0	0	0	259
RCS FPI SA&E							
751421	RCS gamma scan (acq)	97	105	207	243	0	652
755421	RCS FPI sample examination	19	53	443	3	0	518
Ex-RCS FPI SA&E							
7514213	Equipment/building characterization (acq)	0	105	250	175	0	530
7554203	Ex-RCS FPI sample examination	8	162	36	249	13	468
SA&E Program Management Support							
75542PM	Project management	158	493	396	362	0	1409
	Subtotal	5734	5694	3548	2148	428	17552
	Other DOE Labs	115	308	568	75		1066
	Costs prior to 1985						1966
	Total						20584

TABLE 13. TMI-2 AEP SAMPLE ACQUISITION AND EXAMINATION PLAN SCHEDULE SUMMARY

Activity Description	Schedule FY-1986	FY-1987	FY-1988	FY-1989
A. Sample Acquisition and In Situ Measurement Program				
1. Core and subcore bores	X			
2. Six approximately 6-in. long fuel rod segments	XXXX			
3. Small grab samples from upper core debris	X			
4. Large grab samples from upper core debris	X			
5. Fuel assembly upper sections[a]	XXXX			
6. Burnable poison rod spiders	XXXX			
7. Control rod spiders	XXXX			
8. APSR surface deposit	XXXX			
9. Fuel assembly lower sections[b]		XXXXX		
10. Core cavity topography after loose debris removal	X			
11. CCTV of lower core support structure	XX			
12. Core material samples from lower head region: small	X			
large	X			
13. Lower core support structure region loose debris	XX			
14. Control rod leadscrews		XXXXXXXXX	XXXXXXXX	
15. Core former wall samples		XXXXXX	XXXXXXXXXXX	
16. Core lower support structure plate samples		XXXXX	XXXXXXXXXXX	
17. Reactor vessel lower head samples			XXXXXXXXXX	
18. Upper plenum horizontal surface deposits			XXXXX	
19. Lower plenum instrument structures			XXXXX	
20. RCS gamma scans[c]	XXXXXXXXX			
21. B-loop RTD thermowell	XXX			
22. A-loop steam generator handhole cover liner	XXX			
23. B-loop steam generator manway cover backing plate	XXX			
24. Pressurizer manway cover backing plate	XXX			
25. Steam generator tube sheet top and lower head loose debris	XXXXXXX			
26. Pressurizer lower head loose debris	XXX			
27. Reactor building basement floor sediment:				
• RCDT discharge area	XXXX			
• Leakage cooler room, RCDT room, inside and outside D-rings	XXXXXXXX			
• Core instrument chase	XXXXXXXXX			
28. Reactor building basement concrete bores:				
• Floor		XXXXXX		
• D-ring (5000 psi) walls		XXXXXX		
• Shield (3000 psi) walls		XXXXXX		
• Block (elevator and stairwell walls)		XXXXXX		
29. Reactor building basement outer wall steel liner surface	TO BE DETER	MINED		
B. Sample and Data Examination Program				
1. Core region bores	XXXXX	XXXXXXXXXXXX		
2. Subcore region bores	XXXXX	XXXXXXXXXXXX		
3. Fuel assembly upper sections	XXX			
4. Fuel, control, and burnable poison rod sections (upper core)		XXXXXX		
5. Small grab samples from upper core region	XXXXXXX	XXX		
6. Large grab samples from upper core region	XXXXXXX	XXX		
7. Fuel assembly lower sections			XXXX	
8. Fuel, control, and burnable poison rod sections (lower core)			XXXXXXX	
9. Core material samples from upper head region: small	XXXXXXXXXX			
large	XXXXXXXXXX			
10. Lower core support structure region loose debris		XXXXXXXX	XXXXXXXXXXXXXX	XXX
11. Core former wall samples[d]		XXXXXX	XXXXXXXXXXXXXX	XXX
12. Core lower support structure plate samples[d]		XXXX	XXXXXXXXXXXXXX	XXX
13. Reactor vessel lower head samples[d]			XXXXXXXX	XXX
14. Lower plenum instrument structures[d]			XXXX	XXX
15. RCS gamma scan data analysis[d]	XXXXXXXXXXXX			
16. B-loop RTD thermowell[d]	XXXXXX			
17. Steam generator/pressurizer handhole cover/manway liner surfaces[d]		XXXXXXXXXXX		
18. Steam generator/pressurizer loose deposits[d]		XXXXXXXXXX	XX	
19. Reactor building basement floor sediment samples[d]	XXXXXXXX	XXXX		
20. Reactor building basement concrete bores[d]			XXXXXXXXXXXX	XXX

a. Expected to contain spiders; upper end fittings including holddown springs; spacer grids; and fuel rod, guide tube, control rod, burnable poison rod, and instrument string sections.

b. Assumed to contain lower end boxes; spacer grids; fuel rod, guide tube, control rod, burnable poison rod and instrument string sections; and solidified previously molten core material.

c. Includes steam generator insides, pressurizer inside, pressurizer surge line, decay heat removal line.

d. Examination will be performed by an outside laboratory.

fuel rod segments, control rod and burnable poison rod spiders, fuel assembly upper end fittings, fuel assembly upper sections, additional core material samples from the loose debris at the floor of the core cavity and from the lower head region; RCS adherent surface deposit samples from a resistance thermal detector (RTD) thermowell, a steam generator handhole cover liner, and from pressurizer and steam generator manway cover backing plates; RCS loose debris samples from the top of the steam generator tube sheets, the steam generator lower plenum, and the pressurizer lower head; and approximately 17 sediment samples from the reactor building basement floor. Acquisition of the remaining samples is planned for FY-1987 and beyond.

Examination of the samples listed in the Proposed Future Exams column of Table 4. For FY-1986 this includes initiating the examination of six core bores, four fuel rod segments, one control rod segment, one burnable poison rod segment, nine particles of the reactor vessel lower head debris, two "large" samples of core cavity floor loose debris, the B-loop hot leg RTD thermowell, and approximately 12 reactor building basement sediment samples. Initial examination of the remaining "Proposed" samples is planned for FY-1987 and FY-1988.

The TMI-2 AEP will evaluate the availability of and pursue other resources to examine all the samples listed in the Future Additional Samples column of Table 4. Potential resources include the NRC, OECD/CSNI,[a] and domestic fuel suppliers.

A cost breakdown showing the proposed proportions of examination activities to the INEL, private laboratories, and other DOE laboratories is shown in Table 14.

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a. Organization for Economic Cooperation and Development, Committee on the Safety of Nuclear Installations.

TABLE 14. COST BREAKDOWN OF TMI-2 ACCIDENT EVALUATION PROGRAM SAMPLE EXAMINATION

	Funding ($ x 1000)		
Task	INEL	Private Laboratories	Other DOE Laboratories
1. Subsurface debris bed samples	260.0	--	50[a]
2. Ex-reactor coolant system fission product inventory	--	399	--
3. Core bores	1,140.1	--	666.7 500[a]
4. Reactor coolant system fission product inventory	18	375.4	--
5. Discrete core components	740	--	251
6. Lower vessel debris	600	--	50[a]
7. Core former wall samples	25	121	--
8. Core support assembly samples	40	183	--
9. Instrument tube penetrations	40	183	--
10. Reactor vessel lower head samples	40	121	--
Totals	2,903.1	1,382.4	1,517.7

a. Work performed at ANL-E and funded by NRC.

Further subdivision of the Work Breakdown Structure occurs during the process of authorizing the performance of work. INEL staff support and equipment and facilities operations are authorized using a system of Work Releases for nonunion supported activities and Site Work Releases for union-supported activities. Work Release documents include the Work Breakdown Structure account number, detail work scopes, schedules, and cost estimates. Site Work Release operations include step-by-step work procedures and Quality Assurance and Operational Safety organization approval and surveillance.

Offsite (non-DOE) support for services and/or equipment is obtained in two steps. First, the project authorizes the support with a Requisition which includes the Work Breakdown Structure account numbers, work scope/equipment technical specifications, and quality assurance requirements; a subcontract organization then adds the federal-contract-regulation terms and conditions stipulations and obtains a qualified supplier to perform the work.

Other DOE laboratory support services are authorized with a Requisition for services and/or equipment and/or a letter request to DOE with the appropriate work scope description. The finance transaction is conducted by DOE transfer of funds from the INEL cost account to the other laboratory cost accounts.

As work is performed, a comprehensive planning and budgets system provides cost and performance information using the Work Release, Site Work Release, and Requisition charge numbers as the basic accounting level. INEL labor charges are reported weekly, and nonlabor charges are reported monthly.

8. REFERENCES

1. C. V. McIsaac and D. G. Keefer, TMI-2 Reactor Building Source Term Measurements: Surfaces and Basement Water and Sediment, GEND-042, October 1984.

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3. Johan O. Carlson, ed., TMI-2 Core Examination Plan, EGG-TMI-6169, July 1984.

4. D. W. Akers, et al., Preliminary Report: TMI-2 Core Debris Grab Samples--Analysis of First Group of Samples, GEND-INF-060 Volume 1, July 1985.