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RADIONUCLIDE MASS BALANCE FOR THE TMI-2 ACCIDENT: DATA-BASE SYSTEM AND PRELIMINARY MASS BALANCE VOLUME 1

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EXECUTIVE SUMMARY

OBJECTIVES

After the accident at Three Mile Island, Unit 2 (TMI-2), on March 28, 1979, GEND, the combined organization of General Public Utilities (GPU), the Electric Power Research Institute (EPRI), the U.S. Nuclear Regulatory Commission (NRC), and the U.S. Department of Energy (DOE), stated its intention to support an effort "to determine, as accurately as possible, the current mass balances of significant radiologically toxic species." GEND gave two primary reasons for support this effort: "(1) such exercises guarantee completeness of the studies, and (2) mass balance determinations ensure that all important sinks and attentuation mechanisms have been identified."[1]

The primary objective of the studies conducted by NUS Corporation was to support the goals of the GEND planners and to continue the mass balance effort by generating a preliminary accounting of key radioactive species following the TMI-2 accident. As a result of these studies, secondary objectives, namely a computerized data base and recommendations, have been achieved to support future work in this area.

TECHNICAL APPROACH

Developing a radionuclide mass balance calculation for the TMI-2 accident presents an array of problems in balancing the desired results with those technically feasible, in terms of scheduling in concert with the cleanup and resource allocations. In pragmatic terms, the objective is to deploy the resources available, both in the immediate time frame and in the longer term, to achieve the most complete and accurate accounting of radionuclide behavior in TMI-2 during and after the accident. The assessment of the problem, therefore, resolves to considerations aimed both at plans for this study phase and at general plans for the longer term.

The immediate problem was dominated by the need to collect and collate the data required for mass balances and to develop the means to use them repeatedly over an extended period of time. Much of this study phase, therefore, was focused on developing a format for all the values required to calculate mass balances, including the isotope data to allow decay corrections, radiochemical sampling and analysis data, and system volume and mass transfer data, collecting these data, and then entering them into a computerized data base system. The preliminary mass balance was calculated using straightforward accounting arithmetic, multiplying isotope concentrations in liquids and gases by the volumes represented in components and systems and summing these concentration-volume products over the total plant.

In the longer term it will be necessary to consider a variety of phases as well as phenomena that affect interphase mass transfers. These aspects are broadly assessed now, in order to anticipate their relative importances. Therefore, the potential effects on mass transfer of radioactive precursors; vapor, aerosol, aqueous, and solid phases; and mass transfer mechanisms potentially operative between system components and within systems components were generally assessed. The network of systems that constitutes TMI-2 and the time frame of major events both during the accident and subsequent cleanup were considered, and expansion of the data base system will continue during subsequent study phases as more data become available.

MASS BALANCE DATA BASE

A data base format was developed that permits the inclusion of the data necessary to calculate mass balances at any time of interest. This information includes all the values required to determine the calculated total quantities in the whole TMI-2 system at any time after shutdown. The system components likely to contain significant quantities of radioactivity are identified, and the available data (e.g., total component volumes and volumes of the initial liquid contents) are provided for most elements of the reactor coolant system, the makeup and purification system, and the liquid radwaste system. The data base includes the liquid transfer chronology for these system components through April 30, 1979.

An initial scanning of the radiochemical sample/analysis data sought liquid samples from these three key systems with concentrations that appeared to indicate significance (i.e., about 10^{-6} Ci/ml or greater) A second effort was made to ensure thoroughness in the acquisition of data for key components covering the period to April 30, 1979. Gas sample data for the reactor building and station vent are included. Generally, surface and solid sample data are not included.

PRELIMINARY MASS BALANCE

Computerized calculational aids were developed to allow an analyst to set up a mass balance problem in terms of lumped components (i.e, in terms of a simplified model in which groups of actual components are treated as a single lumped component) and to perform the calculation of the liquid volume in each lumped component at a desired mass balance time.

The calculational system is illustrated by a preliminary mass balance for April 30, 1979, at 2400 hours. This mass balance time was chosen as the end of the time period for which the liquid transfer chronology for the key system components has been largely developed and the time for which the greatest amount of the corresponding radionuclide data can be applied.

This preliminary mass balance considers the liquid contents of the reactor coolant system, the reactor building sump, reactor coolant drain tank, the reactor coolant bleed tanks, and the makeup tank. (The liquid contents of the reactor coolant drain tank were assumed to be similar to those of the reactor building sump and the liquid contents of the makeup tank to be similar to those of the bleed tanks.) The preliminary mass balance also accounts for radioisotopes in the reactor building atmosphere and in fission gases dissolved in the reactor coolant. This was judged to be the limit of the present data base. The preliminary mass balance calculation estimated the fractions of isotopes in the previously mentioned components. The identified fractions of strontium-89 and strontium-90 were 1.5 and 3.6 percent, respectively. The identified iodine-131 was found to be 25.1 percent of the total, while the xenon-133 was found to be 38.4 percent. The identified fractions of cesium-134 and cesium-137 were 56.1 and 44.6 percent, respectively.

RECOMMENDATIONS

Recommendations are developed under three categories: computerized data base extension, computer-aided data analyses, and data acquisition. Recommended data base extensions include the completion of system volume data, such as volumes of pipe runs in critical systems, the completion of the liquid transfer chronology, and the development of gas and solid phase transfer chronology. The radiochemical data base should be increased to include all available isotopic analyses of liquid and gas samples from pertinent systems, as well as surface and solid samples. Inclusion of semiquantitative data should be considered (e.g., gross activity in samples, smear sample analyses, and area monitor data). Archived samples should be identified in reference records in the data base, and reanalysis needs and feasibility should be determined. Analyses of archived samples for iodine-129 and tritium may be especially useful to facilitate the use of iodine-129 as a tracer for iodine-131 and tritium as a tracer for reactor coolant.

Computer aids to data analysis should include a more complete development of routines to aid in the accounting arithmetic and in the manipulation of the data base in search of pertinent sample data for analysis of radioactivity in liquids. The scheme should be expanded to aid in the accounting for radioactivity in gases, solids, and surfaces. The accounting-type calculations should not only be used to aid in mass balances but also to review the data for interconsistency and, hence, to identify suspect values in the data base.

Computer-aided modeling of the reactor building, including the reactor coolant system and the pressure vessel, should be initiated to use the reactor coolant data to determine fission product behavior in the reactor coolant system during 3½ years, to allow the data pertinent to the reactor building to answer questions about the several mass transfer mechanisms at play within that building (e.g., absorption/desorption, washout by the spray, particulate deposition, gas/liquid equilibrium, etc.), and to identify the parameters of importance to the mass transfer mechanisms effective during core overheating and, hence, to suggest measurements to make within the pressure vessel.

Recommended data acquisition efforts would include efforts to establish system component volumes (e.g., estimating the lengths of pipe runs in critical systems) and liquid and gas transfer chronologies (e.g., estimating the gas transfers and station vent flows). There are some tanks (the makeup tank and reactor coolant drain tank) whose liquid contents have not been sampled. Surfaces in the lower elevation of the reactor building have not been sampled. Solids (especially in the makeup and purification system components and in the sumps) need to be sampled (or analyses completed if already sampled), and measurements need to be made to estimate the quantities of these solids.

Estimating the quantities of radionuclides still in the pressure vessel is especially important. It is suggested that the number (and location) of undisturbed fuel assemblies and of damaged but intact fuel assemblies, the mass and location of intact segments of fuel assemblies, and the mass, particle size, and composition of debris constitute an outline of the least information from which an approximate account of mass could be made.

1. OBJECTIVES

Following the accident at Three Mile Island, Unit 2 (TMI-2), on March 28, 1979, GEND, the combined organizaition of Public Utilities (GPU), the Electric Power Research Institute (EPRI), the U.S. Nuclear Regulatory Commission (NRC), and U.S. Department of Energy (DOE), began planning a program to use the opportunity provided by the accident to gain information beneficial to the nuclear power industry. In their first publication (Reference 1), the GEND planners stated the general rational eof the program: "the Three-Mile Island (TMI) Unit 2 accident on March 28, 1979 was of great concern to the nuclear industry, electric power generating companies and their customers, regulatory and other government agencies, the entire nuclear community, and to the country as a whole. While the accident resulted in only limited external plant radiation exposure, the plant itself suffered extensive damage with high radiation contamination within the reactor and auxiliary system facilities. TMI Unit 2 currently represents opportunities to provide information for the enhancement of the nuclear power industry safety and reliability of generic benefit to nuclear power technology."[1]

Regarding the accounting for radioactive materials, the GEND planners further stated that "it is desirable to determine, as accurately as possible, the current mass balances of significant radiologically toxic species for two primary reasons: (1) such exercises guarantee the completeness of the studies, and (2) mass balance determinations ensure that all important sinks and attenuation mechanisms have been identified. . . .The species selected for mass balance considerations are to be selected based upon the following criteria: (1) significance from the standpoint of safety to the general public; (2) signifiance from the standpoint of personnel exposure during cleanup-decontamination operations; (3) significance from the standpoint of personnel exposure during normal plant maintenance; and (4) extent to which the species represents other species of similar chemical behavior."[1] On the basis of these criteria, the GEND planners argued that the following chemical species should be given priority: helium, krypton, tritium, iodine, cesium, tellurium, ruthenium, strontium, barium, cobalt, silver, and uranium. The planners recommended, however, that the highest priority should be given to iodine, uranium, krypton, and cesium, in approximately that order.

The GEND planners recognized that "the system over which the mass balances are to be performed can be subdivided in many different ways, with varying degrees of detail. The final strategy is best developed later, however, as the tasks . . . are reviewed and are considered within the context of the decontamination program."[1]

The primary objective of the studies conducted by NUS Corporation is to continue generating an accounting of the key radioactive species for the TMI-2 accident. The key radionuclides in this study are considered to be tritium, cesium-134, cesium-137, iodine-129, iodine-131, strontium-89, strontium-90, krypton-85, xenon-133, uranium-238, and plutonium-239. This list includes the above-noted nuclides of highest priority, as well as several from the lower priority list. Included on the list of key radionuclides is xenon-133, an important isotope in terms of potentially early postaccident health impacts, and one for which some data are available even though the isotope has a 6-day half-life. Plutonium-239 is also included as a second "typical refractory group species," along with uranium-238. Plutonium-239 is of concern because of its potential impact on health and because the data base contains some data for this isotope. Tritium is included in the list because of the possibility of using it as a tracer for reactor coolant.

The secondary objectives of the studies support the primary objective. One secondary objective is the development of a computerized compilation of the data needed to calculate mass

2. TECHNICAL APPROACH

It is desirable to determine the location of the key isotopes as a function of time after accident initiation. Mass balances are a basic tool for tracking the transfers of key isotopes selected during the course of the accident and the recovery period.

The goals of this initial phase of the mass balance effort were to produce a computerized data base, calculate a preliminary mass balance (or mass balances for different times), and make recommendations for future work, recognizing that up to this time such a data base has neither been collected (from the huge collection of data on the TMI-2 accident) nor collated.[2] The first steps in this effort were, therefore, to assemble and collate data.

In the following paragraphs, a description of the approach to providing, in this initial study, the required computerized data base and preliminary mass balance calculation is presented. This is followed by a comprehensive assessment aimed at longer-term planning and recommendations.

2.1 APPROACH TO CALCULATING PRELIMINARY MASS BALANCE

The initial effort was to collect, collate, and format as much data as possible, while focusing on those parts of the TMI-2 plant where most of the radionuclides are expected to be located--namely, the reactor coolant, makeup and purification, and liquid radwaste systems. The preliminary mass balance work was based on a straightforward use of the data (i.e., the multiplication of concentrations and volumes for component contents at times for which the chronology data could be developed). The completeness of the mass balance calculation was evaluated by summing the concentration (volume products over the systems considered) and comparing the overall sum for each nuclide with the total inventory that would be in the reactor core assuming no accident occurred. This was corrected for decay to the time of the mass balance. Liquid and gaseous phases were separately considered in the analysis.

The purpose of the preliminary mass balance calculation was to perform a first estimate of the radionuclide distribution in the plant. The overall plant is conceived in terms of buildings, systems (which are usually but not always wholly contained within one building), components that make up a system, and phases (i.e., gas, liquid, solid, and surface) within a component.

Exhibit 2-1 shows the buildings and systems that were potentially involved in the transfer or accumulation of radionuclides released from the fuel during the accident and its aftermath. This network of systems would ultimately have to be considered in doing a complete mass balance calculation. However, the preliminary mass balance calculation was based on certain portions of the system, selected according to data availability. The primary coolant system, the makeup and purification system, and the liquid radwaste system (including the reactor building and auxiliary building sumps) were considered in calculating the preliminary mass balance for liquids. For gases, the reactor containment building, the reactor coolant system, and the heating, ventilation, and air conditioning systems were considered.

Gas releases during the accident are documented generally as releases from the station vent, but the station vent flows are not well defined. Documentation of transfers within the systems feeding the vent is particularly incomplete. Containment concentrations and the containment venting are well documented. In the preliminary mass balance calculation, the amounts of materials in gases were derived from data on containment concentrations. Liquids were transferred in complex sequences of events; much of the chronology definition in this preliminary mass balance work addresses liquid transfers.

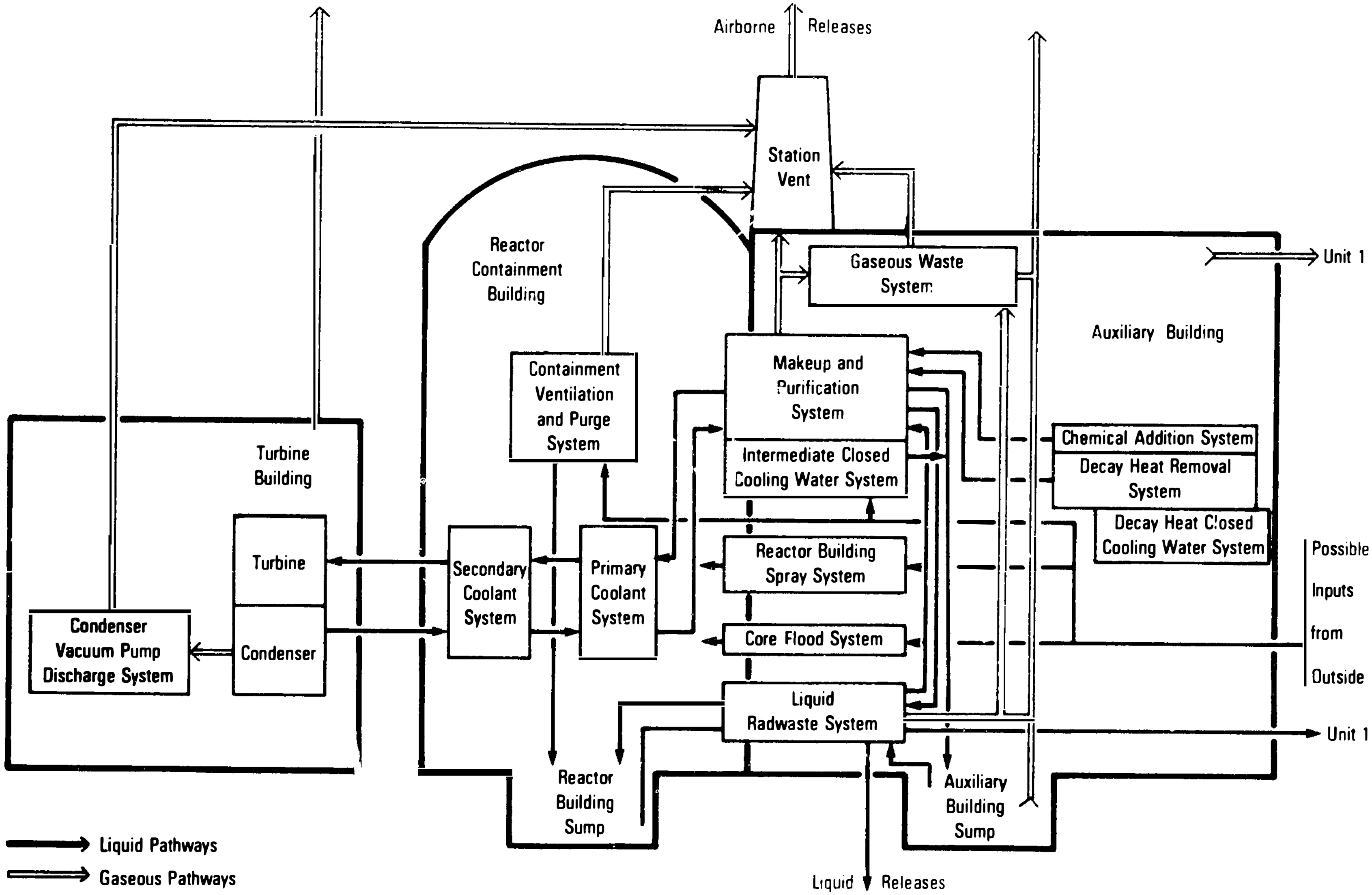


EXHIBIT 2-1
Buildings & Systems

An aspect of importance to the preliminary mass balance work is that the presently available data includes virtually all the gas phase (including airborne particulates) data that will ever be available, much of the total potential data base for liquids, and essentially no data on solids or surfaces. The logical order of cleanup is in the order of gases first, then liquids, with solids and surfaces last; the approach to the preliminary mass balance calculation, therefore, focuses on gases and liquids.

The accident chronology considered in the preliminary mass balance calculation was developed from a table of events based on available documentation for systems and components that are judged to contain the greatest radionuclide inventory. This is discussed in detail in Section 3.3. Note that the amount of material transferred between components was developed as part of the accident chronology.

In the development of the accident chronology, the events of importance became progressively less frequent as the accident progressed and cleanup started. During the first day the flow chronology was quite complex because of the actions taken to achieve a safe shutdown. These actions included the operation of the high-pressure injection system and the use of various makeup and letdown system components. The flow chronology during the next week or so was based on concerns about a hydrogen bubble in the reactor coolant system. After approximately a month, core cooling was accomplished by nature convection. These major events resulted in progressively simpler flow chronologies.

Given the emphasis of the initial study phase, nuclear and chemical characteristics of the isotopes and mass transfer mechanisms other than identified volume transfers were not considered. The identified material transfers during and after the accident were transfers of gases or liquids; solid transfers were not identified as such, but occurred as particulates suspended in gases or liquids and/or carried along with liquids.

Errors are of special concern because the sampling data are not consistent in the methods used to obtain and analyze samples. Further, these data include very little information about the errors. More specifically, the analysis errors (i.e., counting errors) are commonly available; the uncertainty in the representativeness of samples and the uncertainties in volumes and volume flow rates are generally not known. The available error-related data are included in the computerized compilation of data. However, a systematic assessment of errors in all measured and calculated values, and the statistical calculation of the uncertainty, is not possible in this preliminary phase.

2.2 FUTURE APPROACH

Future work would primarily entail further development of the data base and refinement of the mass balance. It is anticipated that the mass balance work should eventually allow mass balances to be determined retrospectively to the time of shutdown. In the process, the distribution and location of key radionuclides at times soon after accident initiation would be established. These results should form a basis for calculations on the transport and deposition of key isotopes in the reactor building during the first few days and perhaps in the reactor coolant system during the first hours. Detailed consideration of radionuclide movements in the reactor coolant system and reactor building can be expected to have the greatest generic importance toward the "enhancement of nuclear industry safety and reliability."[1]

There is currently a research effort underway in the United States, Europe, and Japan to better characterize radionuclide behavior during an accident where fuel damage occurs. Most of this research is focused on accidents in which core meltdown occurs. Research areas include fission product release from fuel, chemistry of cesium, iodine, and other fission products, as well as fission product transport within the primary system and containment. The role of engineering safeguard features in mitigating radionuclide releases during an accident is also being studied. This research is discussed in NUREG-0772.[3]

Data collation and the mass balance work are important parts of these studies. Researchers have been and will continue studying the TMI-2 accident to determine where research is needed and to correlate laboratory results with TMI-2 observations. Nuclear power regulation has been influenced and will continue to be influenced by the TMI-2 accident.

The processes that would be considered in doing a complete radionuclide mass balance calculation are described in the following sections. As the mass balance work proceeds, some of the processes identified may be eliminated, and efforts will be made to correlate ongoing research work to the TMI-2 mass balance to better characterize important processes.

2.2.1 Material Transfer Mechanisms

Exhibit 2-2 is a diagram of mass transfer mechanisms potentially operative during the course of the accident and thereafter. Transfers occurred between system components; volumes of gas or of liquid moved from one component to another, carrying particulates and/or solids in some instances. Transfers also occurred between phases within a component.

2.2.1.1 Between System Components

Transferred gases could contain droplets of liquid (carry-over) and/or solid particulates. Transferred liquids could contain gas dissolved under pressure and/or suspended solids. Certain system components are designed to remove radionuclides from flow streams: carry-over and particulates will be partly removed

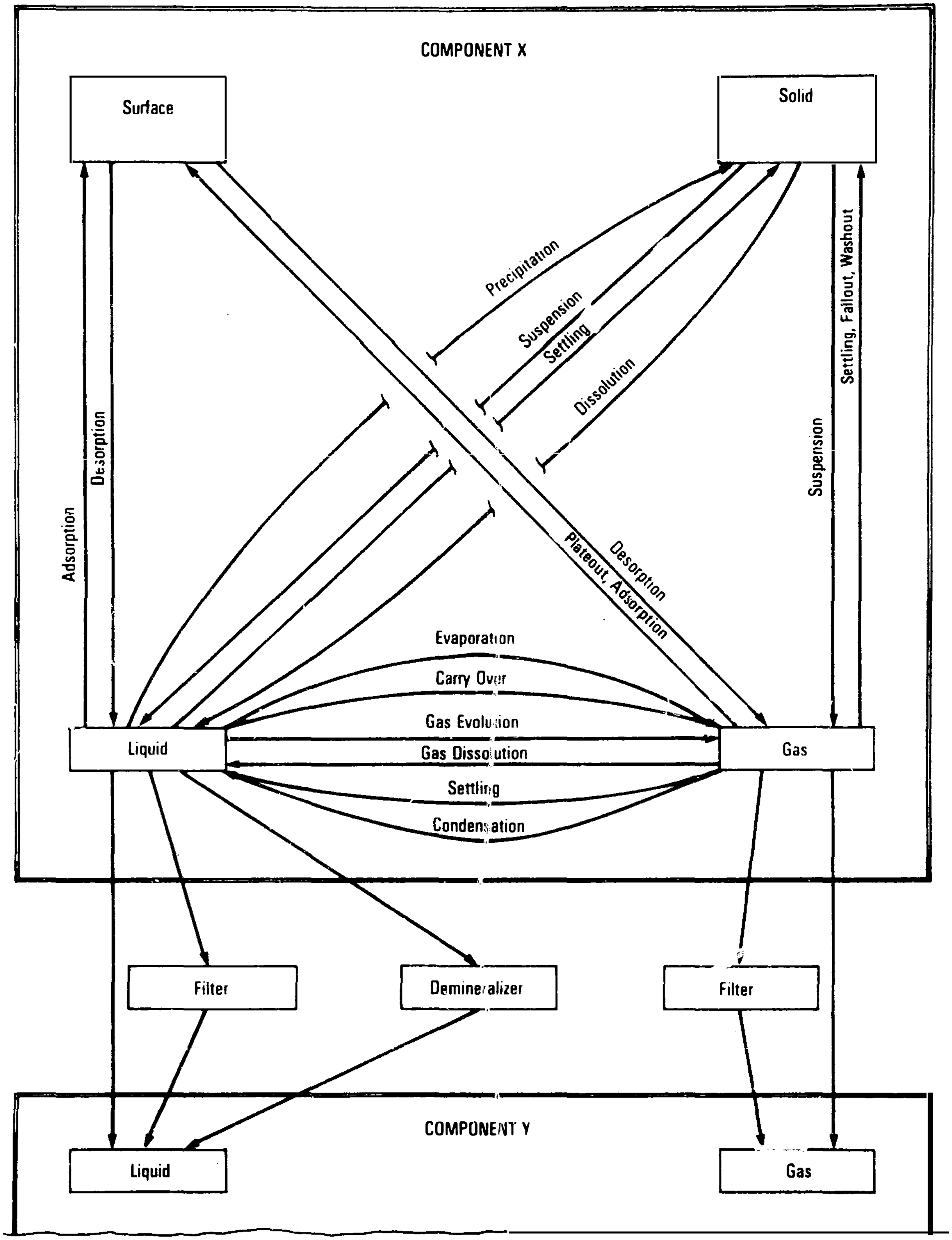


EXHIBIT 2-2
Mass Transfer Mechanisms

from gaseous streams by a filter; suspended solids will be partly removed from aqueous streams by a filter; and dissolved solids will be partly removed from liquids by demineralizers.

The records of material transfers from component to component are generally limited to records of liquid transfers (e.g., valves were opened, a pump started, and a flow continued for a period of time). These records are included in the initial data base on chronology through April 30, 1979. Future efforts will extend that chronology insofar as the data will allow. Additionally, improved system descriptions, including definition of volumes contained in piping between significant components, would aid in mass transfer assessments. In general, gas volume transfers are not well defined by available records, but there are records of gas phase material releases. Solids transfers occurred generally as material suspended in or sluiced along with liquids and therefore will have to be characterized via sampling and observations during cleanup.

2.7.1.2 Within System Components

Material transfer within a given component or system ultimately will be of greatest interest. Such material transfers will take place in the reactor containment building and the auxiliary building, as well as the reactor vessel itself.

Transfers between gases, liquids (primarily water), solids, and surfaces will be considered. Because of data limitations, it is unlikely that each of these transfers will be separately defined. Such transfers will need to be addressed in the future as more information becomes available and identification of alternative mechanisms become clearer. Carry-over (and settling) of liquids in gas streams are likely to be significant mechanisms for gaseous pathways, because it has been noted that water was transported to the reactor building and radwaste disposal gas vent header. Adsorption/desorption from gases onto surfaces are presumed important in building venting, after which concentrations in the gas phase can build up again due to desorption. Gas evolution is important in cases where liquids under high pressure are transferred to low pressures. It is presumed that a major mechanism for solids transport was in the form of suspended materials in liquids; hence, settling of suspended solids from liquids is important.

2.2.2 Radionuclide Characteristics

The mass transfer mechanisms described in the preceding section are affected by the characteristics of the radionuclides being considered. These characteristics include precursor and daughter relationships, vapor pressures, solubilities, and others.

2.2.2.1 Radionuclide Precursors

Chemical properties can be affected by radionuclide decay as shown on Exhibit 2-3. In cases of krypton-85, strontium-89, strontium-90, and cesium-137, the precursor nuclides have half-lives in the range of 3 to 15 minutes. The sequence of events[4] indicates that the core overheating occurred between 1.9 and about 3.25 hours after scram; hence, the 3- to 15-minute half-life precursors would have largely decayed before radioactivity was released from the fuel. Cesium-134 is formed by a neutron activation of stable cesium; hence, this nuclide ceased to be formed at scram. Uranium-238 is, of course, the major constituent of the fuel and was there prior to scram. Plutonium-239 is preceeded by 2.3-day neptunium-239, but both these nuclides are actinide rare earths and, they could be expected to be transported together. Tritium is formed directly by ternary fission in the fuel and by neutron activation of boron-10 and lithium-6 in the reactor coolant. Iodine-129 is preceded by 74-minute tellurium, which is preceded by 4.6-hour antimony. Iodine-131 is preceded by a split chain: 85% if formed via 25-minute tellurium and 23.1-minute antimony; the other 15 percent is preceded by

Element	Atomic Number	Mass Number	Fission Yield	Half-life	Beta Energy, Mev	Gamma Energy, Mev	Decay Chain	Ref
Kr (20% → Kr, 80% → Rb)	36	85m	1.5	4.36 h	0.855	0.15, 0.305	3 m Br → 4.36 h Kr; 4.36 h Kr → stable Rb (80%); 4.36 h Kr → 10.57 y Kr (20%); 10.57 y Kr → stable Rb	1
Kr	36	85	0.3	10.57 y	0.15 (<1%) 0.695 (99+%)	0.54		
Rb	37	85		Stable				
Sr	38	89	4.8	53 d	1 463	No γ	4.51 s Br → 3.18 m Kr → 15.4 m Rb → 53 d Sr → stable Y	1
Y	39	89	4.8	Stable				
Sr	38	90	5.9	28 y	0 61	No γ	~33 s Kr → (2.74 m) Rb → 28 y Sr → 84.8 h Y → stable Zr	1
Y	39	90	5.9	64.8 h		No γ		
Zr	40	90	5.9	Stable				
Sb (~24% → Te, ~76% → Te)	51	129	1.0	4.8 h	1.87 (20%)	0.165 0.308 0.534 0.788	4.6 h Sb → 33.5 d Te (~24%); 4.6 h Sb → 74 m Te (~76%); 33.5 d Te → 74 m Te; 74 m Te → 1.7 × 10[7] y I → stable Xe	1
Te	52	129m	0.34	33.5 d	No β	0.106 0.435 (9), 1.08 (0.7)		
Te	52	129	1.0	74 m	0.29 (10%) 0.69 (4%) 0.989 (15%) 1.453 (71%)	0.0268 0 475 ~0 77 1 12		
I	53	129	1 0	1.7×10^7 y	0 150	0 038		
Xe	54	129		Stable				
Te	52	131m	0 44	30 h	0 47 (52%) 0 98 (4 6%) 0 57 (17%) 2 46 (4 7%)	0 177	23 1 m Sb → 30 h Te (15%); 23 1 m Sb → 25 m Te (85%); 30 h Te → 25 m Te; 25 m Te → 8 d I; 8 d I → ~12 d Xe (1%); 8 d I → stable Xe (99%); ~12 d Xe → stable Xe	1
Te	52	131	2 9	25 m	1 35 (15%) 2 14 (60%) 1 69 (25%)	0 145 (100) 0 950 (~4) 0.450 (24) 1 140 (~8) 0.595 (~6)		
I (1% → Xe, 99% → Xe)	53	131	2.9	8 d	0 815 (0 7%), 0 608 (87%), 0.335 (9 3%) 0.25 (2.8%)	0.08, 0.163, 0 284, 0.364, 0.637, 0.722 0.164		
Xe	54	$131m_2$	0.03	~12 d				
Xe	54	131	2.9	Stable				
I	53	133	6.5	20.5 h	0 4 (~9%) 1 3 (~91%)	0.53 (94) 0.85 (5) 1.4 (1)	4 4 m Sb → 63 m Te; 4 4 m Sb → 2 m Te; 63 m Te → 2 m Te; 2 m Te → 20.5 h I; 20.5 h I → 2.3 d Xe (2 4%); 20.5 h I → 5.27 d Xe (97.6%); 2.3 d Xe → 5.27 d Xe; 5.27 d Xe → stable Cs	1
Xe	54	133m	0.16	23 d		0.232		
Xe	54	133	6 5	5 27 d	0 345	0.081		
Cs	55	133	6 5	Stable				
Cs	55	134	0	2 2 y	0 662	0 57, 0.805, 0 796, 1.038, 1 188, 1.385	stable Cs $\xrightarrow{n, \gamma}$ 2 2 y Cs	2
Cs (95% → Ba, 5% → Ba)	55	137	5 9	27 y	0 523 (92%) 1 17 (8%)		22 s I → 3.9 m Xe → 27 y Cs (~94%); 27 y Cs → 2.60 m Ba (92%); 27 y Cs → stable Ba (8%); 2.60 m Ba → stable Ba	1
Ba	56	137m	5.5	2.63 m		0 66		
Ba	56	137		Stable				
U	92	238	0	4.5×10^9 y	0.038 0.043		Major constituent of original fuel	2
Pu	94	239	0	2.43×10^4 y	0.008 0.019 0.033 0.047	0.039 0.375 0.052 0.414 0.129 0.65 0.77	U-238 (n, γ) U-239 (β^-) Np-239 (β^-) (23 5 m) (2.3 d)	2
H	1	3	0	12.3 y	0.0186	No γ	12.3 y H → stable He	2

1. H Etherington, Editor, *Nuclear Engineering Handbook*, McGraw-Hill 1958, Sec 11, Table 4, pp. 11-12 et seq.
2. U S HEW, *Radiological Health Handbook*, Jan. 1970, Table 1, p 229 et seq

EXHIBIT 2-3
Radioisotope Formation and Decay Schemes and Nuclear Data

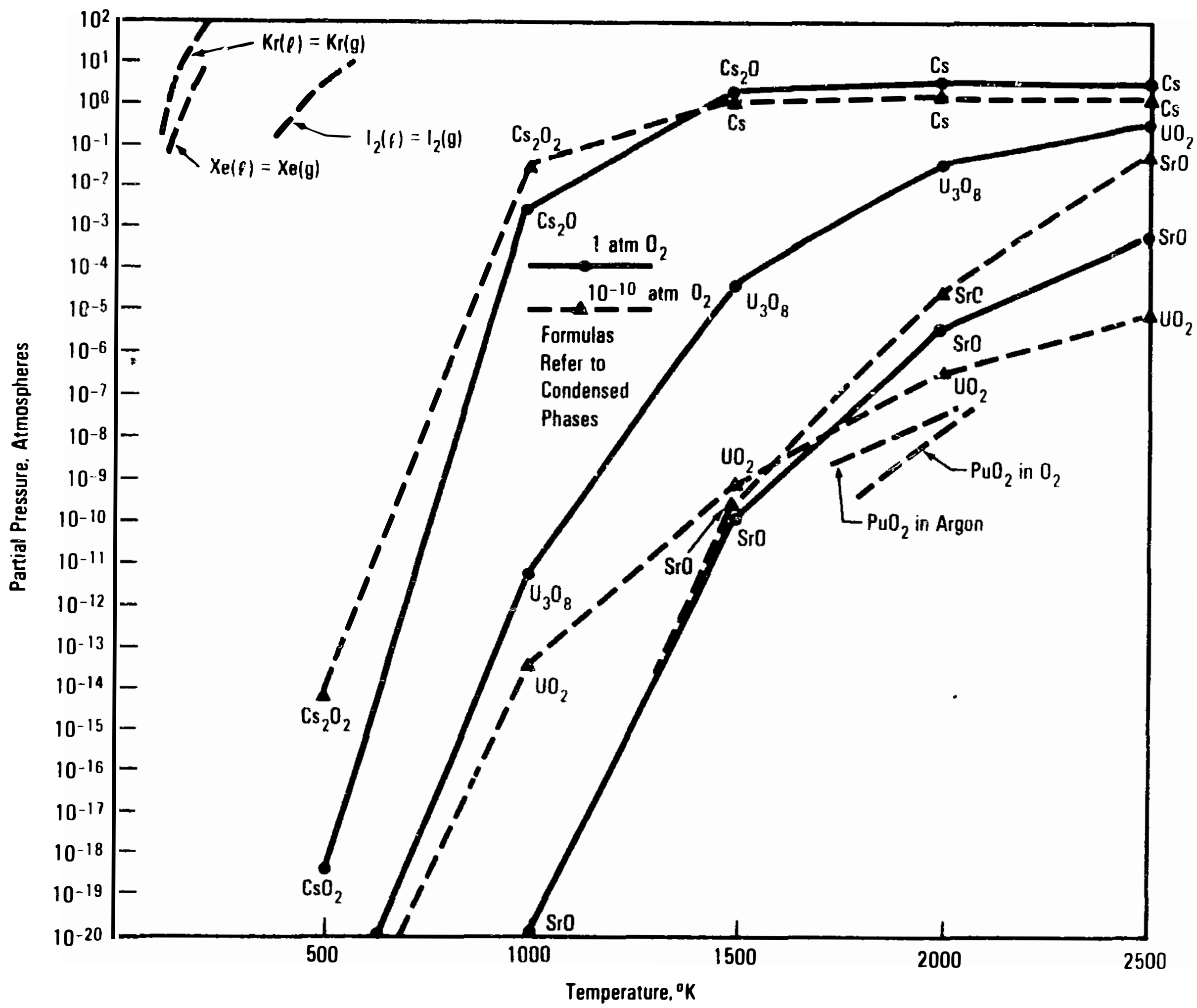
the 25-minute tellurium, 30-hour tellurium, and 23.1-minute antimony. Hence, a fraction (15 percent) of the iodine-131 is preceded by a 30-hour precursor. Xenon-133 is preceded by a 20.5-hour iodine. As noted, for this initial phase, precursor transport is not considered; at some later time, particularly for iodine-129 and xenon-133, it may be useful to consider the effect of this factor on precursor transport.

Radionuclide decay and the associated chemical changes have been assumed to be negligible in the preliminary mass balance determination. However, chemical changes due to radionuclide decay can be important and will be considered in future work.

2.2.2.2 Vapor Phase

In general terms, the vapor phase may have been of major importance in mass transfer events during the accident in those regions where very high temperatures may have existed. General guidance relative to the probability of the key isotopes being transported as gaseous molecules, particularly in high-temperature regions, can be obtained from consideration of the volatilities of fission products and their compounds as a function of temperature and under the oxidizing and reducing conditions shown on Exhibit 2-4.

Briefly, these equilibrium properties tend to put isotopes into groups: The noble gases (krypton-85 and xenon-133) are noncondensable. The halogens (including iodine-129 and iodine-131) have high vapor pressures at the extreme temperatures in an overheated reactor core and can exist (depending on a very complex chemistry) at very significant vapor pressures even at ambient temperatures. The alkali metals (including cesium-134 and cesium-137) are also very volatile at the high temperatures in an uncovered core but are essentially nonvolatile at ambient conditions. Strontium (strontium-89 and strontium-90) may have a greater vapor pressure than uranium (under reducing conditions) or a



Cs, Sr and U Data R G Bedford and D D. Jackson. *Volatilities of the Fission Product and Uranium Oxides*. UCRL-12314, Jan 1965
Pu Data J. M Cleveland, *The Chemistry of Plutonium*. Gordon and Beach, New York, 1970, p. 299.
I, Kr and Xe Data R C Weast, Ed., *CRC Handbook of Chemistry and Physics*, 55 ed., CRC Press, Cleveland, Ohio, 1974, p D 162

EXHIBIT 2-4
Volatilities of Key Radionuclide Elements and Oxides

lesser vapor pressure (under oxidizing conditions). Uranium-238 and plutonium-239, like strontium, are generally considered to be refractory elements (i.e., elements with very low vapor pressures).

The initial mass balance studies consider the distribution of radioactive materials at times after the existence of the extremely high temperatures in the reactor core. The volitities of the key radionuclides and their precursors will be significant in future studies.

2.2.2.3 Aerosol Phase

A vapor phase can also transport suspended particulates, either liquid particulate "carry-over" or solid particulates. Such aerosol particles, if very finely divided, can remain suspended for many hours but do not represent an equilibrium condition.

Apart from the samples of airborne particulates which were taken to indicate concentrations at the time of sampling, there may be more to be learned about aerosols by examination of surfaces and solid materials; some of these materials may have existed as aerosol particulates in one time period during the accident. Aerosol particle formation may occur by means of condensation of material from a concentrated vapor, in which case the particles tend to be agglomerates of very tiny spherical primary particles. Particles formed by the energetic process of quenching very hot fuel rods would tend to be irregular fragments. Of course, the particle shapes may have been changed due to partial dissolution or precipitation during extended contact with water.

Surfaces may record past mass transfer processes involving particulates. Some processes, such as settling and washout by sprays, will tend to deposit material on horizontal surfaces. Other processes (i.e., diffusiophoresis and thermophoresis) can deposit particles on cooler surfaces, including walls. The consideration of such processes will depend on the availability of data adequate to justify such evaluations.

2.2.2.4 Aqueous Phase

General guidance relative to the probability of key isotope transport via the aqueous phase can be gained by reference to the Pourbaix diagrams on Exhibit 2-5. These diagrams show the pH and reduction potential ranges of stability of chemical species that contain one of the key radionuclides in aqueous solution at room temperature. The noble gases (krypton-85 and xenon-133), which are not shown on Exhibit 2-5, exist for practical purposes only in elemental form. They have a small aqueous solubility, but the dissolved concentrations can be significant, with a high overpressure. Iodine (iodine-129 and iodine-131) can exist in aqueous solution in the form of several very soluble species, some of which are volatile; iodine is not likely to be found in insoluble solids. Although in the initial mass balance effort pH and reduction potentials of the pertinent solutions are not considered (i.e., such data are not presently in the data base), it may be useful in future studies to tabulate such data as exist in order to help keep track of the chemical form of the iodine. Cesium (cesium-134 and cesium-137) has a very simple aqueous chemistry as a mono-positive ion; cesium compounds are generally soluble so cesium will tend not to be in insoluble, solids. Strontium (strontium-89 and strontium-90) also has a simple chemistry as a divalent alkaline earth metal, but it forms many compounds of low solubility and will, therefore, tend to exist in both solution and solid phases. Uranium-238 and plutonium-239 are actinide rare earth elements with several stable valence states with soluble compounds but, like strontium, will tend to exist in both aqueous and solid phases. Plutonium oxide has a tendency to exist as a colloid and, hence, may appear as if in solution at concentrations higher than its solubility.

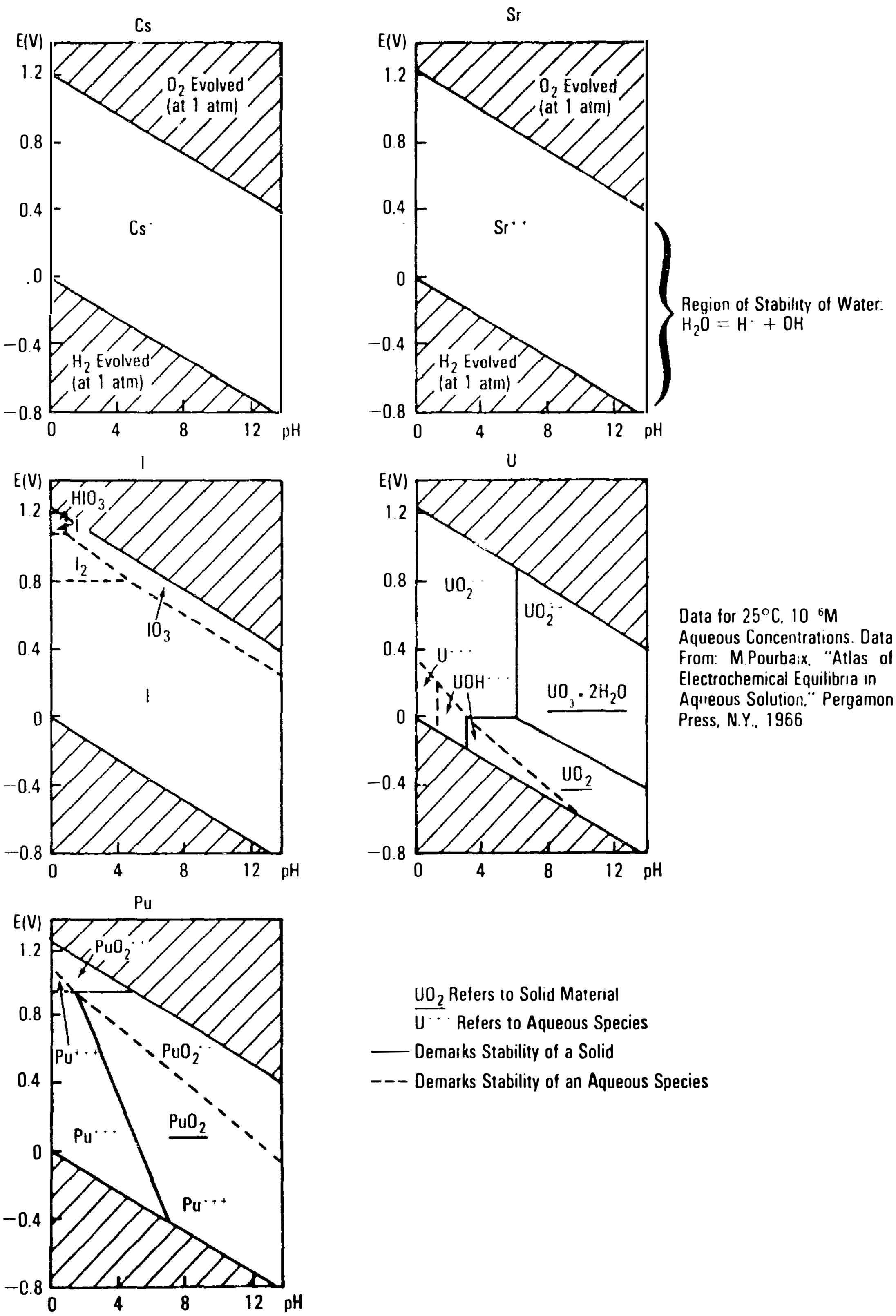


EXHIBIT 2-5
Equilibrium Aqueous and Solid Species

Again, future studies will need to incorporate considerations of solubility in making more sophisticated mass balance assessments.

2.2.2.5 Solid Phase

Particulates and solid fragments of fission products, fuel material, and so forth were not intentionally transferred during the accident so the sequence of events does not provide any record of such transfers. But these solids were carried along with liquids. The quantities transferred, as well as the radionuclide concentrations in them, must therefore be obtained from other sources. The total (suspended) solids concentration in liquid samples (where such are available) is instructive but not generally conclusive because these samples do not represent the great mass of solids transferred in early accident phases. The solids contents of many components may be reasonably estimated only during the process of cleanup of those components.

Another feature of solid fragments and particulates is that they may have stratified and/or subsequently solidified onto component surfaces. It may be difficult to obtain adequate samples of particulate material in these conditions. For the same reason, these solid materials should provide a more lasting record than liquids or gases. Future mass balance work will have to focus on obtaining particulate data as they become available during recovery operations.

2.2.2.6 Surface Phase

Of all the interphase transfers, those from liquids and gases to surfaces may be most significant in addressing the behavior of released nuclides because surfaces in some components (e.g., the reactor building) represent important sinks for these radionuclides and because surface deposition (in many cases) remains to allow sampling.

Material can be sorbed on surfaces from liquids or gases as atoms or molecules; the process is potentially reversible. Material can precipitate from the aqueous phase onto surfaces or within the volume of the aqueous phase and settle. Suspended material in either gases or liquids can also settle onto surfaces. Settling results in more deposition on horizontal than on vertical surfaces. In many cases, debris may have accumulated on surfaces prior to the accident (e.g., construction debris).

The definition of surface-phase substances, for pragmatic reasons, must include whatever is taken up in the sampling of surfaces. In other words, the definition is implied by the sampling process. For the purposes of mass balance work, it is essential that the definition of surface-phase material include all materials not in the gaseous, aqueous, or solid phases. The interpretation of surface-phase data will, therefore, involve consideration of construction debris, adsorption/desorption, settling and plateout from liquids on surfaces below high-water marks, and deposition of airborne particulates.

2.2.3 The Accident and Cleanup Chronology

The longer-term approach to mass balance calculations includes finer definition of the systems used during plant stabilization and subsequent activities, as discussed in Section 2.2. In particular, cleanup systems that acted as sinks to much of the released activity should be defined. For example, EPICOR I, an organic resin demineralizer system, was used to decontaminate areas in TMI-1, and EPICOR II was used beginning in October 1979 to decontaminate the TMI-2 auxiliary building. A submerged demineralizer system (SDS) was used starting in the summer of 1981 to process the reactor building sump water.

Chronology development is of major importance to the long-term effort. The chronology of liquid transfer needs eventually to be developed as far forward in time as the sampling and analysis program and for each important system up until it is decontaminated. Gas transfers to the station vent need also to be developed for the period (of about a month) during which releases occurred; the containment venting also is an important element of the chronology. Finally, it appears that the chronology of solids transfer generally will have to be deduced from the data, realizing that for certain components in the makeup and purification system, the volumes occupied by the solids may be a significant part of the total component volumes and will tend to manifest themselves as errors in the liquid volumes.

2.2.4 Errors

In a well-planned experiment, errors are considered both during the design and execution, and efforts are expended on those aspects that experimentally produce the greatest accuracy in the final result. The TMI-2 accident was neither a well-designed nor carefully executed experiment, and it is recognized that many of the efforts in sampling, sample analysis, measurements of material transfer, component volumes, and so on were not planned with a concern for the accuracy of a mass balance. In the course of mass balance calculations, the accuracy of the data used will vary widely. It therefore becomes more important (than in a well-designed experiment) to estimate errors and uncertainties in data values and in the values of final results, such as the mass balance closure (i.e., fraction of an isotope accounted).

Generally the only available data relevant to errors are those reported with the radiochemical analyses. These errors are the uncertainties in the radiochemical analyses calculated from the statistics associated with the counting of radioactive decay events.

Other uncertainties that must be considered (and may well be much larger in many cases than the counting error) are the uncertainties in sampling (i.e., the uncertainty with which the sample represents the total volume or mass that it is presumed to represent) and the uncertainties in the volume (or mass) values. Uncertainties in the volumes of components (e.g., tank volumes, void volumes in filters, and demineralizers) and the volumes of material transferred (e.g., the volume flow rates and flow times) are also of interest in the long term.

It appears that error analyses will gradually accrue, first to identify values that are inconsistent with the other related data points (and, hence, to identify questionable values) and second to quantify the precision of mass balances calculated in different ways or for different times.

2.3 SUMMARY OF THE TECHNICAL APPROACH TO MASS BALANCE CALCULATIONS

The technical approach to mass balance calculations includes an immediate approach (for preliminary mass balance calculations) that ensures that the use of presently available data will contribute to a longer-term effort. Included in the immediate approach were the estsblishment of a data base system and data collection relative to system descrptions, chronology of mass transfers, and sample analyses. The first study phase focused on the systems expected to contain the most radioactivity (i.e., the reactor coolant, makeup and purification, and liquid radwaste systems). The chronology was developed with primary focus on these systems and starting from reactor shutdown. It was important also to calculate a preliminary mass balance, to demonstrate this approach using the data base, and to identify recommendations for future work.

In the longer term it appears likely that accrual of all pertinent data will remain a valid objective toward a complete accounting of key isotopes. More detailed investigations will focus on what happened, in terms of material transfer, in the reactor building and reactor coolant system.

balances. The complexity of the data base, the expectation that data will be added to it for several years to come, and the expectation that it will be used over and over suggest the desirability of computerizing the data. Additionally, the data pertinent to mass balance calculations are not collated separately from the enormous mass of general data from the TMI-2 accident and are difficult to find and retrieve. The computerized data base, with references to the original data sources, will make the process of developing mass balances more open to scrutiny.

Another secondary objective is the development of recommendations for future work. It is recognized that sampling of many components, especially of solid materials within components, is still possible; the preliminary mass balance calculations will provide some insights for recommendations on priority of sampling and analysis. Similarly, the preliminary work may suggest future developments in data base management that would facilitate better mass balance calculations. It is also expected that an increase in the variety and sophistication of calculations will be possible and will provide estimates of concentrations and volumes for times and components beyond those covered by the limited data.

In summary, the objectives are to provide a computerized data base to support mass balance determinations, to calculate a preliminary mass balance (or mass balances), and to recommend future work to improve mass balances.

3. MASS BALANCE DATA BASE

The TMI-2 mass balance data base contains interrelated data to support calculations of mass balances. These data, stored in record form, have been organized as eight different tables with unique formats (Exhibit 3-1). A table is a file of homogeneous records with an associated description of the fields contained in each record. All fields within a given record are searchable (records may be selected or located by the value of any field) by the data base management system described briefly in Section 3.6.

As indicated in the previous section, a variety of data is required to calculate even preliminary mass balances on key radionuclides at selected times following the onset of the TMI-2 accident. Apart from the fundamental information on the radionuclides themselves (initial inventories, decay rates, etc.), data are required for affected system and component descriptions (locations, volumes, surface areas, operating pressures, temperatures, etc.), results of analyses of samples taken of the contents of those systems and components, and a history or chronology of mass transfers (flows between systems and components) over time following onset of the accident.

The sources of data are diverse, particularly with respect to radiochemical analyses. In the early period following onset of the accident, sample analyses were done by, or on behalf of, a number of organizations other than GPU (General Public Utilities), and identifying the mere existence of samples taken before April 10, 1979 (when a Sample Coordinator was established) was difficult. Similarly, system descriptions, including data on the length of pipe runs between components, or initial component volumes (i.e., at accident initiation) are not readily available. Thus, assembly, verification, and collation of data requires a systematic and comprehensive search of information, preferably from documented sources.

TABLE NAME: ISOTOPE

ISOTOPE	DECAY CONSTANT 1/SEC	INITIAL ACTIVITY CURIES	HOUR 1 CURIES	HOUR 2 CURIES	HOUR 3 CURIES	HOUR 4 CURIES	HOUR 6 CURIES
AAAAAA	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX

HOUR 12 CURIES	HOUR 24 CURIES	HOUR 36 CURIES	HOUR 37 CURIES	DAY 2 CURIES	DAY 10 CURIES	DAY 13.1 CURIES	DAY 18 CURIES
X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX

DAY 19.1 CURIES	DAY 20.1 CURIES	DAY 21.7 CURIES	DAY 25.2 CURIES	DAY 28.2 CURIES	DAY 35.0 CURIES	DAY 40 CURIES	REFERENCE	NOTE
X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	AAAA	AAAA

TABLE NAME: SAMPLE

SAMPLE.ID	SAMPLE SIZE	UNITS	SAMPLE ERROR PERCENT	COMPONENT	STATE	TIME Y M D H M S	TIME ERROR	ERROR UNITS	REFERENCE	NOTE
AAAAAAA	X.XXE±XX	AAAA	X.XXE±XX	AAAAAAAAAAAAAA	AAAA	AAAAAAAAAAAA	X.XXE±XX	AAA	AAAA	AAAA

TABLE NAME: ANALYSIS

SAMPLE.ID	ANALYSIS.ID	STATE	TIME Y M D H M S	ISOTOPE	CONCENTRATION μCi/ml, cc	DETECTION LIMIT μCi/ml, cc	ERROR PERCENT	REFERENCE	NOTE
AAAAAAA	AAAAA	AAAA	AAAAAAAAAAAA	AAAAAA	X.XXE±XX	X.XXE±XX	X.XXE±XX	AAAA	AAAA

TABLE NAME: SYSTEM

BUILDING	ELEVATION	SYSTEM	COMPONENT	STATE	TOTAL VOLUME FT**3	VOLUME ERROR PERCENT	TOTAL AREA FT**2	AREA ERROR PERCENT	REFERENCE
AAAA	AAA-AA	AAA	AAAAAAAAAAAAAA	AAAA	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	AAAA

INITIAL VOLUME FT**3	INITIAL VOLUME ERROR PERCENT	INITIAL AREA FT**2	INITIAL AREA ERROR PERCENT	PRESSURE PSIG	TEMPERATURE DEGREES F	REFERENCE	NOTE
X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	AAAA	AAAA

TABLE NAME: CHRONOLOGY

EVENT.NUMBER	SEQ	START TIME Y M D H M S	START ERROR	START ERR UNITS	STOP TIME Y M D H M S	STOP ERROR	STOP ERR. UNITS	FROM.COMPONENT
AA.AA.AA.AA.AA.AA.AAA.AAA	AAA	AAAAAAAAAAAA	X.XXE±XX	AAA	AAAAAAAAAAAA	X.XXE±XX	AAA	AAAAAAAAAAAAAA

VIA COMPONENT	TO COMPONENT	STATE	TRANSFER RATE VOLUME GPM, CFM	TRANSFR RATE ERROR PERCENT	MASS TRANSFERRED GAL, FT**3	MASS ERROR PERCENT	REFERENCE
AAAAAAAAAAAAAA	AAAAAAAAAAAAAA	AAAA	X.XXE±XX	X.XXE±XX	X.XXE±XX	X.XXE±XX	AAAA

TABLE NAME: EVENT

EVENT.NUMBER	REFERENCE	DESCRIPTION
AA.AA.AA.AA.AA.AA.AAA.AAA	AAAA	AAA → A

TABLE NAME: NOTE

NOTE	DESCRIPTION
AAAA	AAA → A

TABLE NAME: REFERENCE

REFERENCE	TIO*	GPU.MF*	NSAC.MF*	GPU.SAM*	DATE Y M D	AUTHOR.TITLE
AAAA	AAAAAAA	AAAAAAAAAAA	AAAAAAAAA	AAAAA	AAAAAA	AAA → A

A = ALPHANUMERIC
X = NUMERIC

*TIO REFERS TO EG&G TIO DOCUMENT CONTROL NUMBER
GPU.MF REFERS TO GPU MICROFILM
NSAC.MF REFERS TO NSAC MICROFILM
GPU.SAM REFERS TO GPU SAMPLE NUMBER

EXHIBIT 3-1. FORMAT OF TABLES IN TMI-2 MASS BALANCE DATA BASE

The sections that follow describe both the sources for and the information assembled on key radionuclides, on plant systems, on the chronology of events following the accident onset that affected mass flows, and on samples taken of various system and component contents and on the results of their analyses. A list of the data base contents as of October 10, 1982, is presented as the appendix to this report (Volume 2).

3.1 KEY RADIONUCLIDES

The data necessary to calculate the total activities of key radionuclides in the TMI-2 core at selected times after the accident are assembled in the isotope table in the data base. These total isotope amounts are needed to allow determination of mass balance closures.

3.1.1 Data Sources

The isotope table includes decay constants taken from a recent handbook[5] and calculated activities (in curies) of each key isotope at reactor shutdown and at sequential times thereafter. These calculated activities are taken (except for tritium) directly from a LOR-2 analysis.[6] LOR-2 is a version of ORIGEN developed by the Babcock and Wilcox (B&W) organization to estimate isotope generation and decay in B&W reactors. LOR-2 provides, along with information, the activity of each core isotope at scram and at squential time increments thereafter.

The B&W LOR-2 analysis of isotope buildup and decay were chosen as the best estimates for TMI-2 as a B&W reactor. The LOR-2 results have been compared with those from ORIGEN-II;[7] the comparison indicated that most values agreed within 5 percent. Exceptions among the key isotopes were strontium-89, with the ORIGEN value being 15 percent higher, and iodine-131, with the ORIGEN value being 7 percent higher. Tritium, iodine-129, cesium-134, and uranium-238 were not compared.

Tritium (3-H) production is only partially calculated by LOR-2; that is, the production of tritium in the fuel via fission (3,746 curies at shutdown) is calculated, but the quantities produced in the coolant via neutron activation of dissolved lithium and boron are not calculated. Tritium from these sources was estimated.[8] The total tritium inventory at shutdown was estimated to be 3,872 curies, with 3,746 curies generated in the fuel by fission, 126 curies generated in the coolant from activation of lithium (32 curies) and boron (94 curies). The activity of tritium at times subsequent to shutdown was calculated using the decay constant.

3.1.2 Data Base

The isotope table (Exhibit 3-1) contains basic data for each of the eleven isotopes considered in this work: tritium, krypton-85, strontium-89, strontium-90, iodine-129, iodine-131, xenon-133, cesium-134, cesium-137, uranium-238, and plutonium-239. The data include decay constants and total activities as a function of time up to 40 days after shutdown.

It is anticipated that this table of total activities at specific times will be used to correct total activities determined at any time up to 40 days via exponential interpolation. The interpolation technique allows direct use of the results of the complex parent-daughter relationships included in the LOR-2 estimates without incorporation of those detailed calculations. For periods greater than 40 days after shutdown, the conventional exponential decay relationship is used to correct for decay.

3.2 SYSTEMS DEFINITION

The overall mass transfer pathways that characterize the TMI-2 accident involve systems and components contained in several facility buildings. Since these facilities/systems were used in an array of operational modes over an extended period of time to achieve a safe-shutdown condition, the actual accident scenario and mass transport required for a proper mass balance calculation are complex. Construction of a model useful for defining mass flow at any time following the accident initially requires deliberate simplification of system descriptions and system use. The simplified model conceived to represent the systems involved in the TMI-2 mass balance study consists of relatively large regions (buildings and surrounding environment), systems contained within these large regions, and components associated with each system. Each region, system, and component in the model has been defined to have been associated with mass flow during the accident and shutdown sequence. In addition, the model has been designed through proper subcategorization of systems and components to permit future expansion to allow for greater levels of detail in accident description as information becomes available.

3.2.1 Buildings, Systems, and Components

The basic model used to depict the buildings and systems involved in the TMI-2 accident is defined in Exhibit 2-5. Major interconnections, depicted in this exhibit for each building and system as defined for liquid and gaseous flow during the accident, were obtained from References 4 and 9 through 16. Exhibit 3-2 lists those buildings and systems that were involved with mass transfer during the TMI-2 accident and that will eventually require incorporation into a final mass balance data base. It should be noted, however, that not all systems identified in Exhibit 3-2 were used to generate the preliminary mass balance described in Section 4.

Exhibit 3-3 lists the components contained in each TMI-2 system that are of interest in calculating an overall mass balance. It should be noted that this table does not identify valves or piping that will eventually be required for calculation of a precise mass balance. In addition, the table does not list

EXHIBIT 3-2

REGIONS AND SYSTEMS IDENTIFIED
WITH THE TMI-2 ACCIDENT MASS TRANSPORT

Description	Coded Identification
Regions	
Unit 2 auxiliary building	AUX 2
Unit 2 containment building	CON 2
Unit 2 fuel handling building	FHB 2
River water pump house	RWPH
Unit 2 control and service building	SER 2
Units 1 and 2 general site outside buildings	SITE
Systems	
Chemical addition system	CAS
Core flood system	CFS
Decay heat closed cooling water system	DHS
Decay heat removal system	DHR
Heating ventilation and air conditioning system	HVC
Intermediate closed cooling water system	ICS
Makeup and purification system	MPS
Nuclear services river water system	NRW
Reactor building purge and recirculation system	PRS
Reactor building spray system	RBS
Reactor coolant system	RCS
Radwaste disposal - gas	WDG
Radwaste disposal - liquid	WDL

EXHIBIT 3-3 (Page 1 of 6)

COMPONENTS IDENTIFIED WITH TMI-2 MASS TRANSPORT

Reactor Coolant System (RCS)

Pressurizer	RC-T-2
Pressurizer surge line	RCP-PS-1
Primary reactor coolant cold leg A1	RCP-C-1A1
Primary reactor coolant cold leg A2	RCP-C-1A2
Primary reactor coolant hot leg A	RCP-H-1A
Primary reactor coolant hot leg B	RCP-H-1B
Primary reactor coolant cold leg B1	RCP-C-1B1
Primary reactor coolant cold leg B2	RCP-C-1B2
Reactor coolant pump 1A	RC-P-1A
Reactor coolant pump 2A	RC-P-2A
Reactor coolant pump 1B	RC-P-1B
Reactor coolant pump 2B	RC-P-2B
Reactor vessel	RC-T-1
Steam generator A, primary side	RC-H-1A
Steam generator B, primary side	RC-H-1B

Makeup and Purification System (MPS)

Block orifice	MU-1-FE
Letdown cooler A	MU-C-1A
Letdown cooler B	MU-C-1B
Makeup and purification demineralizer A	MU-K-1A
Makeup and purification demineralizer B	MU-K-1B
Makeup filter A	MU-F-2A
Makeup filter B	MU-F-2B
Makeup pump A	MU-P-1A
Makeup pump B	MU-P-1B
Makeup pump C	MU-P-1C
Makeup, purification, and demineralizer filter A	MU-F-5A
Makeup, purification, and demineralizer filter B	MU-F-5B
Makeup tank	MU-T-1
Seal injection filter A	MU-F-4A
Seal injection filter B	MU-F-4B
Seal return cooler A	MU-C-2A
Seal return cooler B	MU-C-2B
Seal return filter A	MU-F-3A
Seal return filter B	MU-F-3B

EXHIBIT 3-3 (Page 2 of 6)

COMPONENTS IDENTIFIED WITH TMI-2 MASS TRANSPORT

Liquid Waste System (WDL)

Auxiliary building sump	AUX SUMP
Auxiliary building sump filter A	WDL-F-3A
Auxiliary building sump filter B	WDL-F-3B
Auxiliary building sump pump A	WDL-P-3A
Auxiliary building sump pump B	WDL-P-3B
Auxiliary building sump tank	WDL-T-5
Auxiliary building sump tank pump A	WDL-P-4A
Auxiliary building sump tank pump B	WDL-P-4B
Cleanup demineralizer A	WDL-K-2A
Cleanup demineralizer B	WDL-K-2
Cleanup demineralizer effluent filter A	WDL-F-9A
Cleanup demineralizer effluent filter B	WDL-F-9B
Cleanup filter A	WDL-F-6A
Cleanup filter B	WDL-F-6B
Concentrated waste tank	WDS-T-2
Concentrated waste tank pump	WDS-P-2
Contaminated drain filter A	WDL-F-7A
Contaminated drain filter B	WDL-F-7B
Contaminated drain tank A	WDL-T-11A
Contaminated drain tank B	WDL-T-11B
Contaminated drain tank pump A	WDL-P-15A
Contaminated drain tank pump B	WDL-P-15B
Contaminated drain tank room sump	CDT SUMP
Deborating demineralizer A	WDL-K-1A
Deborating demineralizer B	WDL-K-1B
Decay heat pump room sump	DHPR SUMP
Decay heat pump room sump pump A	WDL-P-16A
Decay heat pump room sump pump B	WDL-P-16B
Evaporator condensate demineralizer A	WDL-K-3A
Evaporator condensate demineralizer B	WDL-K-3B
Evaporator condensate pump A	WDL-P-11A
Evaporator condensate pump B	WDL-P-11B
Evaporator condensate test tank A	WDL-T-9A
Evaporator condensate test tank B	WDL-T-9B
Leakage cooler A	WDL-C-1A
Leakage cooler B	WDL-C-1B
Miscellaneous waste holdup tank	WDL-T-2
Miscellaneous waste tank pump A	WDL-P-6A
Miscellaneous waste tank pump B	WDL-P-6B
Neutralizer tank A	WDL-T-8A
Neutralizer tank B	WDL-T-8B
Neutralizer tank filter A	WDL-F-4A
Neutralizer tank filter B	WDL-F-4B
Neturalizer tank pump A	WDL-P-8A

EXHIBIT 3-3 (Page 3 of 6)

COMPONENTS IDENTIFIED WITH TMI-2 MASS TRANSPORT

Liquid Waste System (WDL), Continued

Neutralizer tank pump B	WDL-P-8B
Reactor building spray pump room sump	RBSPR SUMP
Reactor building spray pump room sump pump A	WDL-P-17A
Reactor building spray pump room sump pump B	WDL-P-17B
Reactor building sump	RB SUMP
Reactor building sump pump A	WDL-P-2A
Reactor building sump pump B	WDL-P-2B
Reactor building sump pump filter A	WDL-F-8A
Reactor building sump pump filter B	WDL-F-8B
Reactor coolant bleed holdup tank A	WDL-T-1A
Reactor coolant bleed holdup tank B	WDL-T-1B
Reactor coolant bleed holdup tank C	WDL-T-1C
Reactor coolant drain tank	WDL-T-3
Reactor coolant drain tank pump	WDL-P-7
Reactor coolant evaporator	WDL-Z-1
Reclaimed boric acid pump	WDS-P-3
Reclaimed boric acid tank	WDL-T-3
Resin addition tank	WDL-T-10
Resin traps filter/evaporator condensate demineralizer A	WDL-F-5A
Resin traps filter/evaporator condensate demineralizer B	WDL-F-5B
Spent resin tank A	WDS-T-1A
Spent resin tank B	WDS-T-1B
Spent resin transfer pump	WDS-P-1
Waste transfer pump A	WDL-P-5A
Waste transfer pump B	WDL-P-5B

Gaseous Waste System (WDG)

Atmosphere (sink)	ATMOSPHERE
Containment atmosphere	CON2
Relief valve vent header	WGP-H-1
Station vent	STATION VENT
Station vent monitor	HPR-219
Vent gas header	WGP-H-2
Waste gas compressor A	WDG-P-1A
Waste gas compressor B	WDG-P-1B
Waste gas decay tank A	WDG-T-1A
Waste gas decay tank B	WDG-T-1B
Waste gas filter	WDG-F-1

EXHIBIT 3-3 (Page 4 of 6)

COMPONENTS IDENTIFIED WITH TMI-2 MASS TRANSPORT

Intermediate Closed Cooling System (ICS)

Chemical feed tank	IC-T-2
Intermediate cooler A	IC-C-1A
Intermediate cooler B	IC-C-1B
Intermediate cooling filter A	IC-F-1A
Intermediate cooling filter B	IC-F-1B
Intermediate cooling pump A	IC-P-1A
Intermediate cooling pump B	IC-P-1B
Intermediate cooling surge tank	IC-T-1
Steam generator hot drain cooler	SV-C-1

Chemical Addition system (CAS)

Boric acid mix tank	CA-T-1
Boric acid pump A	CA-P-4A
Boric acid pump B	CA-P-4B
Boric acid tank heater	CA-C-1
Caustic pump	CA-P-5
Core flooding makeup tank	CA-T-8
Core flooding makeup tank pump	CA-P-8
Hydrazine drum A	CA-T-2A
Hydrazine drum B	CA-T-2B
Hydrazine pump	CA-P-1
Lithium hydroxide mix tank	CA-T-3
Lithium hydroxide pump	CA-P-2
Sodium thiosulfate and caustic mix tank	CA-T-5
Sulfuric acid mix tank	CA-T-9
Sulfuric acid pump	CA-P-9

Core Flood system (CFS)

Core flood tank A	CF-T-1A
Core flood tank B	CF-T-1B

Decay Heat Removal system (DHR)

Borated water storage tank	DH-T-1
Borated water storage tank recirculating pump A	DH-P-2A
Borated water storage tank recirculating pump B	DH-P-2B
Decay heat removal cooler A	DH-C-1A
Decay heat removal cooler B	DH-C-1B
Decay heat removal pump A	DH-P-1A
Decay heat removal pump B	DH-P-1B
Sodium hydroxide storage tank	DH-T-2

EXHIBIT 3-3 (Page 5 of 6)

COMPONENTS IDENTIFIED WITH TMI-2 MASS TRANSPORT

Decay Heat Closed Cooling Water System (DHS)

Chemical feed tank A	DC-T-2A
Chemical feed tank B	DC-T-2B
Decay heat closed cooling surge tank A	DC-T-1A
Decay heat closed cooling surge tank B	DC-T-1B
Decay heat closed cooling water pump A	DC-P-1A
Decay heat closed cooling water pump B	DC-P-1B
Decay heat service cooler A	DC-C-1A
Decay heat service cooler B	DC-C-1B
Leakage closed cooling water pump A	DC-P-2A
Leakage closed cooling water pump B	DC-P-2B

Reactor Building Spray System (RBS)

Reactor buildng spray pump A	BS-P-1A
Reactor buildng spray pump B	BS-P-1B
Sodium thiosulfate storage tank	BS-T-1
Spray line header nozzles A	SPRY-A
Spray line header nozzles B	SPRY-B

Nuclear Services River System (NRW)

Nuclear Services river water pump 1A	NR-P-1A
Nuclear Services river water pump 1B	NR-P-1B
Nuclear Services river water pump 1C	NR-P-1C

Reactor Building Purge and Recirculation System (PRS)

Air supply heaters A (8 labeled A through H)	AH-C-15
Air supply heaters B (8 labeled A through H)	AH-C-47
Hydrogen control exhaust fan	AH-E-34
Hydrogen control system filter unit (4 labeled 33, 34, 35, and 36)	AH-F-33-36
Reactor building air cooling fan motor assembly (5 labeled A through E)	AH-E-11
Reactor building air cooling unit 13 (5 labeled A through E)	AH-C-13
Reactor building air cooling unit 14 (5 labeled) A through E)	AH-C-14
Reactor building purge air supply fan A	AH-E-12A
Reactor building purge air supply fan B	AH-E-12B
Reactor building purge air supply filter A	AH-F-18A
Reactor building purge air supply filter B	AH-F-18B
Reactor building purge air supply fan A	AH-E-12A
Reactor building purge air supply fan B	AH-E-12B

EXHIBIT 3-3 (Page 6 of 6)

COMPONENTS IDENTIFIED WITH TMI-2 MASS TRANSPORT

Reactor Building Purge and Recirculation System (PRS), Continued

Reactor building purge air supply filter A	AH-F-18A
Reactor building purge air supply filter B	AH-F-18B
Reactor building purge exhuast fan A	AH-E-19A
Reactor building purge exhuast fan B	AH-E-19B
Reactor building purge exhaust filter unit A (4 labeled 19A, 20A, 21A, and 31A)	AH-F-19-31A
Reactor building purge exhaust filter unit B (4 labeled 19B, 20B, 21B, and 31B)	AH-F-19-31B

components for the heating, ventilation, and air conditioning system, since detailed data associated with the use of this system during the accident have not been evaluated.

For generating the preliminary mass balance described in Section 4, only the systems defined in Exhibit 3-4 were considered to have been predominantly involved in the radionuclide pathways from the reactor. The systems thus represented for the initial mass balance are (1) the reactor coolant system, (2) the makeup and purification system, (3) the liquid waste system, (4) the gaseous waste system (partial), (5) the decay heat removal system (partial), (6) the nuclear services river water system, and (7) the containment ventilation and purge system. Redundant components were considered as one unit for the preliminary mass balance.

The systems data identified to date have been categorized to allow tabulation of the initial design data for any component. Information pertaining to each component for determining mass transfer and developing a mass balance include the following: building, elevation, system, component, state (phase of material in component), total volume, volume error, total area, area error, reference (source of data), initial volume, initial volume error, initial area, initial area error, component operating pressure, component operating temperature, reference (source of data), and note (footnote).

The building and elevation at which the component is located is useful for identification relative to point of origin of mass prior to release. The system to which the component belongs is important for identification of both system use and material retention during the accident and subsequent shutdown. The component identification, total volume and area of the component, and initial volume and area of the component, along with operating pressure and temperature, are required to evaluate the extent of mass transferred and retained by that piece of equipment

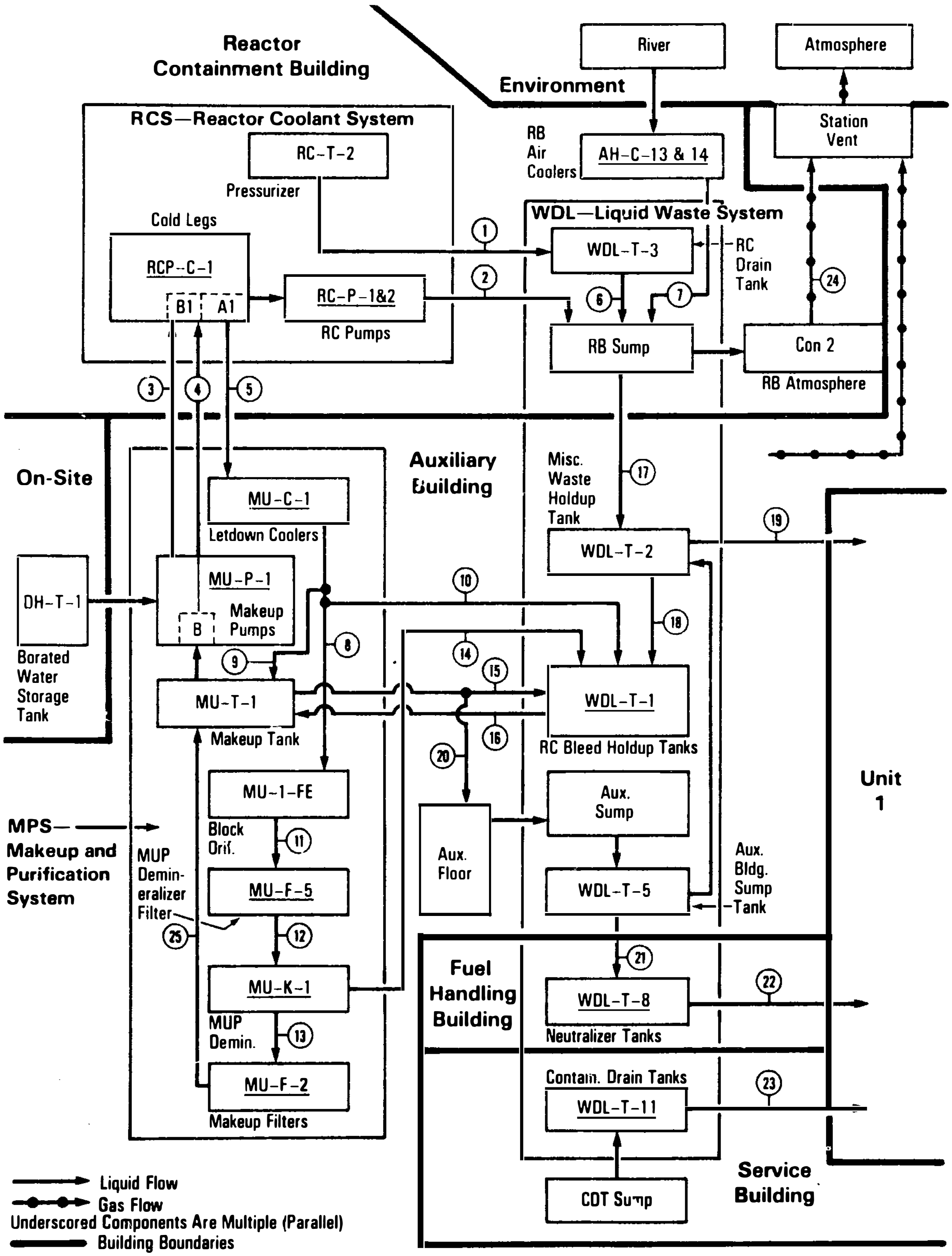


EXHIBIT 3-4
Mass Transfer Flow Paths

during the accident and subsequent shutdown. The state of material identifies the mass phase contained in the component at the time of sampling (i.e., solid, liquid, gas, or combination thereof). The various error categories have been incorporated to recognize sample, analysis, or evaluation inconsistencies that could have been included in the referenced data. To date, few errors have been identified for input into the data base.

3.2.2 Data Base

The information described above has been entered in a system table (Exhibit 3-1) that as of October 10, 1982, contains 219 records. Examination of these records (see the appendix, Volume 2) indicates that, for a number of components, additional data are required.

3.3 ACCIDENT CHRONOLOGY

As discussed above, use of various systems and components in an array of operational modes over an extended time period at TMI-2 presents a complex mass transfer problem. Since any mass balance must be determined on the basis of gross transfers of mass between components or more subtle material transfers between components and between phases within single components or systems, a necessary first step is the definition of discrete, identified mass transfers in chronological order. Although necessarily oversimplified, the discrete mass transfer sequence-of-events approach, when coupled with the facility/system model described earlier, results in a flexible system that can be used to predict gross flow rates and mass transfer at any time following the accident, as long as information pertaining to the time frame of interest has been incorporated into the data base. The mass flow chronology path during the postaccident period through April 30, 1979, is summarized in Exhibit 3-5; the discrete time periods are discussed below.

EXHIBIT 3-5 (Page 1 of 2)

MASS FLOW CHRONOLOGY

Item Number	Mass Flow Description	Flow Path* Identification
1	Incremental mass flow through pressurizer/reactor coolant drain tank/reactor building sump on March 28, 1979	1,6
2	Incremental mass flow through use of HPI on March 28, 1979	3
3	Incremental mass flow for letdown and makeup on March 28, 1979	5, 8, 11, 12, 13, 25, 4
4	8,260 gallons reactor coolant transferred to auxiliary building between 0408 and 0438, March 28, 1979	17
5	Mass flow to reactor building through air coolers (river water) between March 28 and May 27, 1979	7
6	Reactor collant system leakage to reactor building between March 28 and August 12, 1979	2
7	Liquid waste transfer sequencing from the auxiliary building sump through appropriate tanks to Unit 1 from March 28 through April 30, 1979	19, 21, 22, 23
8	Estimated mass transfer through letdown leakage to the auxiliary building between March 28 and April 30, 1979	20
9	Total gaseous radionuclide releases identified during accident and containment purge	24

*Consistent with flow paths identified on Ehxibit 3-4.

EXHIBIT 3-5 (Page 2 of 2)

MASS FLOW CHRONOLOGY

Item Number	Mass Flow Description	Flow Path* Identification
10	Incremental mass flow letdown between March 29 and April 30, 1979, with block orifice, pre-filters, makeup demineralizers, and makeup filters bypassed by 2330 hours on March 30, 1979	9, 10, 14
11	Incremental mass flow makeup between March 29 and April 30, 1979, including makeup tank transfer to bleed holdup tanks and bleed holdup tanks to makeup tank	15, 16, 18

*Consistent with flow paths indentified on Exhibit 3-4.

3.3.1 The First Day

During this period, the largest quantity of mass (liquid) was deliberately added to the reactor coolant system to achieve a safe-shutdown condition. This period is also consistent with the sequence of events.[4] During this time frame (approximately the first 24 hours) six basic flow patterns have been identified and are described as items 1 through 4 in Exhibit 3-5. In addition, portions of items 5 through 9 are included within the first time period.

3.3.2 The First Month

After the first day, the mass flow chronology followed the removal of the bubble in the reactor coolant system, total release of the gaseous radionuclide xenon, loss of letdown flow to the makeup and purification system, significant containment air cooler inleakage of river water, and use of the reactor coolant bleed holdup tanks as a source of makeup to the reactor coolant system. These blocks of events are identified as items 5 through 11 in Exhibit 3-5 and are consistent with the sequence of events reported.[9] It should be noted that Exhibit 3-5 relates the chronology of mass flow to the systems and component model shown on Exhibit 3-4.

3.3.3 The Following Six Months

After April 1979, the mass transfers shift to those makeup requirements needed to balance reactor coolant system leakage, Makeup and purification system leakage to the auxiliary building (not quantified to date), and other inleakage paths not identified to date. It was also during this period that containment air cooler river water inleakage was terminated (May 27, 1979).

Even though the mass balance includes provision for the time periods over which cleanup activities were performed, information has not been generated to date for input into the overall chronology data table. It was planned from the outset of this project that the mass balance model would include cleanup data beginning with the use of EPICOR I but that these activities would be separated from the actual accident mass transfer chronology.

3.3.4 The Cleanup Period

From April 1979 through the summer of 1982, activities were being performed to decontaminate the TMI-2 facilities. EPICOR I was used from April 1979 into the summer of 1979 to decontaminate various areas of the TMI-1 auxiliary building and the fuel handling building. EPICOR II was used from October 1979 through October 1980 to decontaminate the TMI-2 auxiliary building. The submerged demineralizer system (SDS) was used from the summer of 1981 to the summer of 1982 to decontaminate the reactor containment basement contents. Though not included in the current data base or chronology files, these activities will require proper description to complete the mass balance. Thus, three additional time periods will require sequencing of events.

3.3.5 Data Base

The chronology data identified to date have been categorized such that the location of any mass being transferred after the accident and during shutdown operations can be tabulated. Since the chronology is related to the time of the accident, as well as to other non-mass transfer actions, an events file was created from which mass transfer through associated systems and components at any particular time could be defined. Thus, the event number and sequence categories of the chronology file identify the time-dependent sequence of events for any set of components involved in a transfer of mass.

The chronology data identified to date have been chosen on the basis of on information defined by the sequence of events.[4,9-15]

The chronology of events, as summarized in Exhibit 3-5, was intermeshed with available systems information for events through April 1979 and correlated with the mass flow model depicted in Exhibit 3-4. Where available, actual mass transfers identified in References 4, 8, 9, and 13 through 16 were used to define either the total quantity of mass or the flow rate over a given time period. The chronology file has been structured to include the following categories of information: event number, sequence, start time, start time error and error units, stop time, stop time error and error units, from component, via component, to component (all components identified in accordance with system data files), state (phase of material being transferred), transfer rate volume, transfer rate error, mass transferred, mass error, and reference (source of data).

The start and stop time (year, month, day, hour, minute, and second) define the period over which mass was transferred, and from/via/to component categories identify the route of mass transfer. The state of mass refers to the same phases as identified above for the components description, whereas transfer rate volume and mass transferred refer to the quantity of mass known to have passed through or to have been collected in the component over the defined time period. The errors are similar to those identified for the systems description, and have not been identified for input into the data base.

To date, a total of 335 chronology records have been entered into the data base, covering the period through April 1979 (see the appendix, Volume 2). As noted earlier, the data base was expanded to include an event file list. To date, 290 events records, consisting basically of the sequence of events through April 30, 1979, have been incorporated into the data base.

3.4 RADIOCHEMICAL DATA

3.4.1 Data Sources

A major data source pertaining to sampling of TMI-2 systems for radiochemical analyses is the GPU sample coordinator's log, which was established on April 10, 1979, about 12 days after the accident. This log assigns a sample number, and identifies the date of sampling, the system component sampled, the analyses requested, the laboratory (or laboratories) to which the sample was sent, whether the analytical results were received, and other information. The sample coordinator's log provides the primary information about the existence of samples available for April 10 and after. Early sample information (before April 10, 1979) is not readily available because of an understandable lack of organization; however, the sample coordinator has recently provided a list of known samples taken before the log system was set up, which will prove valuable.

Another list of samples by date is included in an SAI report.[2] The laboratory analysis data sheets also provide sample descriptive data. The Entry Quick Look Reports also constitute a primary source of information about those samples taken during entries.

The data for the radiochemical results are generally laboratory analysis reports. Many data (after about mid-April 1979) are reported on a standardized GPU report form that encouraged laboratories to provide a complete and uniform system of information. Earlier data are reported in a variety of analysis report formats. Some data--the reactor coolant analyses performed by the Babcock and Wilcox laboratory and the analyses done at ORNL--were reported to GPU via memo.

This study uses five existing data collections that were made available by the EG&G Technical Integration Office (TIO).

The first was an uncatalogued collection of data, with many analysis reports. The second was the GPU microfilm library, with data indexed by topic; all topics likely to contain radiochemical data were searched. The third was the NSAC microfilm library. These data are stored in a storage and retrieval system that allowed a thorough search via key-words. The fourth collection is of data indexed by a TIO-library number; these data are also in the NSAC storage and retrieval system; hence, they were searched via keywords to retrieve all radiochemical data. A fifth source, the GPU sample coordinator's microfilm library, was recently made available. To date, only early sample data have been reviewed. These data collections were the primary bases of the search for data.

Because of the large quantity of samples and analytical records, it was necessary to cull the less meaningful. In the initial culling process, data pertaining to liquids in the primary coolant system, the makeup and purification system, and the liquid radwaste system were of major importance. Generally, data with concentrations less than one picocurie per milliliter (for liquids) were not included in this initial effort. Data for gases in the waste gas system and in the containment and auxiliary building for the early times were retained. Very few data for solids are available; surface data were not included in this phase.

3.4.2 Radiochemical Data Base

The radiochemical data consist of sampling and analysis data that have been entered into two tables; the sampling data in the sample table and the analysis data in the analysis table. Each sample is assigned a sample identification number that is included in the analysis table to provide the means for cross-reference.

The sample file (see Exhibit 3-1) includes the time at which the sample was taken, the system or component from which the sample was taken, and the state (i.e., gas, liquid, solid, or surface) of the sample. Additionally, the sample size (and size units) is included as a possible indication of sampling errors. A field is provided for a sampling error (i.e., the uncertainty in the representation of the material sampled), and another field for an error in sampling time.

The analysis file includes the analysis time (or the time to which the analyst corrected for decay), the state of the sample analyzed (to allow, as an example, a distinction between precipitate and filtrate, if analyzed separately), the isotope determined, and the concentration. Other data are included that may indicate errors or uncertainties.

The data base sample table contains data for 653 samples and the analysis table contains records for 1,961 analyses. Exhibit 3-6 lists the components and the corresponding samples in the data base.

It is recognized that the current data base is not exhaustive; however, an effort was made to include all available samples for the key components (i.e., generally those in the primary coolant, makeup and purification, and liquid radwaste system) and the time period (to April 30, 1979) for which the mass transfer chronology data base is complete. The correspondence of the data base samples to the sampling dates indicated in the listing of early samples provided by the GPU sample coordinator for all components for the period to April 12, 1979, is shown in Exhibit 3-7. Exhibit 3-8 shows the correspondence of sampling data in the GPU sample coordinator's log for key components during the period to April 30, 1979. As can be seen, the correspondence among these sources of sampling times is good, but not perfect. Additional effort should be made to identify all early pertinent samples.

EXHIBIT 3-6

TMI-2 COMPONENTS AND NUMBER OF SAMPLES

Component	Number of Samples
Auxiliary building air (AMS 281', AMS 305', AMS 328', etc.)	7
Auxiliary building floor	2
Auxiliary building sump	3
Auxiliary building sump demineralizer	1
Auxiliary building sump tank room	1
Borated water storage tank (DH-T-1, BWST valve, BWST cin. blk)	19
Contaminated drain tank room sump	8
Contaminated drain tanks ("WDL-T-11"; WDL-T-11A, WDL-T-11B)	33
Demineralized service water storage tank (CO-T-1B)	2
Containment air (CON2, VAR-748, CON2 626' penetration, org. oils)	75
Decay heat tie-in line	3
Fuel handling bay air	2
Fuel handling building exhaust	1
Condenser hot well	2
Station vent effluent air monitor (HPR-219)	199
Main steam condenser	1
Containment sump (R.B. sump)	5
Steam generators - secondary side (RC-H-1A, RC-H-1B)	41
Pressurizer (RC-T-2)	14
Reactor coolant evaporator condensate tank room	1
Reactor coolant system - letdown sampling point (RCP-C-1A1)	144
Recombiner deck air	2
Spent fuel pool	2
Waste gas decay tanks ("WDG-T-1"; WDG-T-1A, WDG-T-1B)	25
Waste transfer pumps (WDL-P-5)	1
Reactor coolant bleed holdup tanks ("WDL-T-1"; WDL-T-1A, WDL-T-1B, WDL-T-1C)	22
Miscellaneous waste holdup tank (WDL-T-2)	18
Neutralizer tanks ("WDL-T-8"; WDL-T8A; WDL-T-8B)	7
Evaporator condensate tank	1
Spent resin tank	1
Waste gas compressor valve	1
Waste gas filter room air	1
Waste gas decay tank room air	6
Total	653

EXHIBIT 3-7

COMPARISON OF SAMPLES IN THE DATA BASE WITH A LIST OF
EARLY SAMPLES SUPPLIED BY THE GPU SAMPLE COORDINATOR

COMPONENT*	March 28	29	30	31	April 1	2	3	4	5	6	7	8	9	10	11
Reactor Coolant	(1)	(4)													
RC Bleed Holdup Tank A			3 (3)	1 (1)			3 (3)								
RC Bleed Holdup Tank B				2 (2)											
RC Bleed Holdup Tank C			2 (2)												
Miscellaneous Waste Holdup Tank								1							
Contaminated Drain Tank A															
Contaminated Drain Tank B															
Neutralizer Tank A								1							
Neutralizer Tank B															
Reactor Building Sump															
Auxiliary Building Sump															
Contaminated Drain Tank Room Sump							3 (1)		3 (2)	1 (1)					
Reactor Building				2 (2)		3 (3)	(1)	1							
Station Vent	2 (3)	4 (4)	1 (2)	(2)	1	2 (2)	7 (2)	3 (2)	2	1 (2)	(1)	2 (1)		2 (2)	2 (1)

* This list of components is limited to those in the system model used in the preliminary mass balance.

3 - Number of samples on Sample Coordinator's List

(1) - Number of samples in the data base

EXHIBIT 3-8

COMPARISON OF SAMPLES IN THE DATA BASE WITH THOSE IN GPU SAMPLE COORDINATOR'S LOG

April 1979

COMPONENT*	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Reactor Coolant	④		1				①	①	①				①								
RC Bleed Holdup Tank A		1																			
RC Bleed Holdup Tank B														1							
RC Bleed Holdup Tank C																					
Miscellaneous Waste Holdup Tank				1 ①	1																1
Contaminated Drain Tank A				1 ①					1 ①				1 ①				1 ①	1 ①	1		
Contaminated Drain Tank B									1	1						1 ①					
Neutralizer Tank A															1			1			
Neutralizer Tank B															1			1			
Reactor Building Sump																					
Auxiliary Building Sump																					
Contaminated Drain Tank Room Sump		1	1	1 ①				1	1 ②						1	①					
Reactor Building																					
Station Vent	2 ②	3 ①	②	①	2 ③	5 ⑥	8 ⑨	5 ⑦	12 ⑨	6 ⑫	9 ⑮	6 ⑳	7 ⑮	8 ⑭	7 ⑭	5 ⑧	6 ⑨	2 ④	3 ⑤	1 ③	1 ③

* This list of components is limited to those in the system model used in the preliminary mass balance.

3 - Number of samples in GPU Sample Coordinator's Log

② - Number of samples in the data base

3.5 ERRORS

In a well-planned experiment, errors are considered both during its design and execution. The TMI-2 accident was neither a well-designed nor carefully executed experiment, and it not surprising that the efforts in sampling, sample analysis, measurements of material transfers, component volumes, and so on, were not planned to provide the desired accuracy for calculating a mass balance. Thus, in the course of mass balance determinations, the data available vary dramatically in terms of uniformity and accuracy. It, therefore, becomes the more important (than in a well-designed experiment) to estimate errors and uncertainties in data values and the values of final results, such as the mass balance closure (i.e., fraction of an isotope accounted).

Generally, the only available data relevant to errors are those reported with the radiochemical analyses. These errors are the uncertainties in the radiochemical analyses calculated for the statistics associated with the counting of radioactive decay events.

Other uncertainties that must be considered (and may well be much larger in many cases than the counting error) are the uncertainties in sampling (i.e., the uncertainty with which the sample represents the total volume or mass that it is presumed to represent), and the uncertainties in the volume (or mass) values. The volume values involve the volumes of components (e.g., tank volumes, void volumes in filters, and demineralizers) and the volumes of material transferred (i.e., the volume flow rates and flow times).

An analysis of errors is desirable, but, in terms of the present preliminary mass balance calculations, the information at hand is of a superficial or incomplete nature. A systematic error analysis consisting of a statistical determination on the uncertainty of a calculated mass balance from the uncertainties of each experimental value is not useful. It appears that error analyses will gradually accrue, first in the form of the identification of values that are inconsistent with the other related data base values (i.e., the identification of questionable values). The next stage is the assessment of uncertainties that may involve the quantification of the precision of mass balances calculated in different ways or for different times.

3.6 DATA BASE MANAGEMENT SYSTEM

The data, as noted, are formatted into eight tables, as shown on Exhibit 3-1. The data as of October 10, 1982, are listed in the appendix to this report. These data are accessible and can be manipulated by the TMI-2 mass balance data base management system.

This data base management system is described in detail in the TMI-2 Mass Balance Data Base User's Manual; it enables the user to manipulate the data more-or-less at will. Exhibit 3-9 presents the tutorial session from the data base management system, that, in turn, introduces the basic features of the system.

This system and the data base are presently maintained on the NUS PRIME computer (in Gaithersburg, Maryland) and are remotely accessible from TMI.

EXHIBIT 3-9 (Page 1 of 3)

DATA BASE MANAGEMENT SYSTEM,
TUTORIAL SESSION

T M I   M a s s   B a l a n c e   D a t a   B a s e

VERSION 4

A service of NUS Corporation

for EG&G TIO

1	TUTORIAL	List informative text by subject
2	TABLE	Enter/describes current table
3	MAINT	Enter Maintenance subsystem
4	QUERY	Enter Query subsystem
5	EXIT	Terminate

Please select an operating mode number: 1

YOU HAVE SELECTED THE TUTORIAL OPERATING MODE.

THIS DATA BASE CONSISTS OF EIGHT DATA TABLES CONTAINING INFORMATION ESSENTIAL TO MASS BALANCE CALCULATIONS. EACH TABLE CONSISTS OF RECORDS WITH DATA IN SPECIFIED FIELDS. THE FOLLOWING TABLES MAKE UP THE TMI-2 MASS BALANCE DATA BASE:

1	ISOTOPE	Initial total quantities and decay constants
2	SAMPLE	Sample collection data
3	ANALYSIS	Sample radiochemical analyses
4	SYSTEM	Plant system component data
5	CHRONOLOGY	Mass transfer history data
6	EVENT	Notes relative to sequence of events
7	REFERENCE	Sources of information
8	NOTE	Footnotes

YOU WILL LATER BE REQUIRED TO SELECT ONE OF THE ABOVE TABLES.

EXHIBIT 3-9 (Page 2 of 3)

DATA BASE MANAGEMENT SYSTEM,
TUTORIAL SESSION

THE INTERACTIVE DATA BASE MANAGEMENT SYSTEM WHICH YOU ARE USING HAS SEVERAL MODES OF OPERATIONS AVAILABLE:

TUTORIAL
TABLE
QUERY
MAINTENANCE
CALCULATION
EXIT

YOU ARE PRESENTLY WORKING IN THE TUTORIAL MODE. THE TABLE MODE ALLOWS THE USER TO SELECT A TABLE FOR HIS INSPECTION AND LISTS FIELD NAMES OF THE RECORDS IN THAT TABLE. THE MAINTENANCE MODE PROVIDES DATA TABLE ENTRY, MODIFICATION, AND DELETION CAPABILITIES. NOTE: THIS MODE IS PASSWORD PROTECTED. THE QUERY MODE PROVIDES DATA SELECTION, SORTING, MANIPULATING, AND DISPLAY PROCEDURES. THE CALCULATION MODE WILL PROVIDE AN ABILITY TO WORK WITH DATA FROM SEVERAL TABLES, SUPPORTING MASS BALANCE CALCULATIONS. NOTE: THE CALCULATION MODE IS NOT AVAILABLE IN VERSION 4. THE EXIT MODE ALLOWS THE USER TO EXIT FROM THE SYSTEM.

THE DATA BASE MANAGEMENT SYSTEM HAS AVAILABLE THE FOLLOWING COMMANDS:

ADD	CREATE A NEW RECORD
CHANGE	MODIFY FIELD VALUES IN CURRENT SET
DELETE	DELETE (ERASE AND REWRITE) AN EXISTING RECORD
DISPLAY	PRODUCE REPORT OUTPUT
ERASE	DELETES RECORDS IN CURRENT SET
FIND	LOCATE RECORD(S) BY FIELD VALUE
FORMAT	SPECIFY REPORT OUTPUT FORMAT (ALIAS TO IMAGE)
HELP	LIST INFORMATIVE TEXT
IMAGE	SPECIFY REPORT OUTPUT FORMAT
INDEX	DISPLAY OR CREATE INDEX FILES FOR FIELDS
INFO	DISPLAY INFORMATION ON FIELD PARAMETERS
KEEP	REMOVE NON-MATCHING RECORDS FROM THE CURRENT SET
LIST	LIST FIELD OR RECORD VALUES
LOAD	BATCH RECORD ADD FUNCTION
MODIFY	CHANGE FIELDS IN CURRENT RECORD
POSITION	FETCH OR CHANGE CURRENT RECORD
RELEASE	EXIT RESTRICTED UPDATE MODE
REMOVE	REMOVE MATCHING RECORDS FROM THE CURRENT SET
RESERVE	ENTER RESTRICTED UPDATE MODE
SAVE	WRITE CURRENT RECORD
SELECT	ADD MATCHING RECORDS TO THE CURRENT SET
SET	MANIPULATE RECORD SETS
SHOW	ANALYZE CURRENT SET
SORT	SORT RECORDS IN SET BY FIELD VALUE

4. PRELIMINARY MASS BALANCE

The concept of the preliminary mass balance presented below is essentially one of accounting arithmetic in which volumes of liquid or gaseous contents of system components are multiplied by corresponding concentrations of each of the key isotopes to obtain component inventories. This arithmetic is performed at chosen mass balance times; the concentration-volume products are divided by the total activity of each of the key isotopes at the mass balance time, and these isotope fractions are summed to indicate balance closure.

The preliminary nature of this approach is apparent in its limitations. At the outset, this process can be applied only to systems and for times at which applicable volumes and concentrations have been determined. No attempt is made to estimate or assume values for mass transfers, volumes, or concentrations that are not directly calculable from the data, nor are isotopic removal mechanisms considered or modeled.

The scheme for computer-aided determinations of mass balance is outlined in Exhibit 4-1 in terms of five modules. The first module, the Introductory Text Module, will introduce the user to the system and the options it affords. The other four modules are described below.

4.1 PROBLEM INITIALIZATION

The second module, the Problem Initialization Module, will assist the user in problem initialization by allowing him to define a model of the components' flow pattern and chronology. The defined model may be a simplification of the actual TMI-2 system described in the system table derived by lumping components or, perhaps at some later time, a more detailed model than the current system table represents via subdivision of components. The computer aids the user by creating a new system table of

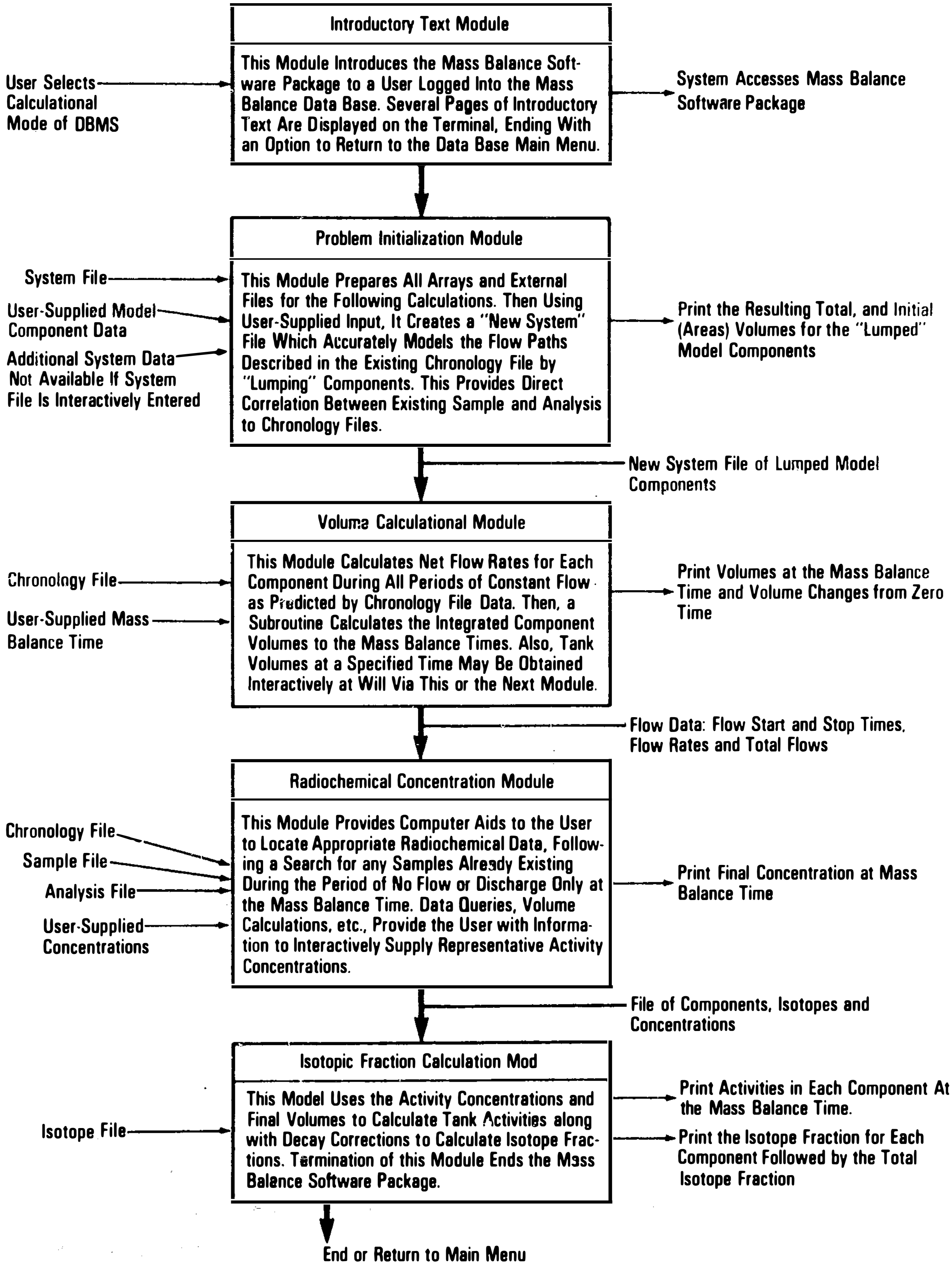


EXHIBIT 4-1
Preliminary Mass Balance Calculation

lumped components and establishing the correlation between the new table and the chronology and sample tables.

The flow path model presented in Exhibit 3-4 is the basis for the present preliminary mass balances; the lumping of components in the data base that this model involves is demonstrated on the computer printout in Exhibit 4-2. The lumped component symbol 17 RCS indicates that this lumped component incorporates all of the 17 components listed under RCS (reactor coolant system). Similarly, 3 MU-C-1 includes three components: MU-C-1A and MU-C-1B (the letdown coolers), as well as MU-C-1, which ensures the inclusion of records not identified as applying to a specific cooler. The computer provides the user at this point with a list of system components for which volume or surface area data have not been entered in the system table and gives him the option to input such data. In the example case, the option to add data was declined and the list of components for which system data are lacking is provided as shown in Exhibit 4-3.

In this case, the lack of those volume data are acceptable for a variety of reasons. For example, the component RCP-C-1 is a designation used in the chronology table for those records of transfer through the cold legs in the reactor coolant system for which the specific cold leg is not known. Hence, the necessary volume data are available in the system table under RCP-C-1A1, RCP-C-1A2, RCP-C-1B1, and RCP-C-1B2. Similarly, RC-P-1&2 is a lumped designator in the chronology table, but volumes are available in the system table for the separate parts (i.e., 4 RC pumps). Similar explanations for WDL-T-1, WDL-T-8, and WDL-T-11 apply.

For other items on the list, the components are sinks (but at present are not specially designated as such in the data base). Hence, the AUX FLOOR (Auxiliary building floor), UNIT 1, and ATMOSPHERE are sinks for which a volume in the system table context is not applicable. For other items on the list, the

EXHIBIT 4-2

USER-SUPPLIED MODEL COMPONENT DATA

```
17RCS              LIQ
RC-T-1
RC-T-2
RC-H-1A
RC-H-1B
RCP-C-1
RCP-C-1A1
RCP-C-1A2
RCP-C-1B1
RCP-C-1B2
RCP-PS-1
RCP-H-1A
RCP-H-1B
RC-P-1&2
RC-P-1A
RC-P-1B
RC-P-2A
RC-P-2B
 3MU-C-1           LIQ
MU-C-1
MU-C-1A
MU-C-1B
 1MU-1-FE          LIQ
MU-1-FE
 3MU-F-5           LIQ
MU-F-5
MU-F-5A
MU-F-5B
 3MU-K-1           LIQ
MU-K-1
MU-K-1A
MU-K-1B
 3MU-F-2           LIQ
MU-F-2
MU-F-2A
MU-F-2B
 1MU-T-1           LIQ
MU-T-1
 4MU-P-1           LIQ
MU-P-1
MU-P-1A
MU-P-1B
MU-P-1C
 1DH-T-1           LIQ
DH-T-1
 1AUX FLOOR        LIQ
AUX FLOOR
 1WDL-T-3          LIQ
WDL-T-3
 1RB SUMP          LIQ
RB SUMP
 1WDL-T-2          LIQ
WDL-T-2
 4WDL-T-1          LIQ
```

(Contined from first column)

```
WDL-T-1
WDL-T-1A
WDL-T-1B
WDL-T-1C
 1AUX SUMP         LIQ
AUX SUMP
 1WDL-T-5          LIQ
WDL-T-5
 3WDL-T-8          LIQ
WDL-T-8
WDL-T-8A
WDL-T-8B
 3WDL-T-11         LIQ
WDL-T-11
WDL-T-11A
WDL-T-11B
 1COT SUMP         LIQ
COT SUMP
 1UNIT 1           LIQ
UNIT 1
 1CON2             ALL
CON2
 1STATION VENT     GAS
STATION VENT
 1ATMOSPHERE       GAS
ATMOSPHERE
 5NR-P-1           LIQ
NR-P-1
NR-P-1A
NR-P-1B
NR-P-1C
NR-P-1D
11AH-C-13&14       LIQ
AH-C-13&14
AH-C-13A
AH-C-13B
AH-C-13C
AH-C-13D
AH-C-13E
AH-C-14A
AH-C-14B
AH-C-14C
AH-C-14D
AH-C-14E
```

EXHIBIT 4-3

COMPONENT DESIGNATIONS WITHIN THE MODEL
FOR WHICH SYSTEM DATA ARE LACKING

THERE IS NO MATCH IN SYSTEM DATA FOR RCP-C-1	OF RCS	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR RC-P-1&2	OF RCS	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-C-1	OF MU-C-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-C-1A	OF MU-C-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-C-1B	OF MU-C-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-1-FE	OF MU-1-FE	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-F-5	OF MU-F-5	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-F-5A	OF MU-F-5	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-F-5B	OF MU-F-5	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-K-1	OF MU-K-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-K-1A	OF MU-K-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-K-1B	OF MU-K-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-F-2	OF MU-F-2	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-F-2A	OF MU-F-2	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-F-2B	OF MU-F-2	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-P-1	OF MU-P-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-P-1A	OF MU-P-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-P-1B	OF MU-P-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR MU-P-1C	OF MU-P-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AUX FLOOR	OF AUX FLOOR	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR WDL-T-1	OF WDL-T-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR WDL-T-8	OF WDL-T-8	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR WDL-T-11	OF WDL-T-11	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR UNIT 1	OF UNIT 1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR STATION VENT	OF STATION VENT	WITH STATE GAS
THERE IS NO MATCH IN SYSTEM DATA FOR ATMOSPHERE	OF ATMOSPHERE	WITH STATE GAS
THERE IS NO MATCH IN SYSTEM DATA FOR NR-P-1	OF NR-P-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR NR-P-1A	OF NR-P-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR NR-P-1B	OF NR-P-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR NR-P-1C	OF NR-P-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR NR-P-1D	OF NR-P-1	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-13&14	OF AH-C-13&14	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-13A	OF AH-C-13&14	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-13B	OF AH-C-13&14	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-13C	OF AH-C-13&14	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-13D	OF AH-C-13&14	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-13E	OF AH-C-13&14	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-14A	OF AH-C-13&14	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-14B	OF AH-C-13&14	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-14C	OF AH-C-13&14	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-14D	OF AH-C-13&14	WITH STATE LIQ
THERE IS NO MATCH IN SYSTEM DATA FOR AH-C-14E	OF AH-C-13&14	WITH STATE LIQ

volumes are not available, and the preliminary mass balance consequently may be limited. Volumes for the NR-P-1 items (river water pumps), the AH-C-13&14 items (reactor building air coolers) and several MU-designated components (of the make-up and purification system) are not currently available.

Finally, the Problem Initialization Module provides a list of the model (lumped) components, total component volumes and areas, and the volumes of the liquid or gaseous contents at the start of the accident, as shown in Exhibit 4-4.

4.2 VOLUME CALCULATIONS

The third module, the Volume Calculational Module, accepts the new system file of model components and the user-supplied mass balance time (in this example case, April 30, 1979, at 2400 hours) and totals the volume deposits into and withdrawals from each model component from the start of the accident to the mass balance time.

Of course, the idiosyncracies of the problem initialization follow through and manifest themselves in the volumes shown on Exhibit 4-5. For example, the calculated liquid or gaseous volumes of components for which some influents or effluents have not yet been quantified are in error. Some components (e.g., pumps) are treated as pass-through elements, and these volumes are considered to be zero. Source components may show negative volumes; for example, the STATION VENT appears as a source because flows into the vent are not yet quantified. Similarly, sink components (e.g., ATMOSPHERE) build up large calculated positive volumes. The net result of the analysis of this list of liquid and gas volumes is that the triple-starred values for the RCS (reactor coolant system), MU-T-1 (makeup tank), WDL-T-3 (reactor coolant drain tank), RB sump, WDL-T-1 (reactor coolant bleed tanks) and CON2 (reactor building containment) are valid and useful for a mass balance determination.

EXHIBIT 4-4

TOTAL AND INITIAL VOLUMES AND
AREAS OF MODEL COMPONENTS

****
THIS IS THE NEW SYSTEM DATA FOR 25 MODEL COMPONENTS
****

COMPONENT	STATE	TOTAL VOLUME	TOTAL AREA	INITIAL VOLUME	INITIAL AREA
RCS	LIQ	8.86E+04	0.00E-01	8.24E+04	0.00E-01
MU-C-1	LIQ	0.00E-01	0.00E-01	0.00E-01	0.00E-01
MU-1-FE	LIQ	0.00E-01	0.00E-01	0.00E-01	0.00E-01
MU-F-5	LIQ	0.00E-01	0.00E-01	0.00E-01	0.00E-01
MU-K-1	LIQ	0.00E-01	0.00E-01	0.00E-01	0.00E-01
MU-F-2	LIQ	0.00E-01	0.00E-01	0.00E-01	0.00E-01
MU-T-1	LIQ	4.49E+03	0.00E-01	2.28E+03	0.00E-01
MU-P-1	LIQ	0.00E-01	0.00E-01	0.00E-01	0.00E-01
DH-T-1	LIQ	4.56E+05	0.00E-01	4.49E+05	0.00E-01
AUX FLOOR	LIQ	0.00E-01	0.00E-01	0.00E-01	0.00E-01
WDL-T-3	LIQ	4.86E+03	0.00E-01	6.64E+03	0.00E-01
RB SUMP	LIQ	2.09E+03	0.00E-01	8.74E+02	0.00E-01
WDL-T-2	LIQ	1.90E+04	0.00E-01	1.39E+04	0.00E-01
WDL-T-1	LIQ	2.27E+05	0.00E-01	1.34E+05	0.00E-01
AUX SUMP	LIQ	6.37E+03	0.00E-01	4.84E+03	0.00E-01
WDL-T-5	LIQ	2.89E+03	0.00E-01	2.50E+03	0.00E-01
WDL-T-8	LIQ	1.51E+04	0.00E-01	1.68E+04	0.00E-01
WDL-T-11	LIQ	4.64E+03	0.00E-01	2.53E+03	0.00E-01
CDT SUMP	LIQ	1.35E+02	0.00E-01	3.15E+01	0.00E-01
UNIT 1	LIQ	0.00E-01	0.00E-01	0.00E-01	0.00E-01
CON2	ALL	2.12E+06	2.38E+05	2.12E+06	2.38E+05
STATION VENT	GAS	0.00E-01	0.00E-01	0.00E-01	0.00E-01
ATMOSPHERE	GAS	0.00E-01	0.00E-01	0.00E-01	0.00E-01
NR-P-1	LIQ	0.00E-01	0.00E-01	0.00E-01	0.00E-01
AH-C-13&14	LIQ	0.00E-01	0.00E-01	0.00E-01	0.00E-01

EXHIBIT 4-5

VOLUMES AT AND ACCUMULATED VOLUME CHANGES
TO THE MASS BALANCE TIME

VOLUMES ARE AT:
YEAR: 79
MONTH: 4
DAY: 30
HOUR: 24
MINUTE: 0
SECOND: 0

****
* TABLE OF COMPONENT VOLUMES *
****

COMPONENT	STATE	VOLUME	CHANGE IN VOLUME	
RCS	LIQ	9.162E+04	9.220E+03	***
MU-C-1	LIQ	0.000E-01	0.000E-01	**
MU-1-FE	LIQ	0.000E-01	0.000E-01	**
MU-F-5	LIQ	0.000E-01	0.000E-01	**
MU-K-1	LIQ	0.000E-01	0.000E-01	**
MU-F-2	LIQ	0.000E-01	0.000E-01	**
MU-T-1	LIQ	1.395E+03	-8.854E+02	***
MU-P-1	LIQ	0.000E-01	0.000E-01	**
DH-T-1	LIQ	1.609E+05	-2.881E+05	**
AUX FLOOR	LIQ	0.000E-01	0.000E-01	**
WDL-T-3	LIQ	7.440E+03	8.000E 02	***
RB SUMP	LIQ	4.463E+05	4.455E+05	***
WDL-T-2	LIQ	-3.664E+04	-5.054E+04	*
WDL-T-1	LIQ	5.684E+04	-7.716E+04	***
AUX SUMP	LIQ	2.964E+04	2.480E+04	*
WDL-T-5	LIQ	-3.800E+03	-6.300E+03	*
WDL-T-8	LIQ	3.800E+03	-1.300E+04	*
WDL-T-11	LIQ	-1.200E+02	-2.650E+03	*
CDT SUMP	LIQ	3.150E+01	0.000E-01	*
UNIT 1	LIQ	6.115E+04	6.115E+04	**
CON2	ALL	2.120E+06	0.000E-01	***
STATION VENT	GAS	-4.060E+09	-4.060E+09	**
ATMOSPHERE	GAS	4.060E+09	4.060E+09	**
NR-P-1	LIQ	-1.028E+05	-1.028E+05	**
AH-C-13&14	LIQ	0.000E-01	0.000E-01	**

* All flows into/from these components are not quantified, hence, volumes are not correct.

** Source, sink, or pass-through components for which volumes represent volume changes are therefore not applicable.

***Volumes are applicable.

4.3 RADIOCHEMICAL CONCENTRATIONS

The Radiochemical Concentration Module has not yet been developed. It will aid the user in the manipulation of the data base in order to identify samples that represent the contents of components at the mass balance time and to provide a basis for calculating the concentrations from other sample or mass transfer chronology data. The input to it will include the flow data file from the Volume Calculational Module. The output will be a file list of components, isotopes, and concentrations.

The function of this module can be illustrated with the example of a prelminary mass balance for April 30, 1979, at 2400 hours. A search of the sample table for samples, taken in the relevant time frames, of components for which volumes are available results in the information shown on Exhibit 4-6. The RCS will probably be considered in many mass balance determinations as a special component because there are many sample data for the RCS and because this system represents the source of, or a transfer vehicle for, radioactivity found in other components. For the present example, a superficial examination of the concentration versus time behavior (Exhibit 4-7) of isotopes in the RCS indicates that the May 2, 1979, sample (which is the one closest to the mass balance time) is representative of the RCS on April 30, 1979. Similarly, Exhibit 4-8 indicates that the May 2, 1979, sample of dissolved gas in the RCS is probably representative of the RCS on April 30, 1979. The first RB-sump sample in the data base was taken on August 28, 1979.

Mass flow information from the chronology table is graphically represented in Exhibit 4-9 and its use indicated in the example mass balance by the following:

> Between April 30 and August 25, there were two flows recorded into the RB sump and none out. One flow was pump leakage of river water (flow 7 on Exhibit 4-9), and the other was

EXHIBIT 4-6

SAMPLES TAKEN WITHIN THE TIME FRAME
POTENTIALLY APPLICABLE TO MASS BALANCE
FOR APRIL 30, 1979

Component	Sample Date	State
RCS	5/2/79 and approximately weekly (see graphs)	Liquid
WDL-T-3 and RB sump	8/28/79	Liquid
WDL-T-1 and MU-T-1	3/30/79, 3/31/79, 4/6/79, and 5/18/79	Liquid
RCS	5/2/79 and approximately weekly (see graphs)	Gas*
CON2	5/4/79	Gas

*Dissolved fission gas

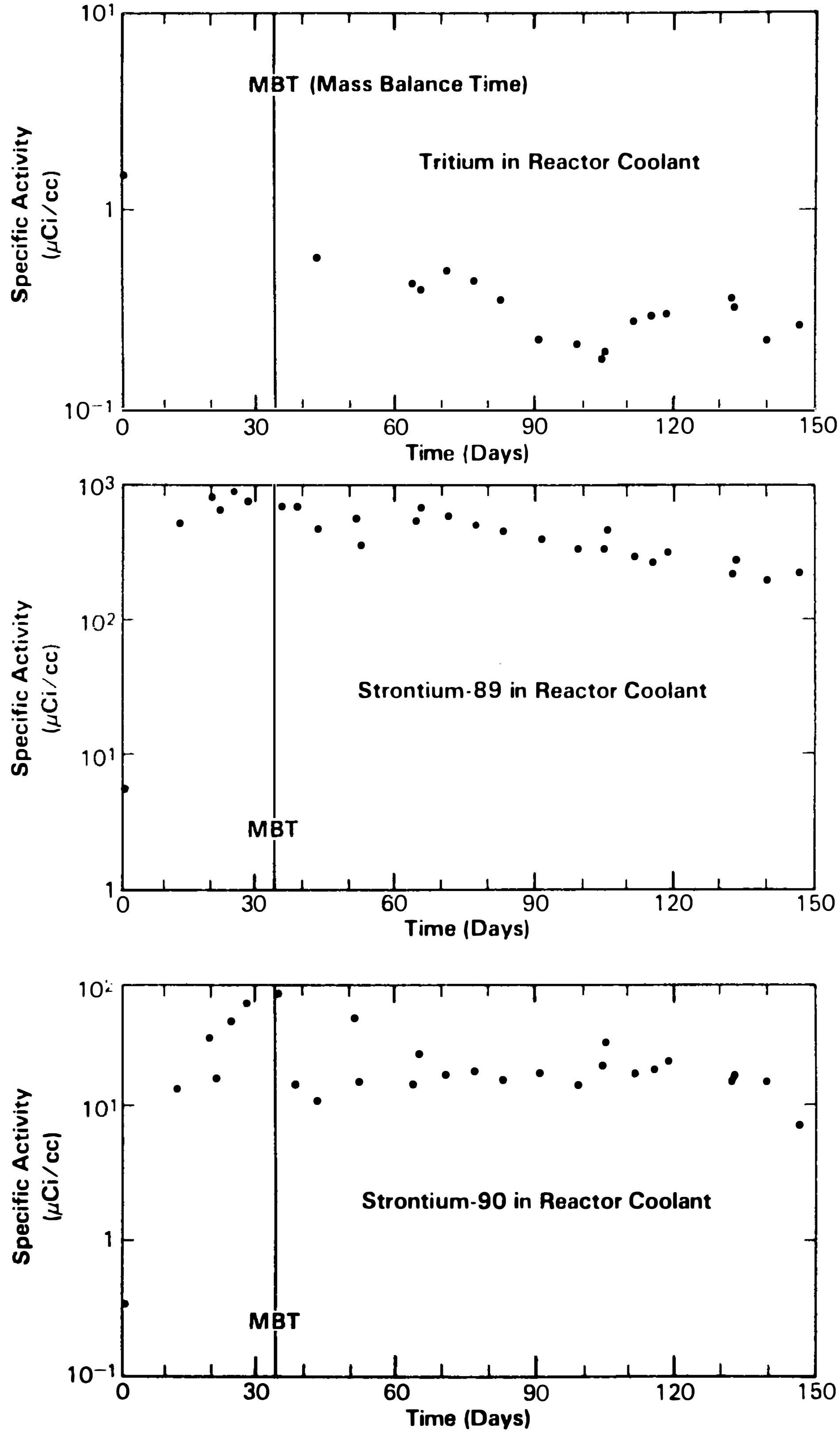


EXHIBIT 4-7 (Page 1 of 2)
Isotope Concentration in the Reactor Coolant vs. Time

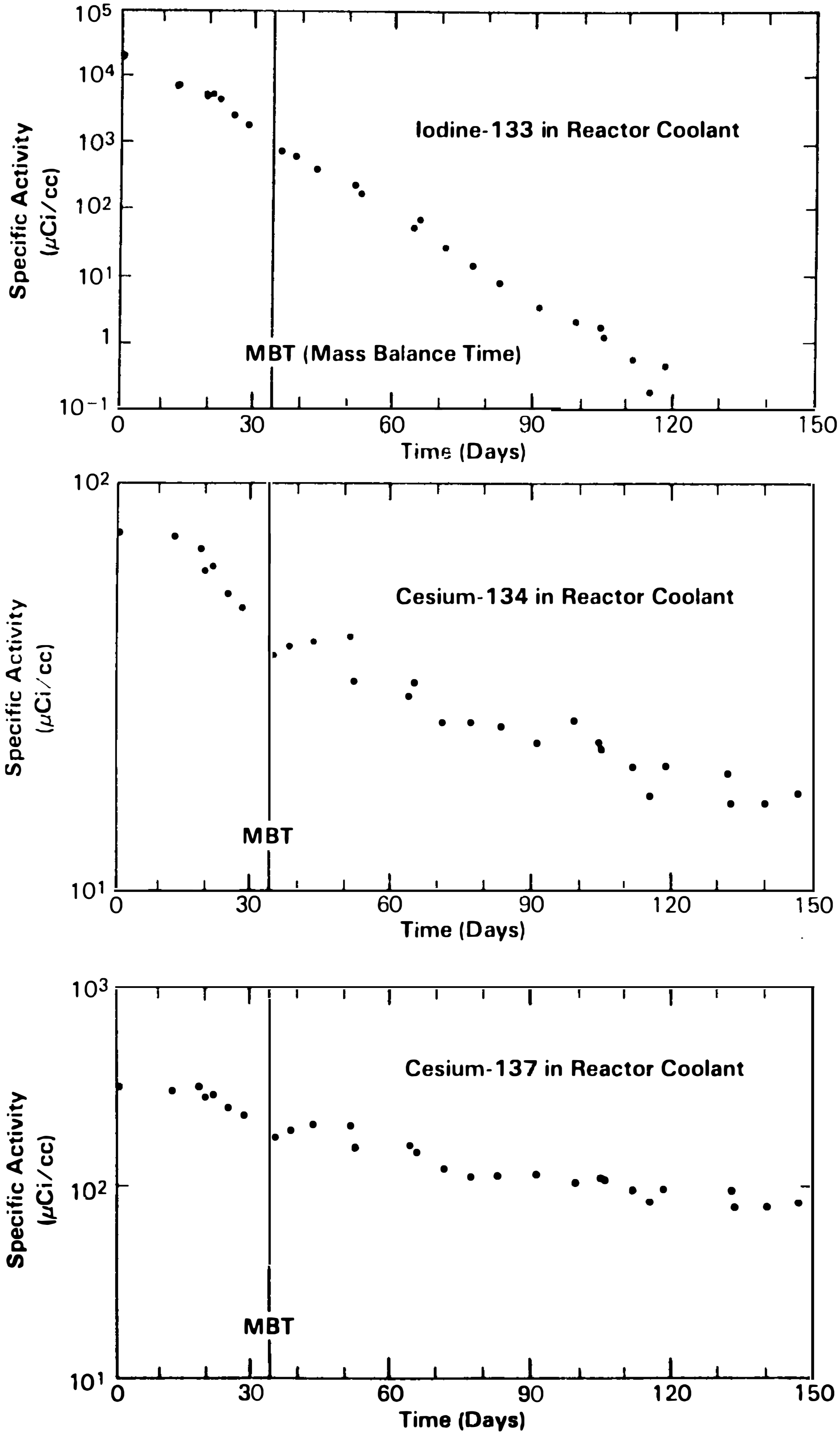


EXHIBIT 4-7 (Page 2 of 2)
Isotope Concentration in the Reactor Coolant vs. Time

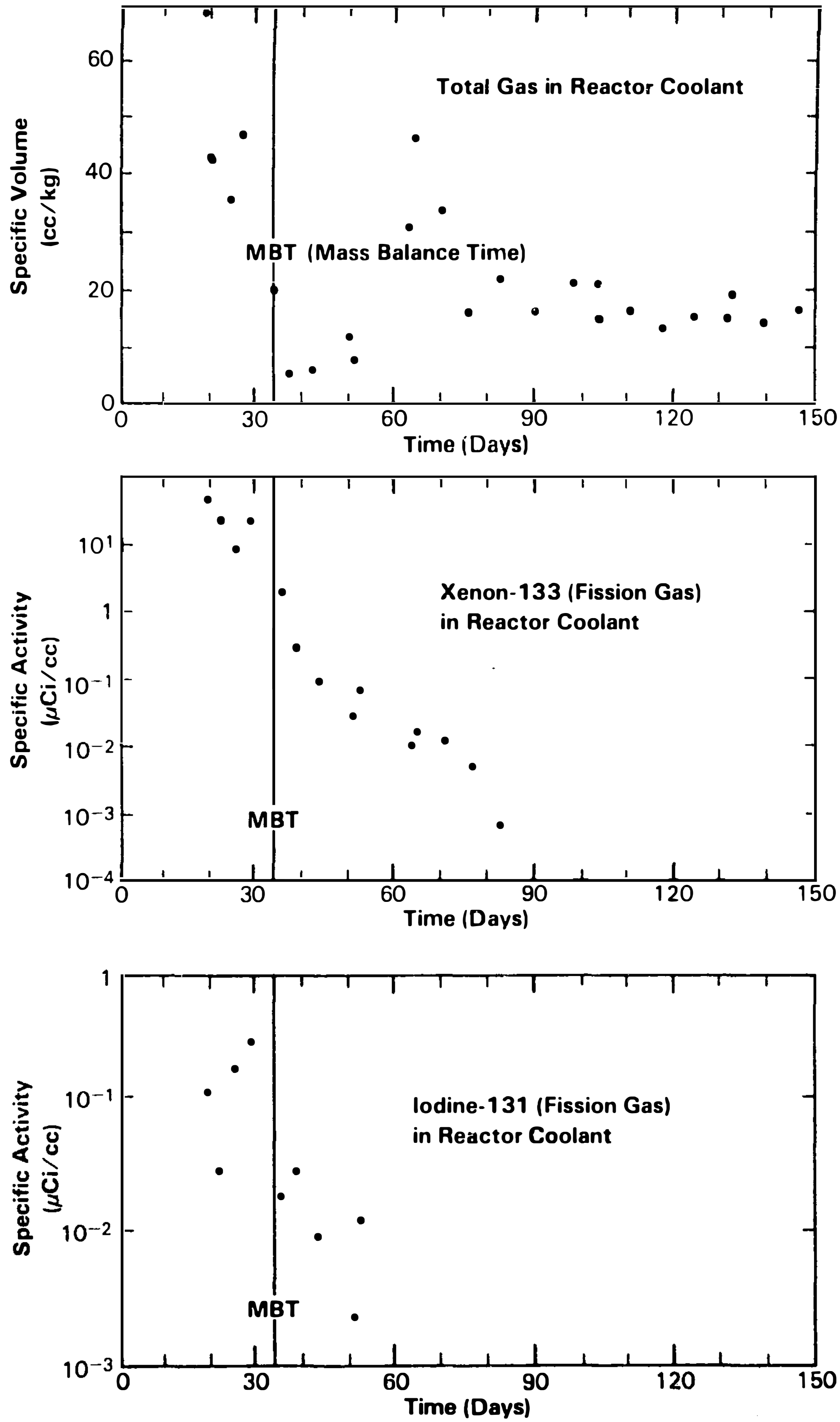


EXHIBIT 4-8
Fission Gas in the Reactor Coolant and Its Isotopic Content

	Volumes: Gallons				DATE
Component	Total Volume	Initial Liquid Volume	Volume at MBT	Flow Path	28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12
RCS: Reactor Coolant System	8.86 E4	8.24 E4	9.16 E4	1	2.86 E5 to WDL-T-3
				2	6.55 E4 to RB Sump
				3	2.88 E5 from DH-T-1
				4	1.08 E6 from MU-T-1
				5	
WDL-T-3: Reactor Coolant Drain Tank	7.43 E4	6.64 E3	7.44 E3 a	1	2.86 E5 from RCS
				6	2.85 E5 to RB Sump
RB Sump and Basement	2.09 E3 (Sump)	8.74 E2	4.46 E5	2	6.55 E4 from RCS
				6	2.85 E5 from WDL-T-3
				7	1.028 E5 from River
				17	8.26 E3 to WDL-T-2
WDL-T-2: Miscellaneous Waste Holdup Tank	1.98 E4	1.39 E4	b	17	8.26 E3 from RB Sump
				18	1.96 E4 to WD
				19	3.92 E4 to Unit 1
WDL-T-1: Reactor Coolant Bleed Tanks	2.50 E5	1.34 E5	5.68 E4	10	1.96 E4 from W
				10	
				14	1.01 E5 from MU-K-1
				15	1.30 E4 from MU-T-1
				16	1.04 E6 to
Aux. Floor and Sump	6.37 E3 (Sump)	4.84 E3	2.96 E4	20	2.48 E4 from MU-T-1
WDL-T-5: Auxiliary Building Sump Tank	3.08 E3	2.50 E3	b	21	6.30 E3 to WDL-T-8
WDL-T-8: Neutralizer Tanks	1.76 E4	1.68 E4	b	21	6.30 E3 from WDL-T-5
				22	1.93 E4 to Unit 1
WDL-T-11 Contaminated Drain Tanks	5.32 E3	2.53 E3	b	23	2.65 E3 to Unit 1
MU-C-1: Letdown Coolers	c	c	c	5	
				4	1.44 E5 to MU-F-5
				9	2.90 E5 to MU-T-1
				10	
MU-T-1: Makeup Tank	4.50 E3	2.28 E3	1.40 E3	4	1.08 E6 to RCS
				9	2.90 E5 from MU-C-1
				15	1.30 E4 to WDL-T-1
				16	1.04 E6 from WD
				25	8.05 E4 from MU-F-2
				20	2.48 E4 to Aux. Sump
MU-I-FE & MU-F-5: Block Orifice and Makeup and Purification Demineralizer Filters	c	c	c	9	1.44 E5 from MU-C-1
				12	1.43 E5 to MU-K-1
MU-K-1 & MU-F-2: Makeup and Purification Demineralizers and Makeup Filters	c	c	c	12	1.43 E5 to MU-F-5
				25	8.05 E4 to MU-T-1
				14	1.01 E5 to WDL-T-1

Notes: a. Volume Based on Assumption That Tank Is Full
b. Flow Chronology Incomplete
c. System/Component Data Not Compiled

EXHIBIT 4-9
Flow Chronology

DATE: MARCH–APRIL 1979

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

ump

om MU-T-1

1.01 E6 to MU-C-1

om RCS

028 E5 from River

1.96 E4 to WDL-T-1

1.96 E4 from WDL-T-2

8.66 E5 from MU-C-1

1.04 E6 to MU-T-1

U-T-1

1.01 E6 from RCS

8.66 E5 WDL-T-1

1.04 E6 from WDL-T-1

8 E4 to Aux. Sump

EXHIBIT 3-9 (Page 3 of 3)

DATA BASE MANAGEMENT SYSTEM,
TUTORIAL SESSION

YOU WILL BE REQUIRED TO USE SEVERAL COMMANDS IN EACH OPERATING MODE. AT ANY TIME, YOU CAN RECEIVE ASSISTANCE FOR A PARTICULAR COMMAND BY TYPING 'HELP' FOLLOWED BY THE COMMAND NAME.

THOSE COMMANDS WHICH HAVE THE POWER TO MODIFY THE DATA BASE ARE ONLY AVAILABLE WITHIN THE PASSWORD-PROTECTED MAINTENANCE MODE. SPECIFICALLY, THE COMMANDS ADD, DELETE, LOAD, MODIFY, POSITION, RELEASE, RESERVE, CHANGE, ERASE, AND SAVE ARE ONLY AVAILABLE IN THE MAINTENANCE MODE.

ADDRESS INQUIRIES TO:

NUS CORPORATION
910 CLOPPER ROAD
GAITHERSBURG, MD 20878

ATTN: LYNN SHAWN

PHONE: (301) 258-8734

T M I   M a s s   B a l a n c e   D a t a   B a s e

VERSION 4

A service of NUS Corporation

for EG&G TIO

1	TUTORIAL	List informative text by subject
2	TABLE	Enter/describes current table
3	MAINT	Enter Maintenance subsystem
4	QUERY	Enter Query subsystem
5	EXIT	Terminate

Please select an operating mode number: 5

pump leakage of reactor coolant (flow 2 on Exhibit 4-9). The river water is considered clean relative to key isotopes, and the reactor coolant concentrations are known. The RB-sump concentration on April 30, 1979, can be estimated (with some implicit assumptions) via a back calculation from the August 25 concentrations, the two flows noted, and the RCS concentration (assumed to be the May 2, 1979, concentrations). Thus, it is assumed that the only mass transfers into or out of the sump water are those represented by the flows (e.g., that no precipitation or gas evolution occurred from the sump water). It is also assumed that the reactor coolant drain tank (WDL-T-3) concentrations are represented by the RB-sump concentrations. This assumption is based on the fact that this tank is open to the sump and inundated by it.

Thirteen sample analyses of the bleed tanks (WDL-T-1) contents are available that are possibly useful between March 30 and May 18, 1979. A review of the flow histories shows a complicated chronology in the time period from March 31 to April 20. The May 18 sample is, therefore, a better choice; between April 20 and May 18 the flows in and out of the bleed tanks and through the makeup tank were being managed to maintain letdown and makeup. Makeup was routed from the bleed tanks through the makeup tank; hence, the bleed tanks and makeup tank would have been (approximately) of similar contents. It appears reasonable that at some future time a calculation similar to that described above for the RB sump could be used here as well. However, the flow chronology relevant to the bleed tanks is not yet adequate to this task. For the present example, the May 18 sample is used directly as an approximate indicator of the April 30 contents.

The choice of sample for estimating the reactor building (CON2) atmosphere contents is the May 4, 1979, sample because this was taken at a time very close to the mass balance time and there are no recorded mass transfers that would have caused significant changes in the interim.

The summation of the estimated radiochemical concentration, decay corrected to April 30, 1979, at 2400 hours is provided in Exhibit 4-10.

4.4 ISOTOPIC FRACTIONS

The Isotopic Fraction Calculation Module has been drafted. It calculates the fraction of each isotope found in each model component, sums the fractions, and indicates the mass balance closure.

4.5 RESULTS AND DISCUSSION

The results of the preliminary mass balance example are shown in Exhibit 4-11 and are consistent with previous reports of radioactivity accounting of TMI-2 fission products. The results do not represent a step forward in the sense of providing a more complete accounting of radioactivity initially present in the core. Indeed, the results shown on Exhibit 4-11 are less complete than some others. For example, the iodine-131 and xenon-133 in the uncontrolled releases of gases are not included (as has previously been done) because the station vent flow data are questionable. The contents of some tanks for which volumes are currently unknown have been sampled and analyzed and one could estimate amounts contained in them using estimated volumes.

It is noted that in Exhibit 4-11 two digits are indicated for values less than 10 percent and 3 digits for values greater than 10 percent. Although these numbers of digits are generally consistent with the number of significant figures reported for analyses (Exhibit 4-10), the accuracy of the values are very uncertain at present; hence, the overall accuracy of the isotope

EXHIBIT 4-10

ESTIMATED KEY ISOTOPE CONCENTRATIONS

Isotope	Concentrations RCS (μCi/ml)	WDL-T-3 and RB-Sump (μCi/ml)	WDL-T-1 and MU-T-1 (μCi/ml)	RCS (fission gases) (μCi/ml)	CON2 (μCi/cc)
Strontium-89	667	206	-	-	-
Strontium-90	67.9	2.8	-	-	-
Iodine-131	789	352	160	4.22E-4	0.0036
Xenon-133	-	-	-	3.57E-2	14.7
Cesium-134	38	45	7.8	-	-
Cesium-137	170	178	35	-	-

EXHIBIT 4-11

PRELIMINARY MASS BALANCE FOR APRIL 30, 1979

State/ Component	Calculated Fraction of Total Isotope Inventory					
	Sr-89	Sr-90	I-131	Xe-133	Cs-134	Cs-137
Liquids						
RCS	0.0058	0.030	0.075	-	0.081	0.071
WDL-T-3	0.00015	0.00010	0.0027	-	0.0077	0.0060
RB-Sump	0.0088	0.0061	0.164	-	0.462	0.360
WDL-T-1	-	-	0.0095	-	0.010	0.0090
MU-T-1	-	-	0.00023	-	0.00025	0.00022
Gases						
CON2	-	-	6.0E-5*	0.384	-	-
RCS	-	-	4.0E-8	5.4E-6		
TOTALS	0.015	0.036	0.251	0.384	0.561	0.446

*6.0E-5 equals 6.0×10^{-5}.

5. RECOMMENDATIONS

This section presents recommendations for future efforts to extend the existing capability to perform mass balance calculations producing better closure. These recommendations encompass three aspects: (1) the further development and entry of data into the computerized data base; (2) the continued development of computer-aided data analyses and mass balance determinations; and (3) acquisition of the additional data.

5.1 COMPUTERIZED DATA BASE EXTENSION

The extension of the data base to incorporate currently existing or derivable information on system descriptions, chronology, and radiochemical analyses is recommended. The followoing recommendations pertain to work described in Section 3.

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Presented below are recommendations for assembly of data on TMI-2 systems. Some of the recommendations are for an expansion of detail to achieve a better definition of systems in the data base; other recommendations are for acquiring fundamental information necessary for completing the description of certain systems so that they can be included in the data base.

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- The liquid radwaste system component description should be improved to permit accounting for mass distributions between various redundant components (e.g., WDL-T-1A, WDL-T-1B, WDL-T-1C).

- Estimates of volumes and surface areas should be developed for pipe runs in the critical systems (makeup and purification system, etc.).

- Critical system/component information for the EPICOR I and II and SDS systems should be developed and input.

- The surface areas of building elements (categorized as components) affected or contaminated by the TMI-2 accident (e.g., in-containment areas, auxiliary building component cubicles, etc.) should be defined.

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- Additional information and calculations should be assembled to refine the probable makeup and purification system leakage to the auxiliary building.

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- The steam generator mass transfer and iodine carryover to interconnecting systems, including the environment, should be defined.

- The chronology of EPICOR I mass processing during the month of April 1979 should be input.

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- Additional information should be developed for the period from March 28, 1979, to the current time frame for detailed mass flows associated with systems incorporated in the system file.

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- The data base does not presently include surface activity data and it should be expanded to include such data. Surface contamination in the reactor building is of considerable importance to the understanding of the gaseous-surface mass transfer interactions there. The predecontamination surface samples taken from reactor building surfaces appear to be especially important in this regard and represent the only samples that have systematically removed and characterized everything from known surface areas. Their use to indicate the radioactivity associated with known areas could be important, although the imprecision of much of the data taken for health physics purposes may be a severe detriment to their quantitative use.

- The data base currently contains very few samples of solid material; these are of suspended solids filtered from liquid samples. Some components of the makeup and purification system contain significant amounts of solid material, and some of these (i.e., filters) are being dismantled and the solid material weighed and analyzed at the present time. These data will be expected to have a considerable influence on mass balance and should be entered into the system as soon as available to allow application of the experiences in using the data in mass balances to further sampling and analyses.

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Some consideration should be given also to include chemical analysis data in the data base; pH values may be particularly useful for characterizing aqueous chemistry.

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Procedures for characterizing and sampling of the contents of the pressure vessel need to be worked out in detail to ensure that the data accrued can support a mass balance calculation. For example, the evaluation of the number and location of undamaged fuel assemblies would indicate the fraction of fission gases and volatile fission products still contained in the fuel, while evaluation of the number and location of damaged but intact fuel assemblies would indicate fuel from which only the highly volatile materials escaped. In addition, information about the mass and location of intact segments would define the location of additional refractory fission products; information about the mass, particle size, and composition of debris would enable an approach to be developed to account for the degraded material.

Again the feasibility and cost of acquiring these data need to be carefully evaluated as an integral part of the detailed recovery operation planning.

6. REFERENCES

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14. Specific information related to use of the makeup and purification system, personal communication between J. Flaherty (GPU) and J. Strahl (NUS Corporation), July 28, 1982.

15. Calculated letdown-makeup leakage to the TMI-2 auxiliary building, personal communication between J. Flaherty (GPU) and J. Strahl (NUS Corporation), August 18, 1982.

16. Assessment of Off-Site Radiation Doses from the Three Mile Island Unit 2 Accident, TDR-059, GPU Service Technical Data Report, February 27, 1980.

fraction is not known and is not intended to be indicated by the number of digits shown.

In this study the decision has been made to establish a data base and method that can eventually determine mass balances as a function of time. This method can, therefore, assess the values in the data base in terms of their consistency with other data, estimate values where data are lacking from mass transfer considerations, interpolate between data, and eventually provide a basis for retrospective extrapolation back into the earlier periods of the accident.

Implicit in the method is the assumption (until evidence accrues to the contrary) that each datum is valid; for example, that a particular sample and analysis does represent the volume sampled. Inevitably this will lead to instances of anomalies that will have to be sorted out until some reasonable explanation arises. Basically, this will be a process of accepting the data as they are, while gradually developing evidence to support certain data in preference to other data that are inconsistent.

As incomplete as the data base is at present, it is sufficient to demonstrate that the method works and to indicate that it will work more effectively with additional data.

EXHIBIT 4-11

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12. Burns and Roe, Inc., Three Mile Island Nuclear Station - Unit No. 2, Mechanical Flow Diagrams, Electrical One Line Diagrams and General Arrangement Drawings, April 1979.

13. Investigation of TMI Hydrogen Phenomena of March 28, 1979, GPU Nuclear Memorandum 7132-82-167, March 26, 1982.

14. Specific information related to use of the makeup and purification system, personal communication between J. Flaherty (GPU) and J. Strahl (NUS Corporation), July 28, 1982.

fraction is not known and is not intended to be indicated by the number of digits shown.

In this study the decision has been made to establish a data base and method that can eventually determine mass balances as a function of time. This method can, therefore, assess the values in the data base in terms of their consistency with other data, estimate values where data are lacking from mass transfer considerations, interpolate between data, and eventually provide a basis for retrospective extrapolation back into the earlier periods of the accident.

Implicit in the method is the assumption (until evidence accrues to the contrary) that each datum is valid; for example, that a particular sample and analysis does represent the volume sampled. Inevitably this will lead to instances of anomalies that will have to be sorted out until some reasonable explanation arises. Basically, this will be a process of accepting the data as they are, while gradually developing evidence to support certain data in preference to other data that are inconsistent.

As incomplete as the data base is at present, it is sufficient to demonstrate that the method works and to indicate that it will work more effectively with additional data.