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SNAP (SYSTEMS FOR NUCLEAR AUXILIARY POWER)
TECHNICAL BRIEFS
PART 8, AEROSPACE SAFETY

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A DIVISION OF NORTH AMERICAN AVIATION, INC.
P.O. BOX 309 CANOGA PARK, CALIFORNIA

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I. INTRODUCTION

The Division of Reactor Development of the AEC established the Aerospace Nuclear Safety Program two years ago under the Assistant Director for Nuclear Safety. The Aerospace Nuclear Safety Program was established to provide an independent assessment of the nuclear safety aspects associated with the space uses of nuclear power.

With respect to nuclear auxiliary power and specifically with respect to the SNAP 10A, 2, and 8 projects (for which AI is the system prime contractor), there are three separate prime contractors participating in the Program. In addition to AI, the unique capabilities of the Sandia Corporation and the Phillips Petroleum Company are being utilized in the areas of nuclear excursion experimentation, atmospheric reentry experimentation, and abort-simulation to provide a comprehensive Aerospace Nuclear Safety Program.

In addition to the tests, experiments, and analyses performed in the AI Aerospace Safety Program, the AI Program also provides technical liaison with the other AEC contractors, guidance to the contractors and the AEC on safety criteria, reactor and special test hardware for the safety experiments, and the communication channel for information flow between the total Aerospace Nuclear Safety Program and the SNAP 10A, 2, and 8 projects. It is in this manner that the programs of Phillips, Sandia, and AI are compiled into an integrated program which will provide an assurance that the safety requirements have been met for each reactor system. In all cases, however, the responsibility for the safety of the specific SNAP projects rests with the AEC and its prime contractor.

The responsibilities of Phillips Petroleum Co. within the Aerospace Nuclear Safety Program lie in the area of reactor excursion test and analysis. The objectives of this test program are to determine and demonstrate the consequences of nuclear accidents and to provide experimental information regarding the characteristics of SNAP reactors of importance in evaluating and predicting the reactor behavior with respect to Nuclear Safety.

Sandia Corporation provides ground and flight test and analysis associated with abort accidents and reentry. The objectives of this program are to determine and demonstrate the behavior of the reactor in the abort and reentry environment and to provide experimental information necessary for predicting the consequences of these environments on nuclear safety.

The programs of Sandia and Phillips, therefore, provide specialized experimentation and analyses in support of the general and more comprehensive Aerospace Safety Program.

II. OBJECTIVES OF THE AI AEROSPACE SAFETY PROGRAM

A portion of the overall AEC Aerospace Nuclear Safety Program has been established at Atomics International. The AI program is associated with, but independent of, the SNAP 2, 10A, and 8 projects. Its primary function is to provide an assessment of the safety associated with the SNAP 2, 10A, and 8 nuclear systems. The objectives of this program are to demonstrate, through analyses and experiments, that SNAP reactors meet the specified safety criteria as established by the project organizations and to verify that these safety criteria are adequate to provide the safety requirements consistent with the use of each SNAP system. These objectives encompass all SNAP uses from feasibility demonstration flights through the operational phases and embody all safety considerations throughout the factory-to-flight and eventual disposal sequence.

To accomplish these objectives, the Aerospace Safety Program provides for a review of the specified safety criteria, the system designs, and the proposed procedures. The results of this independent review are given to the affected project along with any appropriate conclusions or recommendations for modification to the safety criteria, system design, or proposed procedures. Areas of uncertainty not covered by the reactor system development plan are highlighted. Analyses, experiments, and suitable reactor or system tests are then performed within the Aerospace Safety Program to investigate these areas of uncertainty. The purpose of these activities is to ascertain that the designs and procedures are consistent with the specified safety criteria.

The Aerospace Safety review covers not only the proposed reactor program but also investigates other future missions and applications and attempts to evaluate potential safety criteria which may apply to these future uses of the reactor system. In its testing, experimental, and analysis program, Aerospace Safety will develop safety features and procedures necessary for advanced system applications and/or potential missions.

During and after each phase of the experimental, testing, and analysis program, the safety criteria are reviewed. As a result of this review, comments and recommendations are made to the Project.

III. BASIS FOR SELECTION OF CURRENT PROGRAM

The current Safety Program resulted from a review of the present SNAP 10A and SNAP 2 flight test programs, the projected SNAP 8 flight test program, and the future operational uses of SNAP reactor systems. Consideration was given to various launch sites, various means of transportation, possible launch vehicles, and future space missions. The present Aerospace Safety Program, while dealing mostly with the SNAP 10A/2 reactor system, was formulated to include in its future planning the SNAP 8 reactor and operational uses of SNAP 2/10A and 8 for communication satellites, manned space stations, deep space probes, and lunar bases.

In general, it was found that the development plans for the SNAP 10A and 2 reactors and their associated systems adequately covered the safety objectives of the flight test program. For backup data, it was felt that a demonstration of the impact performance of the system and an experimental verification of the shipping sleeve and void-filler block nuclear design was desirable.

IV. TECHNICAL DESCRIPTION OF PROGRAM

The experiments, tests, and analyses to be performed under the Aerospace Safety Program were derived to obtain data on potential hazards and to demonstrate the inherent safety of the SNAP systems. A brief description of the SNAP 10A, 2, and 8 reactors is included here for the purpose of familiarization.

The SNAP 10A, 2, and 8 reactors have certain common features. They incorporate a hydride alloy of fully enriched uranium-zirconium as fuel and moderator in a core which is sufficiently compact to allow control to be exclusively provided by manipulation of external beryllium reflectors. This results in a considerable simplification of core design and a more uniform power distribution.

The primary heat transfer medium in these reactors is NaK. In SNAP 10A, a 500-w electrical design, the NaK is circulated by an electromagnetic pump to thermoelectric elements mounted in a converter-radiator structure. This system is designed for operation without the presence of an active control system.

In SNAP 2, a 3-kw electrical design, the NaK is pumped into a mercury boiler. The mercury vapor drives a two-stage turbine, an alternator rotor, and the mercury pump. All the rotating components of the power conversion system are mounted on a single shaft. In the SNAP 8 system, a somewhat larger core, smaller fuel element diameter and higher operating temperature permits a power rating of 60 kwe.

The core configurations for SNAP 2 and 10A are identical. The concentration of hydrogen in the fuel is 6.5×10^{22} atoms/cm³. Each fuel element is 1.212 in. in diameter and 12.25 in. in length. The fuel is canned in Hastelloy-N, the interior surface of which is coated to minimize hydrogen loss. Thirty-seven elements are arranged on 1.260-in. centers in a hexagonal array. The core vessel consists of a cylindrical shell of 0.031-in. -thick 316 stainless steel. Beryllium inserts fill the volume between the fuel and the core vessel.

The SNAP 8 fuel loading consists of 211 fuel elements, each ~0.6 in. in diameter and 18 in. in length. The overall dimensions of the hexagonal array are slightly larger than those of the SNAP 2/10A array.

A more detailed description of each of the SNAP nuclear systems is presented in the respective technical brief.

The formulation of the testing program resulted from a detailed analysis of the sequence of events, starting at the time the reactor is first a potential critical mass, and ending after it has reentered from orbit and been reduced to a noncritical mass. During the various handling and operational sequences, accidents can be postulated to occur, from which it is possible to formulate a test program to determine the consequences of these accidents. The following paragraphs present a brief discussion of the handling and operational sequence. A more detailed discussion can be found in the technical brief entitled "Flight Test Safety Program."

A. ASSEMBLY, HANDLING, AND PACKAGING OF APU AT SANTA SUSANA

In this operation, the reactor will be loaded with fuel and brought to criticality in the Acceptance Test Facility at Santa Susana. A nuclear accident can be postulated due to operational malfunctions. The reactor will then be packaged for shipment to the launch site. During the subsequent handling and packaging procedure, it can be postulated that the APU can be dropped or in some way damaged. Since the shipping sleeve will be in place and water will be excluded from the area, no nuclear accident will occur.

B. TRANSPORTATION OF APU FROM SANTA SUSANA

After packaging in an appropriate container, the APU will be mounted on a truck-trailer and shipped to the launch site. The transportation will be made by convoy early in the morning when minimum traffic conditions exist. During the trip, accidents such as a collision with a speeding gasoline truck, etc. can be postulated. Since the reactor will have the shipping sleeve installed and will be packaged in a double-walled container, no nuclear accident is postulated.

C. ASSEMBLY AND HANDLING AT LAUNCH SITE

After the APU arrives at the launch site, it will be unpacked and inspected for transportation damage. Non-nuclear tests will then be performed. While at the assembly building, the shipping sleeve will be removed and the Be reflectors installed. The Be reflectors contain keyed void filler blocks, lockout pin, etc. that prevent the control drums from rotating. During these operations, the APU might be transported to other facilities for further non-nuclear testing. No nuclear accident is postulated, since all operations are performed in facilities where water is excluded.

D. PRELAUNCH OPERATIONS

After the APU arrives at the launch pad, a series of mating tests with the vehicle will be performed. During these prelaunch tests, the launch vehicle is fueled and could produce fire, explosion, or other chemical interactions. During such an accident, the APU could fall to the pad where it could be engulfed in the deluge water. A nuclear accident would possibly occur under such conditions. Prior to the fueling operation, however, the pad area would be evacuated and a nuclear accident would not result in a harmful dose to personnel.

E. LAUNCH AND ORBIT INJECTION

Prior to launch, while the vehicle is being fueled, accidents similar to those postulated in the prelaunch operations can be postulated. In addition, prior to the final fueling, the void filler blocks will have been removed, thus the reactor would be in a more reactive configuration.

During the launch and orbit injection, a vehicle abort is possible at any point. Should this happen, the point in the trajectory where the abort occurs will determine the approximate point of impact and the velocity at impact. During a near-ground abort, the APU could fall to the launch pad intact and be engulfed in the deluge water, resulting in a nuclear excursion. At aborts occurring at higher altitudes, the resulting impact would be at a terminal velocity.

F. ORBITAL OPERATIONS

After a safe orbit is achieved, the reactor will be started up. For the initial R & D flights, the objective is to achieve an orbit of sufficient duration so as to preclude the possibility of a highly radioactive reactor reentering and falling in a populated area. An accident condition could result if the end-of-life shutdown device failed and the reactor continued operation (at some reduced power level) for hundreds or even thousands of years, thus not permitting the inventory of fission products to decay to a safe level.

G. ORBITAL REENTRY

After the orbit of the APU degenerates to a low altitude, the reactor will reenter the earth's atmosphere. As previously stated, the objective of the first R & D flight series is to achieve a long-lived orbit. Thus, when the system reenters, there will be only a harmless amount of radioactivity remaining.

For operational systems, it is possible that a low or short-lived orbit would be required. For such a case, the reactor, upon reentry, would have a high radioactivity level and could present a serious hazard problem if allowed to reenter intact. Consequently, it is desirable to have the system designed such that, under reentry conditions, the reactor would disassemble, fuel elements would be ejected, and the elements would burn up with subsequent dispersal of the fission products in the upper atmosphere.

V. CURRENT PROGRAM

The present AI Aerospace Safety Program is divided into seven projects which cover the factory-to-disposal sequence. These projects are entitled, Critical Configuration Tests, Mechanical and Thermochemical Effects, Reactor Transients and Excursion Tests, Fission Product Release Studies, Reactor End-of-Life Shutdown Devices, Reactor Separation and Fuel Element Ejection, and Fuel Element Burnup and Fission Product Dispersal.

The Critical Configuration Tests project is designed to investigate the areas associated with the transportation, assembly, and handling phases. The project is determining the reactivity of the SNAP reactors when they are subjected to various water-immersion configurations (see Figure 1) and demonstrating that the shipping sleeve (see Figure 2) and filler block designs are adequate to prevent criticality upon water immersion and subsequent flooding of the core. The current series of tests will also assist in developing the ability to analyze a general poison-void shipping sleeve design without the necessity of performing experiments to evaluate each new design.

While the reactor is enroute and prior to the actual launch, various accidents have been postulated. Potential accidents such as impacts, chemical interactions, fires, and explosions could occur. The Mechanical and Thermochemical Effects project has conducted and is continuing to conduct several series of tests to evaluate the possible effects of these mechanical and thermochemical changes on the SNAP system. Full-scale mockup reactors and systems have been and are being subjected to conditions similar to those which would occur in the various postulated accidents. The data (see Table I) obtained from these tests will permit an analysis of these potential hazards.

The Reactor Transient and Excursion Tests project and the Fission Product Release Studies project are studying, by experimental and analytical means, the nuclear behavior of the SNAP systems under various accident conditions. Two SNAPTRAN reactors have been designed and are being fabricated for test purposes (see Figure 3). These reactors will be used to determine the response characteristics of the SNAP reactors to varying reactivity insertions. The inherent shutdown mechanisms, such as the prompt negative temperature coefficient and hydrogen release from the fuel moderator material, will be evaluated. These shutdown mechanisms will be further demonstrated by observing the

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Figure 1. Water Immersion Critical Machine

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Figure 2. Shipping Sleeve Configuration

TABLE I
MECHANICAL AND THERMOCHEMICAL EFFECTS - PHASE I

Test No.	Type	Environment	Configuration	Status	Results
1	LOX spray	LOX vapor	Reactor vessel	Completed	No damage
2	LOX-NaK interaction	LOX vapor	Reactor vessel	Completed	No interaction
3	NaK-H ₂ O interaction	Water tank	Reactor vessel	Completed	Violent reaction, test tank destroyed - incomplete
4	Fire test	3700°F - 2 sec 1500°F - 15 min	Reactor and reflector	Completed	Reflector ejected
5	Explosion	250 lb TNT	Reactor and reflector	Completed	Reflector ejected
6	Drop test	100 ft tower head	Full APU	Completed	Drums severed, reflector ejected
7	Drop test	100 ft tower tail	Full APU	Completed	Drums severed, reflector ejected
8	Drop test	100 ft tower side	Full APU	Completed	Drums severed, reflector ejected
9	Impact	560 ft/sec - concrete head	Reactor and reflector	Completed	Complete destruction
10	Impact	750 ft/sec - concrete head	Reactor, reflector and shield	Deleted	Test model to be used for soil impact
11	Impact	580 ft/sec - water head	Reactor and reflector	Completed	Drums severed, reflector ejected, top cover removed
12	Impact	594 ft/sec - water tail	Reactor and reflector	Completed	Drums severed, reflector ejected, partial core disassembly
13	Impact	560 ft/sec - water side	Reactor and reflector	Completed	Drums severed, reflector ejected
14	Impact	750 ft/sec - water head	Reactor, reflector and shield	Completed	Velocity was only 428 ft/sec, shield and converter ejected, core remained intact

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Figure 3. SNAPTRAN Reactor Schematic

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responses of the reactor to reactivity insertions large enough to cause an irreversible reactor shutdown. After a postulated excursion, the amount of fission product release will govern the potential hazard. The Fission Product Release Studies project is investigating the fractional release of radioactive material from uranium-zirconium hydride fuel. A series of release tests has been conducted at the NRTS to obtain reliable data with respect to this potential hazard.

The Reactor End-of-Life Shutdown Devices project has been studying various mechanical and chemical methods of reliably reducing the reactor to a subcritical state. Should the reactor enter the atmosphere still intact, the results obtained from the Reactor Separation and Fuel Element Ejection and Fuel Element Burnup and Fission Product Dispersal projects would come into play.

Under the former project, the mode of breakup of the reactor and its associated structure, when it is subjected to reentry heating, are being investigated. The principles of aerodynamic and thermodynamic theory, along with available experimental data, are being used in this study. Later in the program, flight tests using reactor models (see Figure 4) will be conducted to provide further data for the study. Under the latter project, the behavior of the fuel elements following their ejection from the reactor is being studied. An analytical model of the ablation process is being developed to assist in this area. A series of arc-jet tests has been conducted (and more are planned) to increase the knowledge of fuel element ablation phenomena. Elements filled with flare material will be released into the upper atmosphere to determine the rate of ablation under actual reentry conditions. Ways of enhancing the fuel burnup and the subsequent dispersal of the fuel material will be studied. This project will provide the data necessary to establish the fuel element release altitudes which are necessary to insure upper atmospheric dispersal of the fission products.

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Figure 4. Flight Test Reactor Model

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VI. TECHNICAL STATUS

A. CRITICAL CONFIGURATION TESTS

Experiments to determine the reactivity associated with water immersion and flooding of SNAP 2, 10A, and 8 reactors have been performed using the critical assembly machine shown in Figure 1. This machine contains a removable water reflector which is physically separated into three regions surrounding the reactor core. Each region may be remotely filled with or emptied of water.

Initial tests have been performed which measured the reactivity worth of water flooding and immersion for a SNAP 2/10A core. The nuclear design of shipping sleeves to insure subcriticality under conditions of water flooding and immersion has been determined. Figure 2 shows the final configuration for the shipping sleeve.

Beryllium and void filler blocks have been tested to demonstrate that a subcritical configuration results from water immersion. The program for developing the ability to analyze general poison-void sleeve designs has started. A similar program is underway for the SNAP 8 reactor.

B. MECHANICAL AND THERMOCHEMICAL EFFECTS

During the factory-to-orbit sequence, the SNAP reactors and their related systems will be subjected to various handling, transportation, and launch conditions. As a result of these conditions, potential accidents have been postulated. In order to provide adequate nuclear safeguards, the potential hazards that could result from the postulated accidents must be analyzed. A series of tests has been completed whereby full-scale mockup reactors and systems were subjected to conditions similar to those which would occur in the various postulated accidents. These Phase I tests were conducted at Holloman Air Force Base. The results are summarized in Table I. These tests utilized reactor models which were designed and fabricated as required by the conditions of each test. Tests were conducted which simulated the fire, explosion, and impact environments expected during aborts. The design of four reactor models to be used for additional Phase II impact tests during FY 63 has been completed and fabrication has started. Phase II of the ground test series has been initiated and will be completed during FY 64. During FY 64, six test models will be

fabricated for ground tests. The specific tests with emphasis on the SNAP 2 reactor will be determined after thorough analysis of the Phase I and II test results.

Analysis of the results of the Phase I ground test series has established that the reactor is virtually unaffected by fire, explosion, thermochemical environments, or impacts (at less than terminal velocity on concrete). A detailed report is in the final stages of preparation describing the performance and results of the Phase I tests. The Phase II and Phase III tests will be completed during FY 63 and FY 64. This will provide further detail with regard to the effects of possible hazardous environments on the SNAP 10A and SNAP 2 reactor systems. Analyses effort will be expended concurrently to investigate the results of each of the Phase II and Phase III tests. FY 64 will also include the preliminary analysis and test effort to determine the most appropriate new designs for operational SNAP reactors. A series of tests simulating the SNAP 8 reactor will be conducted when the flight design becomes finalized.

C. REACTOR TRANSIENT TESTS

The ability to predict the consequences of reactor nuclear excursions depends on an understanding of the role of each of the shutdown mechanisms on the termination of the transient. For SNAP reactors, there are two such mechanisms. The first is the prompt (fuel) negative temperature coefficient, comprised of an axial expansion contribution and a spectral (neutron thermalization) contribution. The second is the rapid evolution of hydrogen gas from the zirconium hydride fuel at high temperatures, insofar as it produces loss of moderator and/or severe pressure gradients across the core which cause core disassembly.

At present, very little experimental data is available to quantitatively evaluate each of the above effects over the temperature range of interest ($100^{\circ}\text{F} \leq T \leq 3400^{\circ}\text{F}$), except at the lower end of the scale. A preliminary study of hydrogen diffusion rates at temperatures approaching 2200°F was conducted by means of electrical heating of fuel samples. The results have been reported in NAA-SR-7398 and NAA-SR-7736. The apparatus employed was not capable of rapid enough heating to explore the region above this temperature, i. e., all the

hydrogen was driven out of the fuel during the time (~ 0.5 sec) of the transient. These experiments will be continued in FY 64 with a somewhat more elaborate switching arrangement and power supply to achieve an order-of-magnitude increase in heating rate. Also, additional instrumentation will be provided to measure the coefficient of expansion of the fuel during the transient.

Still more rapid heating rates can be achieved with capsule experiments in the TREAT reactor. Such experiments have the additional virtue of heating the fuel in precisely the same manner (fissioning of U^{235}) as in the SNAP reactor. A few preliminary experiments of this type have been performed in the KEWB reactor, but the integrated neutron flux in the KEWB pulse is not sufficient to meet the requirements of the tests. A series of experiments in the TREAT reactor is therefore planned for FY 64.

The shock wave and particle velocities in SNAP fuel have been measured, as they are important to a description of reactor disassembly.

The value of the prompt (fuel) temperature coefficient in SNAP reactors has not been accurately measured due to operational safety limitations on the types of experiments that can be performed in existing facilities. The SNAPTRAN series of transient experiments, to be conducted at the NRTS in Idaho, will not be constrained in the same manner. An integral measurement of the prompt coefficient, as a function of temperature, will therefore be performed. Additionally, each of the SNAPTRAN test series will be terminated by a destructive transient. The first such transient will be a high-reactivity input ($\sim \$5$) excursion to demonstrate the adequacy of the previously developed calculational model in giving the correct energy release. Due to the nature of the destructive experiment, little in the way of an understanding of the phenomena can be expected. This must come from the other experiments previously described.

Accurate internal core instrumentation is essential to a meaningful SNAPTRAN project. To this end, an instrumented fuel element has been designed which provides fuel temperature and hydrogen pressure information. These instrumented elements will be employed in the nondestructive experiments.

The first and second SNAPTRAN reactors (SNAPTRAN-2/10A-1 and -2) (see Figure 3) are beryllium-reflected SNAP 2/10A reactor cores. The third and fourth (-3 and -4) are water-reflected assemblies for investigating,

respectively, the possibility of achieving a steady-state mode of operation in water and the consequences of rapid water immersion. The reactivities associated with water immersion have been measured by the Critical Configuration Test project.

The fifth SNAPTRAN reactor (SNAPTRAN-8-5) is to consist of a beryllium-reflected SNAP 8 reactor.

The schedule shown in Figure 5 indicates when design, fabrication, testing, and destruction of each of the SNAPTRAN reactors are planned. At present, the -1 and -2 reactors are being assembled at Atomics International. Testing of the first reactor at the NRTS will begin in April.

An extensive analytical effort is being conducted concurrently with the testing programs. By maintaining a close relationship between experiment and analysis, each will provide information of value to the other, to the benefit of the project. For the SNAPTRAN program, rapid yet thorough data analysis will be provided by a digital computer code presently being developed.

D. FISSION PRODUCT RELEASE STUDIES

Radioactive contamination following a nuclear excursion is a function not only of the energy release but of the species and fractions of fission products released from the fuel. An experimental project to study these properties at high temperatures has recently been completed. Radiochemical analyses of the fuel and of various test apparatus components are now being performed. Additional data will become available and be analyzed as a result of the Reactor Transient and Excursion Tests project.

E. END-OF-LIFE SHUTDOWN DEVICES

Two approaches to end-of-life shutdown devices have been studied. Both suffer from the disadvantages of dispersing fuel in space. A more satisfactory solution to the problem would be an intrinsic shutdown mechanism not requiring disruption of the fuel element array. This program is currently being reevaluated to assess the possibility of a more satisfactory approach. Future direction of the work will depend upon the results of this reevaluation.

F. REACTOR REENTRY SEPARATION AND FUEL ELEMENT EJECTION

Before a SNAP reactor is placed into orbit for a prolonged period of operation, the consequences of its return to earth must be considered. To combat the potential hazards which could result from such an occurrence, knowledge of the melt down and dispersion sequence of the reactor during the reentry phase is required. Extensive analytical and experimental projects are needed to determine these characteristics. Such projects are presently in progress.

Of primary significance to these projects is the development of accurate aerodynamic heating calculations. To date, the original work, completed some 2 to 3 years ago, has been much improved, but continued effort is required during the coming fiscal years.

Studies accomplished up to this time include calculations of local heating rates on reactor and vehicle components and of heat transfer within the components. However, only one vehicle attitude has been considered. Additional studies are required which will include other attitudes. These will be completed during the remainder of this fiscal year and during FY 64. Experiments will also be performed during this period to measure actual local heating rates.

It has been determined that the NaK in the coolant system will be liquid while the reactor is in orbit, even without heat from radioactive decay processes. The effect of the coolant on the mode of reactor breakup has yet to be determined.

Extensive effort has gone into the determination of the characteristics of orbital decay and vehicle motion. The most significant requirement of this study is the determination of a proper drag coefficient. This will require increased study and experiments during FY 64. Effort to date has established the expected lifetimes as a function of altitudes utilizing three values for the drag coefficient. Considerable refinement of this effort will be accomplished during the remainder of this fiscal year and during FY 64.

Orbital perturbations which the vehicle may undergo due to the oblateness of the earth and atmosphere, with respect to vehicle altitudes and oscillations, will be investigated during the coming year. To date, a computer code has been established for the calculations of satellite trajectories during reentry considering an oblate, rotating earth. A detailed study of the oscillations created by the aerodynamic and gravitational forces acting on the vehicle during reentry is currently in progress. This study will be continued through FY 64.

The vehicle attitude angle, as a function of time, cannot be predicted for the entire reentry period on the basis of the available information on the structure and aerodynamic heating intensities. The analyses to date have been made for the postulated case of zero angle of attack. Further analyses for other angles must be made in the remaining months of FY 63 and during FY 64 to further our abilities in these areas.

The experimental effort required to determine reactor separation and fuel element ejection characteristics during reentry includes the demonstration flight tests. The design and fabrication of the reactor models for the reactor flight demonstration (RFD-1) have been completed. (See Figure 4.) The flare-fuel elements to be included as a part of the test flight are ~50% complete. The final planning and engineering efforts have not yet been initiated for the two demonstration flights during FY 64.

G. FUEL ELEMENT BURNUP AND FISSION PRODUCT DISPERSAL

The radiological hazard associated with a SNAP system reentering the atmosphere is primarily contained in the fuel elements released from the reactor following breakup. Therefore, special emphasis must be given to the sequence of events that the fuel elements undergo once they are released to the atmosphere during reentry.

Again, experimental and analytical projects are required to determine that sequence of events. The objective of the project is to complete an analysis of fuel element ablation under the conditions of reentry to firmly establish the results of release of the elements.

Some qualitative tests for the determination of the thermochemical behavior of the fuel material during reentry have been completed during FY 63. Additional quantitative tests are required during the remaining portion of FY 63 and during FY 64 to definitely establish these behavioral characteristics.

Fuel element ablation characteristics have been investigated for three postulated release altitudes. Supporting calculations of heat rates and drag coefficients were completed to supplement these investigations. Additional analyses are required based on the firm expected release altitude. This will be accomplished as soon as the base data are made available.

Ablation analyses to date have been based on three assumed modes of fuel element motion. The study of the tumbling of fuel elements will be extended to establish a meaningful foundation for the ablation analyses.

Preliminary arc-jet tests have been completed to establish proper testing procedures and to give qualitative indications of fuel element ablation characteristics. Additional tests will be accomplished this fiscal year and during FY 64. The information gained will also be applied to establishing a description of the properties of fuel materials. A literature search has been completed and enthalpy characteristics has been established. Emissivities, oxidation effects, viscosity, and surface tension measurement tests will be initiated and continued throughout FY 64. The effect of the cladding on fuel elements ablation will also be investigated.

Analysis and experimental work is planned to allow conclusions to be established regarding particle breakup during reentry. A study has been completed which shows that little radioactivity is removed if all the gaseous and volatile fission products are stripped out of the fuel. Extended studies of particle fallout will be made during FY 64 utilizing newer trajectory data and particle generation rates.

VII. FUTURE SPACE MISSIONS

To date, the Aerospace Safety Program has been geared to provide adequate nuclear safeguards for the entire Flight Test Program and operational systems. As our technology advances and manned space flight activity increases, requiring advanced nuclear power systems, it will become necessary to expand the scope of the Aerospace Safety Program. Studies and experimental activities must continue to be performed to ensure that our astronauts will not be subjected to undue nuclear hazards while they are completing their space missions. As more powerful reactors are developed for these missions, the Aerospace Safety Program must provide, with a high degree of confidence, the nuclear safeguards necessary to ensure that these missions are completed safely. Special emphasis will be given to the problems associated with manned space exploration, space stations, and lunar bases which utilize nuclear power sources.

VIII. PROGRAM SCHEDULE

The planned activities of the Aerospace Safety Program through fiscal year 1970 are shown in Figure 5. The Program has been planned to establish that adequate safety considerations are an inherent part of the sequence of events which occur from the loading of the reactor with fuel through eventual disposal for SNAP 10A, 2, and 8 reactor systems. Other advanced reactor systems which will come into existence as a part of the communications satellites, space stations, planetary bases, and other advanced concepts will be similarly investigated and defined.

The schedule of effort for the Aerospace Safety Program activities must necessarily be flexible to absorb perturbations in the required work created by significant design changes and by the results of tests and analyses performed within the program itself. In all instances, the determination of possible hazards resulting from nuclear excursions, reactor history during reentry, and fuel element history after release to the atmosphere will be simultaneously pursued. This effort will first be directed to the SNAP 2/10A configuration, then to SNAP 8 and subsequently to the advanced reactors that will be developed for space. The specific aspects of each system which must be analyzed and described will be determined by the individual reactor systems and their applications. The Aerospace Safety Program is therefore an all-inclusive and dynamic program, established to ensure that all phases of SNAP safety are investigated and verified from the present stages of development through the continuing phases of operational SNAP systems.

Figure 5. Aerospace Safety Program Schedule (Sheet 1 of 2)

Figure 5. (Sheet 2 of 2)

APPENDIX A
AEROSPACE SAFETY PROGRAM BUDGET

	FY 1963 (000)	FY 1964 (000)	FY 1965 (000)
Project Engineering	110	113	170
Critical Configurations Tests	141	106	250
Mechanical and Thermochemical Effects	249	453	550
Reactor and Excursion Tests	2,046	1,573	2,500
Fission Product Release Studies	168	-	200
End-of-Life Shutdown Devices	100	175	200
Reactor Reentry Separation and Fuel Element Ejection	325	467	550
Fuel Element Burnup and Fission Product Dispersal	<u>111</u>	<u>563</u>	<u>580</u>
Total	3,250	3,450	5,000

APPENDIX B

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