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DECEMBER 15, 1988

GE Astro Space

FINAL SAFETY ANALYSIS REPORT FOR THE GALILEO MISSION

VOLUME II
SUMMARY

GENERAL PURPOSE HEAT SOURCE
RADIOISOTOPE THERMOELECTRIC GENERATOR
PROGRAM
CONTRACT DE-AC01-79ET32043

PREPARED FOR
U.S. DEPARTMENT OF ENERGY

DISCLAIMER

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ASTRO-SPACE DIVISION
SPACECRAFT OPERATIONS
Valley Forge Space Center
P.O. Box 8555 Philadelphia, PA 19101

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This technical report has been approved for publication.

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TABLE OF CONTENTS

SUMMARY
TO THE
FINAL SAFETY ANALYSIS REPORT, VOLUMES I AND II

SECTION 1.0
INTRODUCTION

The General Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG) will be used as the prime source of electric power for the spacecraft on the Galileo mission. The use of radioactive material in these missions necessitates evaluations of the radiological risks that may be encountered by launch complex personnel and by the Earth's general population resulting from postulated malfunctions or failures occurring in the mission operations.

The purpose of the Final Safety Analysis Report (FSAR) is to present the analyses and results of the latest evaluation of the nuclear safety potential of the GPHS-RTG as employed in the Galileo mission. This evaluation is an extension of earlier work that addressed the planned 1986 launch using the Space Shuttle Vehicle with the Centaur as the upper stage. This extended evaluation represents the launch by the Space Shuttle/IUS vehicle. The IUS stage has been selected as the vehicle to be used to boost the Galileo spacecraft into the Earth escape trajectory after the parking orbit is attained.

The format of the FSAR conforms to the requirements established in the Overall Safety Manual from the DOE and provides for three volumes or sections:

1. Volume I: Reference Design Document (RDD)
2. Volume II: Accident Model Document (AMD)
3. Volume III: Nuclear Risk Analysis Document (NRAD)

Volumes I and II are published in this document, Report No. 87SDS4213, while Volume III is published in Report No.NUS-5126.

The Summary presents the following:

SECTION 2.0
MISSION OVERVIEW

2.1 NUCLEAR POWER SYSTEM

The GPHS-RTG is a radioisotope fueled, thermoelectric generator comprised of two major functional components: the thermoelectric converter and the nuclear heat source. The power system is designed to provide 285 watts of electrical power under initial space operational conditions for a thermal fuel loading of 4410 watts. The GPHS-RTG system, (Figure 2-1) to be used in the Galileo mission has a weight of 123.5 pounds. A detailed description of the RTG and its components is presented in Volume I of the FSAR.

The converter is approximately 44.9 inches long and 16.6 inches in diameter. It contains 572 silicon germanium (SiGe) thermoelectric couples (unicouples) surrounded by multifoil insulation to reduce thermal losses. Each unicouple assembly is attached to an aluminum outer case (radiator) by sealing screws inserted through the case wall.

The General Purpose Heat Source (GPHS), shown in Figure 2-2, supplies the thermal energy to the thermoelectric converter. The GPHS is comprised of rectangular parallelepiped modules, each having dimensions approximately 3.7 by 3.8 by 2.1 inches, a weight of about 3.2 pounds, and a thermal output at launch of approximately 233 watts. Each module contains four (4) plutonium dioxide fuel pellets which are clad in iridium post-impact containment shells. Two of these fueled clads are encased in each of two graphite impact shells (GIS), each of which is surrounded by a thermally insulative graphite sleeve. The two GIS's are inserted into a graphite reentry aeroshell. Eighteen (18) of these modules constitute the heat source stack for the GPHS-RTG and provide a nominal total thermal output of 4197 watts at beginning-of-mission.

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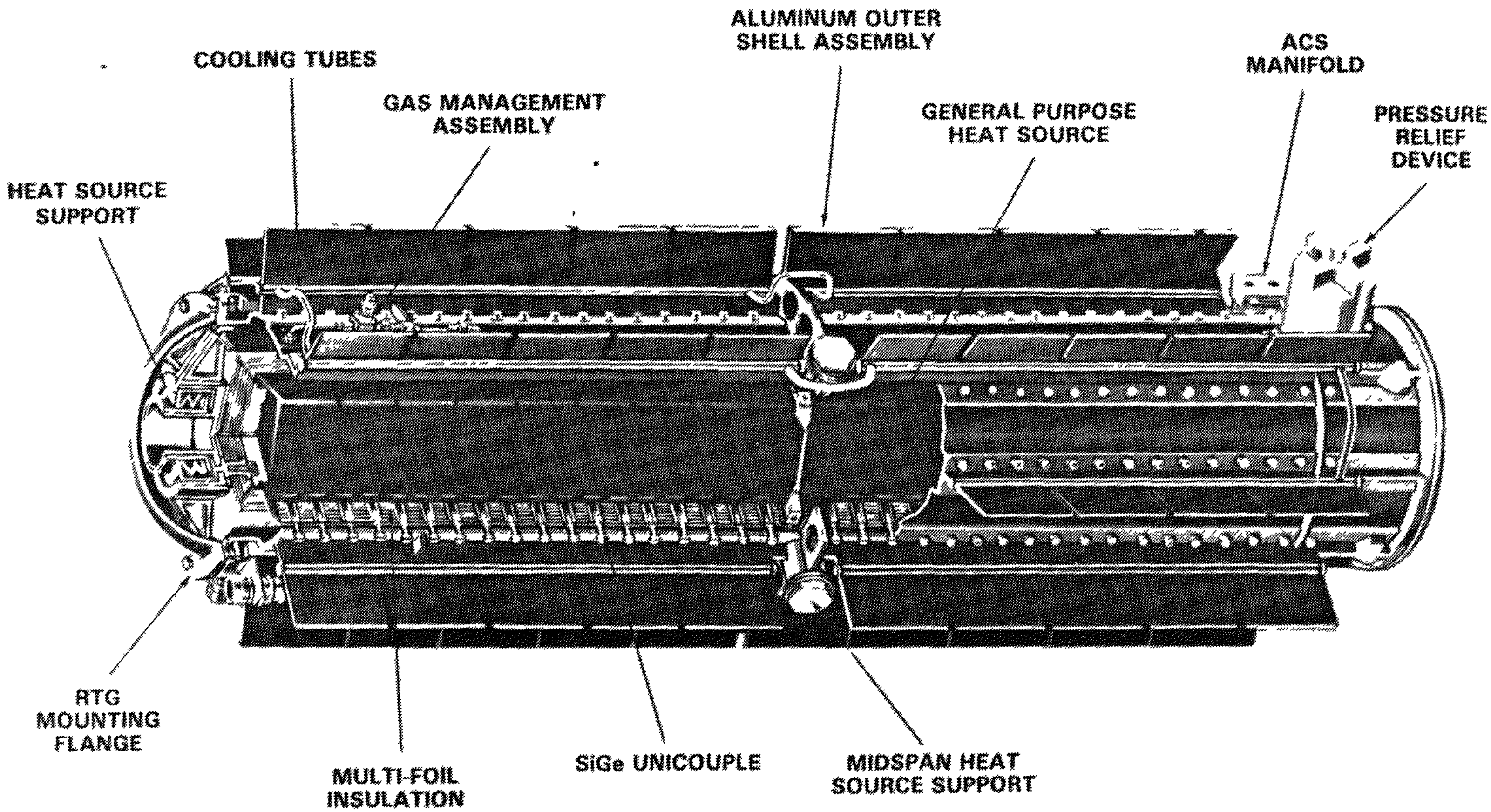

Figure 2-1. GPHS-RTG

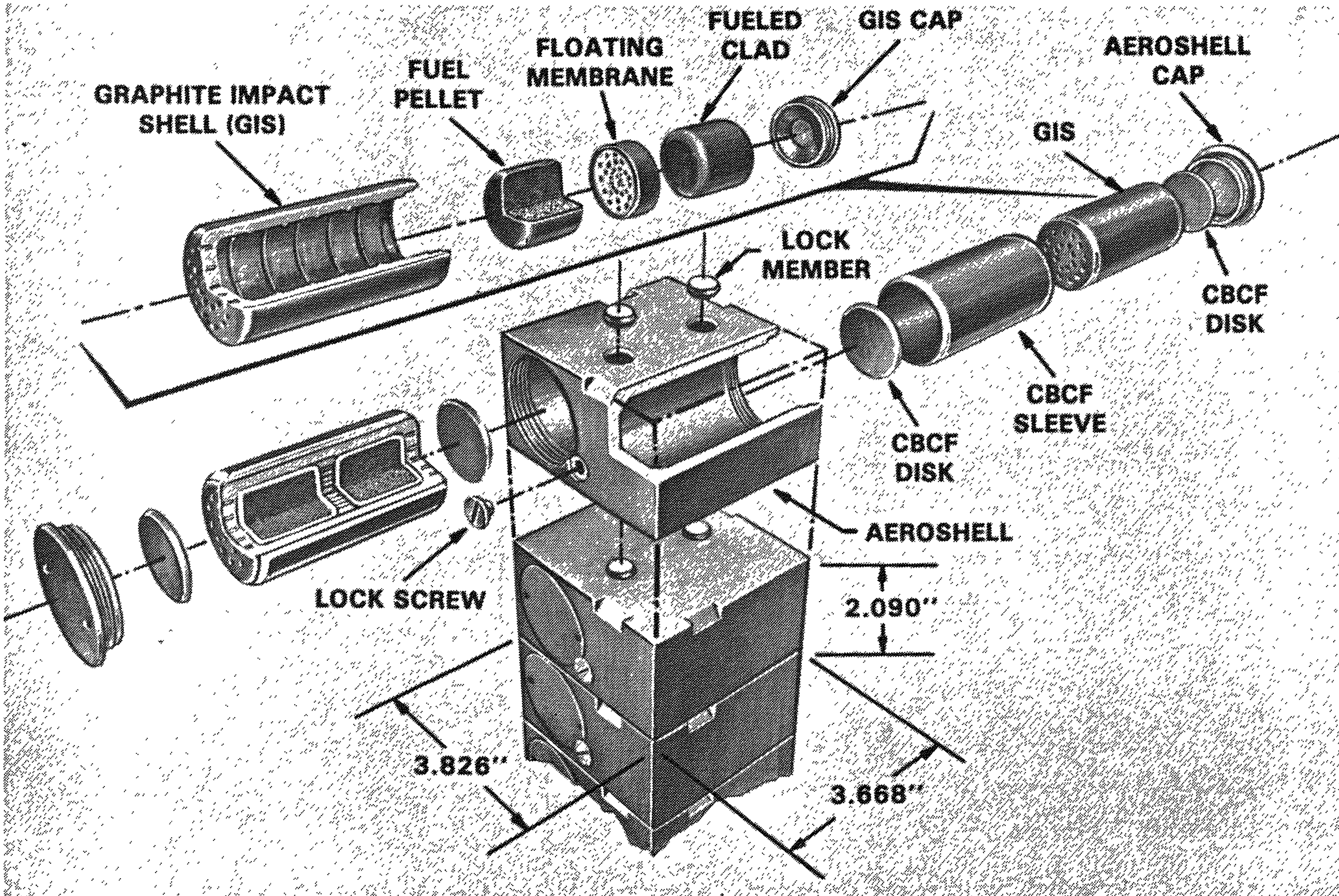

Figure 2-2. General Purpose Heat Source Modules
(Exploded View)

2.2 MISSION DESCRIPTION

The Galileo mission will be launched during October 1989 by the Space Shuttle to attain a temporary Earth parking orbit; the IUS upper stage will be used to propel the spacecraft from the parking orbit into the escape trajectory toward Jupiter. The spacecraft will arrive in the vicinity of Jupiter after an interplanetary transit of 6 years and 4 months. Part of this period will be occupied with the VEEGA maneuver involving a Venus and two Earth flybys to attain the energy required for the trajectory to Jupiter. A probe will be deployed from the spacecraft 150 days before the arrival at Jupiter and will descend into the Jovian atmosphere. The scientific objectives of the mission are to conduct comprehensive investigations of the Jupiter planetary system by making in situ and remote measurements of the planet, its environment, and its satellites. The Galileo spacecraft will use two GPHS-RTGs for its prime electrical power source. The RTGs are attached to the Galileo orbiter, as shown in Figure 2-3 which is the launch configuration of the spacecraft.

2.3 SPACE TRANSPORTATION SYSTEM (STS)

The Galileo mission will be launched by the Space Shuttle from Pad A of Launch Complex 39 at the Kennedy Space Center (KSC), Cape Canaveral, Florida. The current Galileo launch configuration is shown in Figure 2-4. A view of the spacecraft on the IUS vehicle is shown on Figure 2-5.

2.4 MISSION PHASE DEFINITION

The reference mission for Galileo is divided into six (6) distinct phases for purposes of the safety analysis. These phases cover all mission related operations beginning with loading of the liquid propellants into the Shuttle External Tank (ET), after the spacecraft with RTG(s) has been installed in the cargo bay, and ending with the attainment of the hyperbolic Earth escape trajectory. At this point, with a successful and correct burn of the IUS, escape of the spacecraft from the Earth's gravitational pull will be effected, and the RTGs will no longer present a potential risk to the Earth's population. Definitions of the phases are as follows:

Phase 0 - Prelaunch/Launch

This phase begins with the initiation of loading the liquid propellants into the ET and ends with liftoff. The duration of the phase is from T-8.0 hours to T-0.

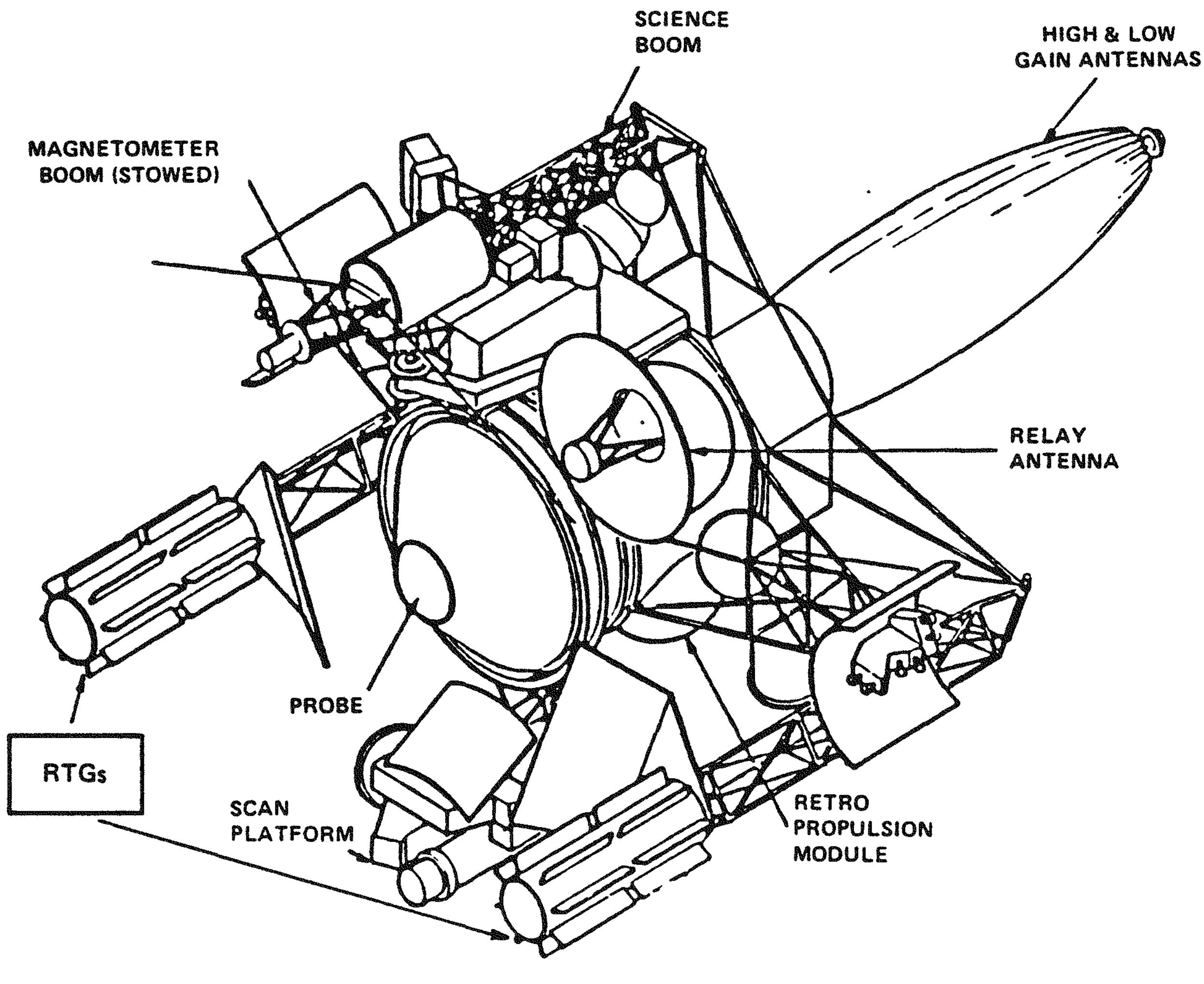

Figure 2-3. Galileo Spacecraft: Stowed Configuration

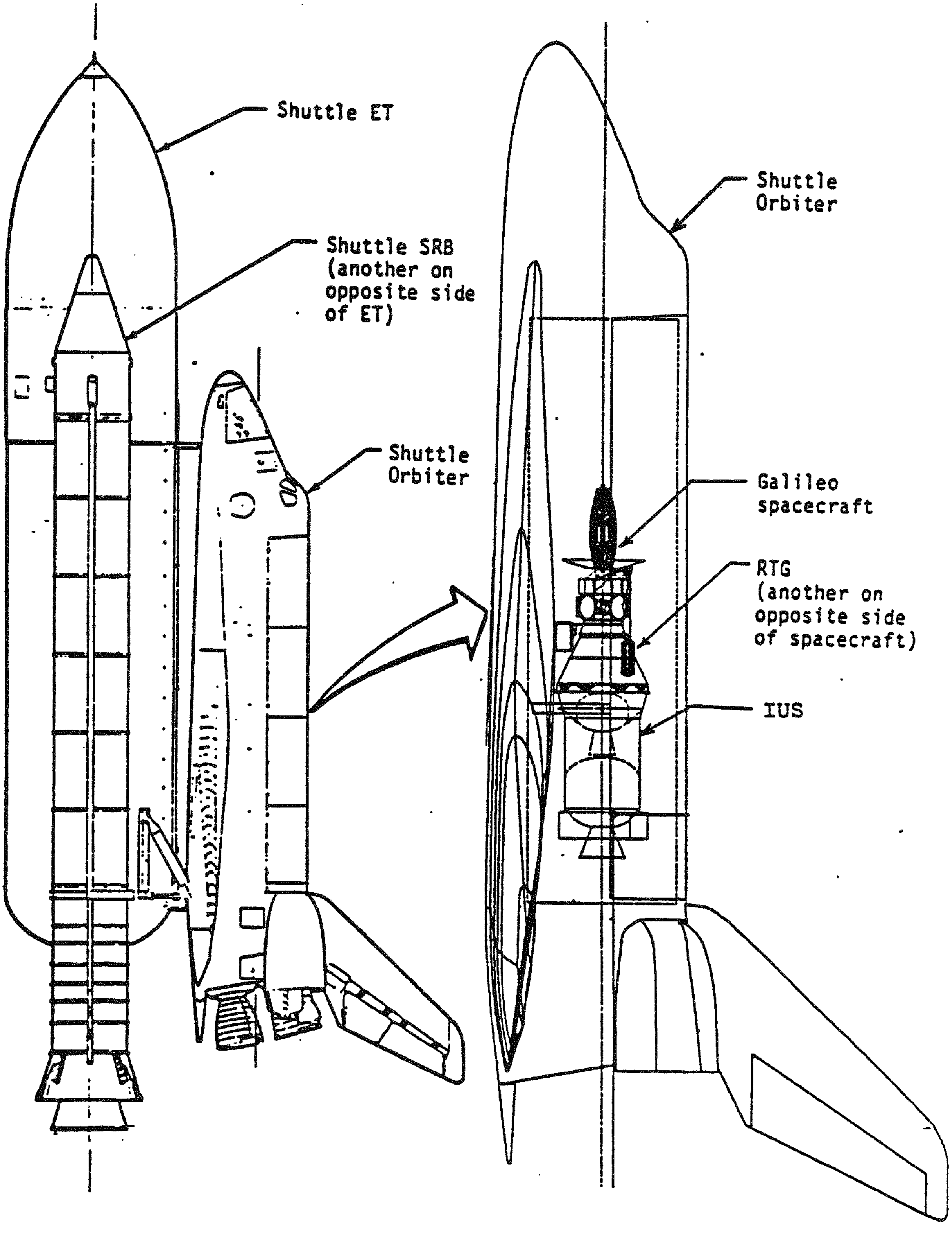

Figure 2-4. Galileo Launch Configuration

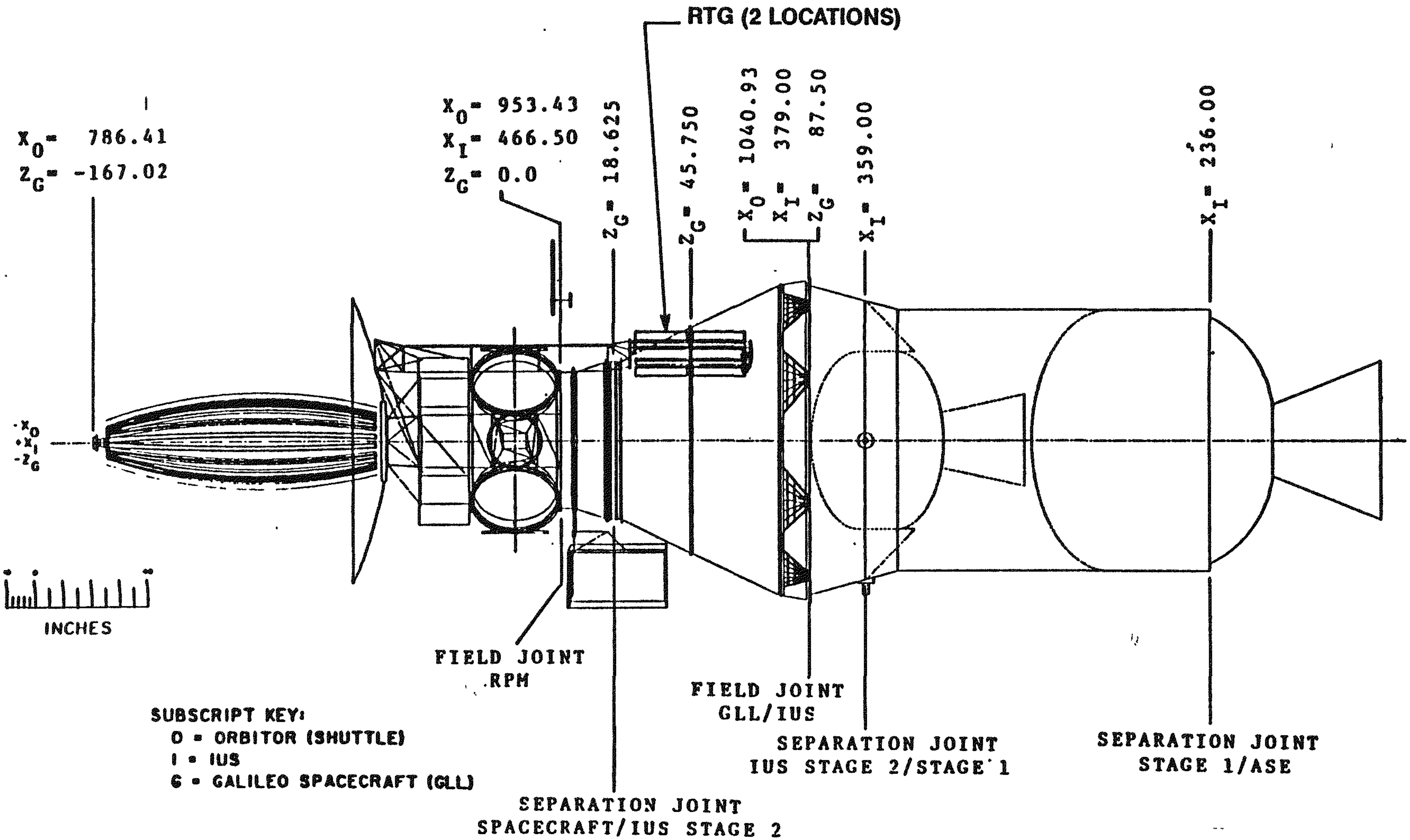

Figure 2-5. Galileo/IUS Configuration

Phase 1 - Ascent

This phase begins with liftoff of the Space Shuttle IUS vehicle from the launch pad at T-0 and continues until the Solid Rocket Boosters (SRBs) are jettisoned at T+128 seconds.

Phase 2 - Second Stage

This phase includes the period from T+128 seconds until T+532 seconds when the first burn of the Orbital Maneuvering System (OMS) engines begins. Included in Phase 2 are the events of the Shuttle main engine cutoff (MECO) and the release of the ET.

Phase 3 - On Orbit

Phase 3 starts with the first burn of the OMS (OMS-1) at T+532 seconds and ends when the IUS with spacecraft are deployed from the Orbiter at T+24084 seconds (6 hours, 41 minutes, 24 seconds). The significant events that occur during this phase include the first and second burns of the OMS (OMS-1 and OMS-2) for orbit attainment and circularization, the release of the IUS with spacecraft, and the firing of the Orbiter Reaction Control System (RCS) to move the Orbiter away from the IUS/spacecraft configuration.

Phase 4 - Payload Deploy

Phase 4 starts at T+24084 seconds and ends when the IUS has attained Earth escape velocity even though the spacecraft has not yet been deployed.

Phase 5 - VEEGA Maneuver

Phase 5 starts when the IUS with spacecraft escapes the Earth's gravitational pull and ends when the second Earth flyby is completed successfully at approximately three (3) years after launch.

SECTION 3.0
ACCIDENT EVALUATION AND FAILURE MODE ANALYSIS SUMMARY

Presented in this section is a summary of the potential mission accidents and failures and the RTG response mechanisms to those accidents and failures that could result in fuel release. The potential accidents and failures are defined, Including their probability of occurrence. The methodology used to assess the RTG response to the effects of the mission accidents and failures is described. A summary of the safety testing and analysis performed to validate and assess the response mechanisms is also provided. The principal conclusions from this effort to date are then presented. The predicted fuel release data follows in Section 4, Results.

3.1 MISSION ACCIDENTS

NASA has conducted an extensive review and evaluation of possible Shuttle, IUS, and spacecraft failures that may lead to vehicle catastrophic explosions, failure to insert the spacecraft into an escape trajectory, or a reentry of the spacecraft arising from a faulty VEEGA maneuver. NASA Document NSTS 08116 "Space Shuttle Data for Planetary Missions Radioisotope Thermoelectric Generator (RTG) Safety Analysis" defines these failure modes and describes the environments produced by the failures, except for the VEEGA maneuver failures. References 3-1 and 3-2 discuss the VEEGA maneuver failure and consequences. A brief summary of the information provided in those documents is included in this section of the FSAR.

NASA's approach to defining the potential accident scenarios consisted of the following:

1) Identify potential failures that might present a threat to the RTGs in each of seven major elements in the Space Shuttle system, including contributions from failures of major components.

2) Review failures for credibility and eliminate those not considered credible because of redundancy or the necessary condition of multiple failures.

3) Divide the mission into a number of phases with fault trees being developed showing the contribution to each failure from the seven major Shuttle systems.

4) Finally, because of observed similarity of many scenarios subsequent to some point in the accident sequence, irrespective of the initiating failure, develop representative accident scenarios for each mission phase. The representative accident scenarios defined by NASA are summarized in the following paragraphs.

3.1.1 ON-PAD ACCIDENTS (-8 HOURS TO T-0)

Pad Fire Scenario

An uncontrolled pad fire develops from an initial leak of ET propellants. The fire engulfs the Orbiter causing onboard propellant tanks to burst, releasing additional propellant that pools in the payload bay and explodes.

Pad Explosion Scenario

Aft compartment failures in the Orbiter cause rupture of LO_x and LH_2 engine feed lines or of the ET releasing significant quantities of propellants that pool on the Mobile Launch Platform (MLP) and in the flame trench and explode. The blast wave engulfs the Orbiter, causing the payload bay to implode around the spacecraft and RTGs.

Inadvertent Range Destruct

The linear shaped charges on both SRBs and the ET inadvertently detonate.

3.1.2 NEAR PAD ACCIDENTS

Tower Impact Scenario

For a left SRB loss of thrust or nozzle burnthrough prior to MET = 2 sec, the Shuttle vehicle will impact the launch tower within MET = 7 sec. Rupture of the ET will release the liquid propellants that will pool on the pad and in the flame trench and explode. The blast wave engulfs the Orbiter as in the explosion scenario.

Aft Compartment Explosion, 0-10 sec MET

Propulsion system failures and ensuing aft compartment explosions are postulated to rupture the propellant feed lines or the ET, similarly as for the pad explosion scenario, except that vehicle motion will continue until the blast wave from the pool of propellants on pad breaks up the Orbiter. Both SRBs will continue ascent until destroyed by Range Safety.

SRB Case Rupture Scenario, 0-10 sec MET

A failure of an SRB case such as a burn-through will cause the case to fragment, rupturing the ET with spillage of the liquid propellants. Pooling of propellants on the MLP and in the flame trench will lead to an explosion.

Inadvertent Range Destruct, 0-10 sec MET

Destruct charges on both SRBs and the ET are inadvertently detonated. A massive dump of the ET propellants occurs with pooling on the MLP and in the flame trench followed by an explosion.

3.1.3 IN-FLIGHT ACCIDENTS

SRB Case Rupture Scenario, 10-128 sec MET

A SRB case rupture during this period is expected to cause breakup of the Orbiter and ET with lateral dispersion of the structure as well as the liquid propellants, thus minimizing any vapor cloud explosion. The other SRB is not expected to be damaged due to shielding by the ET and will continue to fly until burnout or Range Safety destruct.

Range Destruct Scenario, 10-128 sec MET

Both SRBs and the ET are destroyed by the Range Destruct system on command. As with the SRB case rupture, the fragments induce lateral dispersal of the liquid propellants, minimizing any vapor cloud explosion.

In-Flight Breakup Scenario, 10-30 sec MET

Initial structural failures in the ET propagate to major structural failure due to small local explosions and aerodynamic loads. Massive dump of the liquid propellants are projected to result in vapor cloud explosions due to more enhanced mixing conditions as contrasted with the dispersal conditions for a SRB Case Rupture or a Range Destruct scenario.

In-Flight Breakup Scenario, 30-128 sec

The breakup scenario is the same as for the 10-30 sec period, but the massive dump of propellants will result in a trailing fire and possibly small, local explosions as opposed to a vapor cloud explosion.

In-Flight Breakup Scenario, 128 sec MECO

This accident is initiated in the same manner as the 30-128 sec scenario also with a trailing fire and possible small local explosions. The resulting breakup may occur immediately, followed by reentry, or the Orbiter may reenter out of control or possibly with minimal damage and controlled reentry.

3.1.4 ON-ORBIT REPRESENTATIVE SCENARIOS

Uncontrolled Orbiter reentry is the only scenario for the On-Orbit phase.

3.1.5 PAYLOAD DEPLOY SCENARIOS

Upper stage and/or spacecraft reentry is representative of the scenarios that might occur during the IUS free flight phase of the mission. Also, the potential exists for pressure rupture of the IUS solid rocket motor (SRM) casings, which also would result in reentry of the spacecraft and RTGs.

3.1.6 VEEGA MANEUVER SCENARIO

The only scenario identified that can present a severe environment to the RTGs is a very high velocity reentry of the spacecraft due to a spacecraft failure or a mission failure, such as puncture of the spacecraft propellant tank by a micrometeoroid.

3.1.7 MISSION ACCIDENT PROBABILITIES

The probabilities of failures occurring in the Space Shuttle and payload components that result in the accident scenarios previously described are shown in Figure 3-1. These were provided by NASA solely for use in the RTG safety analysis. The phase accident probabilities shown are only for those accidents that could endanger the RTGs. The highest accident probabilities occur in mission phases 1 and 4 as summarized following:

<u>Phase 1</u>

- A SRB failure probability of 3.8×10^{-3} is predicted for the ascent phase of which loss of thrust is the highest contributor at a mission probability of 2.49×10^{-3}.

PHASE 0 PRE-LAUNCH/LAUNCH	PHASE 1 ASCENT	PHASE 2 SECOND STAGE	PHASE 3 ON-ORBIT	PHASE 4 PAYLOAD DEPLOY	PHASE 5 VEEGA MANEUVER
RSS DESTRUCT 6.32×10^{-9}	SRB FAILURES 3.80×10^{-3}	ORBITER FAILURES 2.37×10^{-4}	ORBITER FAILURE & REENTRY 1.58×10^{-4}	IUS SRM CASE BURST 3.28×10^{-4}	HIGH VELOCITY REENTRY 5.00×10^{-7}
FIRE/EXPLOSION 1.79×10^{-4}	RSS DESTRUCT 1.51×10^{-6}	ET FAILURES 1.9×10^{-5}		OTHER IUS FAILURES & REENTRY 9.63×10^{-3}	
	AFT COMPARTMENT EXPLOSION 3.95×10^{-4}	SSME FAILURES 1.23×10^{-3}			
		PAYLOAD FAILURES 2.40×10^{-5}			
	VEHICLE BREAK-UP 8.95×10^{-5}	RSS DESTRUCT 1.58×10^{-6}			
	CRASH LANDING 3.79×10^{-6}	CRASH LANDING 8.85×10^{-6}			
	OCEAN DITCH 7.21×10^{-5}	OCEAN DITCH 1.68×10^{-4}			

Figure 3-1. Mission Accident Probabilities

Phase 4

- A IUS failure probability of 9.96×10^{-3} is predicted for the Payload Deploy phase of which erratic burns is the highest contributor at a mission probability of 3.37×10^{-3}.

The correspondence between the accident scenarios discussed in previous sections and the system failures and accidents shown on Figure 3-1 is given in Table 3-1.

3.2 RTG RESPONSE TO ACCIDENTS

Various consequences could result from the accident environments that have been defined for the Galileo safety evaluation in the FSAR. In Phases 0 and 1, the possible accidents resulting from SRB failures, either self induced or resulting from Range Safety destruct, can in certain instances lead to damaged GPHS modules and release of intact or breached fueled clads with subsequent release of fuel due to: 1) impact by SRB case fragments and 2) subsequent impact of the modules or fueled clads on ground surfaces or launch pad structures. In Phase 2, vehicle breakup resulting from ET and Orbiter failures can result in reentry of the RTG and breakup of the GPHS modules on hard ground surfaces. In Phases 3 and 4, Shuttle failures can result in reentry of the spacecraft (and RTGs) with subsequent breakup and release of the GPHS modules to impact on ground surfaces.

Considerable testing has been performed to determine the response of the RTG, the GPHS module, and the fueled clads to the environments to which they can be subjected as a result of the potential accidents. In areas where test data were not available, analyses were performed to supplement or substitute for the data.

From the results of the safety testing and analysis performed, failure mechanisms have been identified for those extreme cases that could potentially result in RTG fuel containment damage and fuel release for the accident environments defined. These failure mechanisms provide the basis for the

Table 3-1. Relation of Accident Scenario to System Failure/Accident

SYSTEM FAILURE/ACCIDENT WITH PROBABILITY / ACCIDENT SCENARIO	PHASE 0		PHASE 1						PHASE 2							PHASE 3	PHASE 4		PHASE 5
	RSS DESTRUCT 6.32×10^{-9}	FIRE EXPLOSION 1.79×10^{-4}	SRB FAILURE 3.8×10^{-3}	RSS DESTRUCT 1.51×10^{-6}	AFT COMPARTMENT EXPLOSION 3.95×10^{-4}	VEHICLE BREAKUP 8.95×10^{-5}	CRASH LANDING 3.79×10^{-6}	OCEAN DITCH 7.21×10^{-5}	ORBITER FAILURE 2.37×10^{-4}	ET FAILURE 1.9×10^{-5}	SSME FAILURE 1.23×10^{-3}	PAYLOAD FAILURE 2.4×10^{-5}	RSS DESTRUCT 1.58×10^{-5}	CRASH LANDING 8.85×10^{-5}	OCEAN DITCH 1.68×10^{-4}	ORBITER FAILURE/REENTRY 1.58×10^{-4}	SRB CASE BURST 3.28×10^{-4}	OTHER IUS FAILURE/REENTRY 9.63×10^{-3}	HIGH VELOCITY REENTRY 5.0×10^{-7}
PAD FIRE/EXPLOSION - 8HR TO T-O		O																	
INADVERTENT RANGE DESTRUCT	O																		
TOWER IMPACT SCENARIO 0-2 SEC			O																
AFT COMPARTMENT EXPLOSION 0-10 SEC					O														
SRB CASE RUPTURE 0-10 SEC			O																
10-128 SEC			O																
RANGE DESTRUCT 0-10 SEC				O															
10-128 SEC				O															
INFLIGHT BREAKUP 10-30 SEC						O			O	O	O	O							
30-128 SEC						O			O	O	O	O							
128S TO MECO						O			O	O	O	O	O						
UNCONTROLLED REENTRY																O	O	O	
HIGH VELOCITY REENTRY																			O
CRASH LANDING							O							O					
OCEAN DITCH								O							O				

determination of the source terms which are a characterization of plutonium releases including their quantity, location, and particle size distribution.

3.2.1 SRB FRAGMENT ENVIRONMENT

Recent large fragment tests in the GPHS safety test program have demonstrated that SRB case fragments in the face-on attitude impacting the full RTG configuration will not breach the fueled clads at velocities as high as 212 m/s (695 ft/sec). Other recent tests of SRB fragment interaction with Orbiter structure indicate that attenuation of fragment velocity and spin rate as much as 46% and 100%, respectively, can occur in passage through the wing and payload bay wall. Passage through only the payload bay wall can reduce velocity up to 20%. These results coupled with those of the large fragment tests indicate that SRB fragments in the face-on attitude at impact during the first 105 seconds MET will not cause a breach of the fueled clads. Also, a Range destruct of the vehicle during the 105-128 second MET will not breach the clads for a face-on fragment impact. At least 95% of the fragments from a SRB case rupture (i.e., self induced) during the 105-128 second MET will not breach the fueled clads in a face-on impact. Hydrocode analyses of the edge-on SRB fragment impact with the RTG indicate that the fueled clads can be breached at velocities in the range of 40-113 m/sec (130-370 ft/sec) depending on the fuel and iridium characteristics, the location of the impact with respect to the clads, and the position in the stack of modules.

3.2.2 ET PROPELLANT EXPLOSIONS

Explosions of ET propellants on or near the launch pad with the consequent implosion of the Orbiter payload bay walls around the RTGs are not predicted to cause breach of the fueled clads. Distortions of the clads as determined by hydrocode analyses are less than 10% which is well below the approximate 30% threshold for breach in the full RTG configuration. The latter value has been determined through recent tests of SRB fragment impact on smaller simulated RTG converter sections with the actual plutonia fuel.

3.2.3 SECONDARY IMPACT AROUND LAUNCH PAD

If ET propellant explosions or SRB fragment impacts result in fueled clads being released from the RTGs and GPHS aeroshells as free bodies, which is predicted to occur in a few percent of the accidents, then secondary impact of the fueled clads on the concrete and steel surfaces around the launch pad can possibly result in breach of some of the clads on some occasions. However, this postulated situation requires sequential insults, that is, distortion of the clads by initial SRB fragments on payload bay wall impact followed by secondary impacts.

3.2.4 FIREBALL FROM ET PROPELLANTS

Both intact and damaged GPHS fueled clads and modules may have some residence time in the liquid propellant fireball accompanying on-pad and near-pad catastrophic accidents. The effects of the fireball (and residual fire on the ground) will not result in breach of the clads (i.e., when the clads have not previously been breached). This result is a carryover from the previous analysis and testing for the GPHS-RTG program. The particle size distribution or location of any plutonia fuel released by SRB fragment impact or by secondary impact in the near pad area is, however, modified by the thermal action of the fireball.

3.2.5 REENTRY FROM ORBIT AND IMPACT

Modules released during On-Orbit or the Payload Deploy phase accidents that lead to reentry may release some of the plutonia fuel upon striking a rock or other hard surface when land impact occurs. Breaches of the clads for impact on hard surfaces have been shown by test to be small areas; consequently, small quantities of fuel are predicted to be released.

3.2.6 VEEGA MANEUVER REENTRY

If reentry occurs as a result of Galileo Spacecraft failures during the VEEGA maneuvers, the aeroshells of the GPHS modules are predicted by analysis to experience temperatures in the range of 6500-7000°F (3600-3900°C) and are assumed to fail and release the graphite impact shells (GISs) with fueled clads (FC). The iridium clads are predicted to melt from eutectic formation with the graphite in the GIS. Impact on a hard surface on the ground is then assumed to release all the fuel from the GIS. Impact on soil or water is not predicted to cause fuel release.

SECTION 4.0
RESULTS

In order to present the RTG response to the various accident scenarios in the logical sequence of cause and effect, detailed Failure/Abort Sequence Trees (FASTs) have been constructed for each mission phase and for each type of accident to aid in evaluating those situations that could result in release of radioisotope fuel. The assessment of the risks involved as the result of any potential plutonium dioxide (PuO_2) fuel release, which is addressed in Volume III of the FSAR, is based on the probabilities of the accident environments involved.

Each FAST is a graphical representation of potential causal sequences which can impose physically severe environments on the RTGs, and each begins with the phase identification and the distinction between mission phase success and failure. The success branch indicates that the mission phase objective is achieved and leads directly to the next mission phase. The failure branch is subdivided, as conditions require, into various primary initiating situations or events. From each of these initiating events, a sequence of intermediate events and conditions progresses to a terminal event which either results in (1) a significant fuel release, (2) a fuel release of little or no consequence, or (3) no fuel release. In this manner, the FASTs are constructed based on the accident scenarios identified for each of the six mission phases in a logical sequence of occurrence.

Fuel release events identified in the RTG safety analysis are evaluated for radiological impact in Volume III of the FSAR, the Nuclear Risk Analysis Document. In general, the risk analysis includes the following steps:

1) Analysis of the time behavior/dispersion of released radioactivity to determine the concentration in environmental media (air, soil, water) as a function of time.

2) Analysis of the interaction between the environmental concentrations and humans (ingestion, inhalation and external doses) through each environmental exposure pathway.

3) Evaluation of the radiological impact on humans in terms of population doses received and the resulting health effects.

Three types of fuel release cases have been identified for radiological analysis: 1) the most probable release case for each phase, 2) a maximum release case for each phase, and 3) a release expectation case for each accident and phase. These cases were selected from the source terms resulting from the RTG safety analysis.

1) Most probable release - that FAST/sub-branch in a phase with a predicted fuel release having the highest probability. This includes any associated or sequential related source terms.

2) Maximum case - the combination of events in a FAST/sub-branch having the largest total release. This includes any associated or sequentially related source terms selected to maximize the risk. A maximum release is identified for each of the mission phases.

3) Release expectation case - a summary characterized by a probability weighted source term based on all the identified predicted fuel release events in a given mission phase.

The evaluation of the most probable and maximum cases presented in the Nuclear Risk Analysis Document includes the following categories:

1) Distributed values out to 100 Km for:

   a. total body burden
   b. whole body equivalent dose commitment
   c. ground concentration of Pu-238

2) The number of persons receiving total body burdens and doses above specified values.

3) Areas of dry land, swamps, inland water and ocean with initial surface concentrations of Pu-238 above specified levels.

The release expectation cases are analyzed in a similar manner. However, they include only the latter two types of information.

The release expectation values are the most general and significant of the results produced by the safety analysis. These represent the best estimate, average values for each release category and can be carried as probability-weighted sums to any level of the mission (i.e., for a given accident consequence, for a phase of the mission, or for the entire mission). Maximum and most probable releases are special cases. The most probable release is the event most likely to occur, but it does not carry any weighting for the lower probability but higher fuel release events. The most probable event at the mission level, for example, is a successful launch with no failure. The maximum release case is of interest to provide understanding of upper limit consequences, even though it is usually associated with a very low probability. The maximum and most probable releases do not sum as do the expectation values.

A summary of the release expectations is presented in Table 4-1 at the mission phase level, showing the relative contributions of the various accidents. Inspection of this table shows that the release shown to arise from the SRB failures in Phase 1 (i.e., with a value of 0.167 curies) is dominant. The next most significant contributor is the VEEGA reentry in Phase 5 with a value of 0.0129 curies.

Tables 4-2 and 4-3 present the most probable and maximum source terms, respectively, by mission phase. From Table 4-2, the most probable source term for the overall mission is seen to occur as a result of IUS failures with subsequent reentry having a release of 0.17 curie and a probability of 8.54 x 10^{-3}. The ground location for this release is anywhere in the latitude band

Table 4-1. Mission Source Term Expectations and Probabilities by Phase and Accident (Curies)

Phase	Phase Accident Probability	Expectations in Curies				Aft. Comp. Explosion	Vehicle Breakup	Reentry
		Phase Total	Fire and Explosion	RSS Destruct	SRB Failures			
0	1.79×10^{-4}	2.22×10^{-5}	2.22×10^{-5}	–	–	–	–	–
1	4.36×10^{-3}	3.25×10^{-1}	–	2.40×10^{-6}	3.14×10^{-1}	9.39×10^{-3}	1.69×10^{-3}	
2	1.69×10^{-3}	1.97×10^{-6}	–	–	–	–	1.97×10^{-6}	–
3	1.58×10^{-4}	2.69×10^{-5}	–	–	–	–	–	2.69×10^{-5}
4	9.96×10^{-3}	1.45×10^{-3}	–	–	–	–	–	1.45×10^{-3}
5	5×10^{-7}	6.45 [redacted]x10^{-3}	–	–	–	–	–	6.45 [redacted]x10^{-3}

Table 4-2. Most Probable Source Terms for Radiological Consequence Analysis

Phase	Accident Mode	Source Term (Curies)	Release Probability	Release Location
0	Fire/Explosion	44.3	5.01×10^{-7}	ground (FB)*
1	SRB Loss of Thrust (w/Vehicle Breakup)	796	3.30×10^{-4}	ground (FB)
2	Vehicle Breakup	0.0016	1.21×10^{-3}	ground
3	Uncontrolled Orbiter Re-entry	0.17	1.58×10^{-4}	ground
4	IUS Failure	0.17	8.54×10^{-3}	ground
5	Guidance Failure & Re-entry	12900	5.0×10^{-7}	ground

*FB indicates the release occurs within the area engulfed by the fireball

Table 4-3. Maximum Source Terms for Radiological Consequence Analysis

Phase	Accident Mode	Source Term (Curies)	Release Probability	Release Location
0	Pad Fire/ Explosion	44.3	5.01×10^{-7}	ground
1	Loss of Thrust	1860	1.39×10^{-4}	air - 147,800
2	Vehicle Breakup	0.136	3.32×10^{-7}	ground
3	Uncontrolled Orbiter Re-entry	1.19	3.33×10^{-7}	ground
4	IUS Failure & Re-entry	1.78	1.49×10^{-7}	ground
5	Guidance Failure & Re-entry	12900	5.0×10^{-7}	ground

of approximately 33° north to 33° south. Table 4-3 shows that the maximum realizable source term for the mission occurs from SRB case rupture accidents in Phase 1, the Ascent phase, at a value of 39,854 curies and a probability of 5.1×10^{-8}. This release occurs at the high altitude of 147,800 feet. Actually, a larger release can be postulated to occur in Phase 5, the VEEGA maneuver phase, if all 72 free GISs impact rock on land after having gone through reentry at an angle between 20-90°. In this situation, and because of the total failure assumed as previously discussed in Section 3.2.6, release of the total inventory of 277,600 curies can be postulated. The probability for this result is essentially non-existent at an overall mission value of approximately 1×10^{-102}. Actually, any number of GISs from 1 to 72 can hit rock, with the corresponding probability based on the binomial distribution of events. Section 3.4.8 of the FSAR presents that distribution.