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SERIES A

MASTER

SNAPSHOT NUCLEAR FLIGHT

SAFETY PROGRAM

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ABSTRACT

A nuclear flight safety program for the SNAPSHOT program is presented as a preliminary plan. The program is intended to be compatible with the Atomic Energy Commission's responsibility for nuclear materials used in the SNAPSHOT satellite launch series.

Analytical and experimental safety studies are described under three headings: Nuclear Studies, Radiological Safety Studies, and Engineering Design Studies. Program milestones are listed and a description of continuing studies is appended.

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I. INTRODUCTION AND SAFETY CRITERIA

A. SNAPSHOT PROGRAM

The general SNAP program concerns the development of long-lived auxiliary electrical power generators for satellites and other applications using nuclear energy from both radioisotope decay and nuclear reactors. Nuclear reactor units for this application under development at Atomics International for the Atomic Energy Commission include a 500 watt electrical system designated SNAP 10A, a 3 kw system (SNAP 2) and a 30/60 kw system (SNAP 8). The 500 watt and 3 kw systems are designed for Air Force Requirements, and the 30/60 kw SNAP 8 system will meet requirements for NASA programs including electrical propulsion. Figures 1, 2, and 3 are conceptual illustrations of these electrical power supplies in their flight configuration. The SNAP 10A system circulates NaK eutectic to thermoelectric converter elements with an electromagnetic pump, and thus has no moving parts except the fluid. The SNAP 2 and 8 systems both use mercury vapor Rankine cycle turbogenerators.

The initial orbital flight test program for the SNAP 2 and 10A systems has been designated SNAPSHOT.¹ As currently planned, this program consists of two SNAP 10A flights in 1963 and two SNAP 2 flights in 1964. The initial two flights in the SNAPSHOT series will use a SNAP 10A in an Agena-B MIDAS configuration. The Agena-B will use an engine restart to circularize a 2000 mile polar orbit. The system will use an Atlas booster and be launched from the Pacific Missile Range.

B. SNAP DEVELOPMENT

Development of the SNAP reactor systems has progressed through initial critical assemblies, zero-power tests, and full-power nuclear prototype operation over long periods. Test power operation with flight electrical generation equipment is currently starting for the SNAP 2 system. Test operation of the developmental and flight model APU's will be carried out in the SNAP Environmental Test Facility (SETF) at the Santa Susana Field Laboratory. This facility is illustrated in Figure 4. The vault structure in addition to providing reactor containment and shielding, houses test equipment to simulate the vacuum, and effective temperatures of a space environment. Non-nuclear vibration, shock,

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SNAP 10A

POWER — 500 Watts
TYPE — Thermoelectric Conversion
WEIGHT — 550 Pounds (Unshielded)
LIFE — 1 Year
AVAILABILITY — 1963

Figure 1. SNAP 10A Flight Configuration

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SNAP 2

POWER — 3 KW Electrical
WEIGHT — 600 Pounds (Unshielded)
LIFE — 1 Year
TYPE — Mercury-Turboalternator
AVAILABILITY — 1964

POWER — 3 KW Electrical
WEIGHT — 600 Pounds (Unshielded)
LIFE — 1 Year
TYPE — Mercury-Turboalternator
AVAILABILITY — 1964

Figure 2. SNAP 2 Flight Configuration

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Figure 3. SNAP 8 Flight Configuration

SNAP 8

POWER — 30-60 KW Electrical
WEIGHT — 50 Pounds/KW
LIFE — 10,000 Hours Operation
TYPE — Mercury-Turboalternator
AVAILABILITY — 1965

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Figure 4. SNAP Environmental Test Facility (SETF)

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and atmospheric tests of the flight machines will be conducted in the Environmental Test Laboratory, Building 027.

Nuclear and non-nuclear acceptance tests will be conducted on delivery systems in a special facility to be constructed soon.

Critical assemblies, zero-power tests, and some nuclear safety tests are carried out in Building 373 at the Santa Susana site, Figure 5, and nuclear prototype operation (SER) in Building 010, Figure 6. Shield development is planned for Building 028, Figure 7.

Figure 8 illustrates the design of the prototype SNAP 2 reactor core currently undergoing test in the SETF. Although this is a second generation, flight design core, results of the analytical and test programs are expected to lead to further design refinements. The SNAP 10A system is being designed to use an identical core but it will not require control drum motion after the startup period. A complete description of this test core and its operating conditions is given in Reference 2.

C. SAFETY PROGRAM

An extensive safety program has been initiated for the development of the SNAP 2, 10A, and 8 projects. This general program is carried out to investigate the safety requirements for a variety of mission applications for SNAP units including possible ground startup coupled with launch phase operation and low perigee orbit operation with associated short time interval prior to re-entry. Results of the program's initial operational safety analyses have been reported in References 3 and 4. Initial evaluations of re-entry hazards are given in Reference 5.

At the present time, the SNAPSHOT flight safety program is most concerned with the initial planned application - orbital startup use of the SNAP 10A thermoelectric converter power supply in applications where the orbital life of the satellite is so great that the fission products decay before re-entry.

The hazards due to the liquid metal and other chemicals present in the SNAP systems can be accommodated within the exclusion radii and range safety facilities necessary for the chemical propellents in the vehicle system. The only additional hazard of significance would involve the release of fission products

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Figure 5. Experimental Development Building

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Figure 6. SNAP Experimental Reactor Building

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Figure 7. Shield Test Experiment Facility

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Figure 8. SNAP Development Reactor (S-2-DR)

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generated during a reactor power excursion. Although it can be shown that such a release does not seriously alter the magnitude of missile abort hazards, the prevention of accidental criticality remains as the principle requirement for radiological safety.

The principle tasks necessary to obtain the program goals consists of the preparation of operating procedures in compliance with range safety practices, training of operation personnel, the analyses of the possibility and consequences of accidents during the operating periods, the specifications of safety equipment and system design safety features, the execution of experimental and test programs to yield safety information, and the preparation of reports for liaison with operating and approval agencies.

Of prime importance in the safety program is the acquisition of environmental data. Early generation and analysis of launch vehicle data, flight path data and reliability, vehicle abort data, and the possible effects on the reactor system of vehicle launch aborts will allow the development and testing of nuclear flight systems with built-in, inherent safety.

D. SAFETY CRITERIA

The goal for the SNAPSHOT flight safety program is to accomplish the operational procedures within existing satellite vehicle launch safety restrictions. Presently accepted launch pad and range safety practices will be retained through the establishment of adequate nuclear safety practices and nuclear system design.

Following manufacture, tests of the SNAPSHOT unit's electrical generation apparatus will use an electrical heater to simulate reactor operation. Actual reactor operation will be restricted to short "zero-power" runs required for fuel loading and reflector-control element calibration. Consequently, fission products generated during operations at the Atomics International facilities are so decayed that shipping and vehicle integration procedures will require precautions pertinent only to uranium handling, liquid metal coolant chemical hazards, and the prevention of accidental criticality.

The reactor will be launched in a shutdown condition. The nuclear design, combined with safety features incorporated into the control system, will prevent

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the reactor from obtaining a critical configuration for any credible launch abort and impact situation. The high perigee orbits planned for the SNAPSHOT flights will allow operation of the reactor power supply for a design life of one year followed by greater than 300 year decay of the fission product radioactivity. Verification of the orbit parameters will be required before orbital startup is signaled, thus assuring that satellite re-entry will involve no radiological hazard.

At time of launch direct radiation from the SNAP 10A core will be less than 20 mr/hr at the surface. After 300 years, radiation from a complete core will be less than 0.4 mr/hr at 1 meter.

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II. NUCLEAR STUDIES

A. DISCUSSION

1. Scope and Safety Goals

a. Criticality Investigations

The present concept of protection against unscheduled reactor operation during shipment, handling, launch, orbital flight, and re-entry is based on mechanical arrangements or scram actions which will keep the reactor subcritical in all accident situations. Because the postulated accidents could introduce a variety of environments: impact forces, thermal effects, corrosion effects, chemical energy releases, and immersion in media of various reflector-moderator characteristics, a fundamental investigation of environmental reactivity effects is needed to guide the system design.

In addition to this investigation, techniques to modify the reactor core design to obtain a minimum reliance on mechanical scram action must be developed. Ideally, the nuclear design should be so sophisticated that release of the spring-loaded safety elements results in $k_{eff} < 1$ for the worst combinations of the above accident situations. If the SNAPSHOT flights occur before such an ideal design is obtained, additional scram devices in the form of destruction ordnance and the like must be developed.

b. Power Excursion Analyses

The technique of analog computer simulation for the reactor and Power Conversion System (PCS) will be used to predict power and thermal transients produced by assumed control and safety equipment failures. Combined with the radiological studies (Section III), these results will be used to evaluate the consequences of credible accidents. These accident consequences are in turn used in two ways: to specify the emergency protective equipment and procedures, and to provide a "risk" evaluation for the project. Portions of both the criticality investigations and the excursion analyses will be used to design the control systems, scram systems, shipping equipment, etc.

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2. Nuclear Analysis Techniques

a. Digital Computation

The development of techniques for accurate prediction of the reactivity insertion due to accident environments principally involves obtaining accurate parameters for machine calculation input.

Analytical studies are performed using a wide variety of both new and established digital computer programs. General surveys are made with AIM,⁶ a one dimensional, multigroup diffusion theory code. Particular details of thermalization phenomena are investigated using ZOOM,⁷ and ULCER,⁸ both one dimensional diffusion theory codes allowing upscattering in selected "thermal" groups. In addition, SNG⁹ and CURE¹⁰ are employed for studying details of reflector and control worths. Calculations are normalized to results of SNAP critical experiments which include clean geometry assemblies as well as mockups of proposed configurations.

A portion of the transient behavior studies will be done with AIREK.

b. Analog Simulation

To obtain transient reactor power and temperature behavior for the reactor (or entire APU) system, a series of linear and nonlinear differential equations is used as a mathematical reactor (or APU) model. Employing the computer's amplifiers, relays, integrators, servomultipliers, etc., an electronic analog is constructed. Function generators may then be used to program reactivity, coolant flow, thermal effects, etc., in a fashion representing the real situation under study.

3. Approach to Minimize Criticality Hazards

One of the most effective environmental materials available to replace the reactivity of the beryllium control-reflector apparatus is water. Maximum reactivity addition effects of other reflector-moderator materials can be machine-calculated based on measured water effects.

The reduction of the criticality hazard associated with submerging SNAP reactor cores in water is most logically approached by investigating the inherent response of SNAP cores to reflector configuration. Thus, studies will be made to ascertain methods of increasing the difference in reflector worth of beryllium

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and water. This difference is described in general terms by noting that beryllium returns both fast and thermal neutrons quite well whereas water is primarily a thermal neutron reflector.

It is obvious that configurations which emphasize sensitivity to fast neutron reflection and minimize sensitivity to thermal return will aid in reducing the water submersion criticality hazard. Configurations of this type include high L/D geometries and designs incorporating thermal neutron poisons at the core-reflector interface or distributed through the core. In addition, there exists the theoretical possibility of selecting thermal neutron "poisons" which are more deleterious to the spectra characteristic of water than spectra characteristic of zirconium hydride. This last method is, of course, extremely difficult if possible at all.

The two basic approaches above, arbitrarily categorized as geometric (L/D studies) and spectral (poison usage), are aimed at "inherent" hazards reduction; i. e., the use of inherent nuclear characteristics to produce a desired differentiation between the operating beryllium reflected configuration and the abnormal water reflected configuration. There exists a third approach to the problem, that of using external mechanical or chemical shutdown devices. These include insertion of poison or removal of fuel by mechanical contrivances, and chemical poisoning schemes using physical properties of the materials (boiling, subliming, etc.) for removal prior to or during startup following successful orbiting. Upon abort, the removal is prevented, again by the physical properties of the poison material.

In addition to the reflector-moderator submersion problem, the critical assembly data will be used to explore analytically the effects of core dimension and configuration changes due to impact, thermal, and chemical effects.

B. GEOMETRIC STUDIES

1. Analytical Program

Preliminary studies have been made with regard to the effect of geometric configurational change in SNAP systems. Figures 9 and 10 give a summary of these studies. As can be seen, increasing L/D and the resultant increase in reactivity investment in the beryllium reflector lead to possible subcritical

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Figure 9. S-2-PR-1 Weight Survey (Weight Includes Reflector Less Piping and Structure)

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Figure 10. Reactivity Contained in Reflector

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systems when reflected by water. It is currently indicated that a nonoptimum L/D ratio will be required, resulting in a weight penalty. These analytic studies will be continued in conjunction with experimental studies to verify the predictions.

Further studies will be undertaken to include flooding (water inside) of the core. L/D ratio changes could preserve subcriticality for the case where water immersion is followed by replacement of the NaK with water in the inter-fuel coolant passages. Preliminary data indicates an excessive weight system would result; other methods, described below, may be used in combination with geometry changes. With experimentally verified calculational models, reactivity effects due to impact dimensional changes may then be predicted.

2. Experimental Programs

Critical assemblies will be made to verify and improve theoretical predictions. These will include clean geometry cores with representative L/D variations in the range of interest. These experiments, although not representing precise SNAP mockups, allow improvement of the theoretical model.

Those configurations deemed most applicable to SNAP systems will be mocked up in detail for experimental studies.

The general experimental scheme used is illustrated schematically in Figure 11.

C. THERMAL POISON STUDIES

1. Analytical Program

As indicated, various thermal poisons can be used to reduce core sensitivity to thermal neutron return. These include both "interdicting" poisons (those that intercept thermal neutrons at the core-reflector interface) and spectral poisons (those that preferentially absorb water spectra neutrons as opposed to hydride spectra neutrons). Table I summarizes the preliminary calculated results of interdicting poisons in a S-2-DR core configuration.

Although these results have not been experimentally verified (S_n code results), they indicate that a cadmium interdiction poison results in both an adequate excess reactivity for operation ($Cd + Be - NaK$) and a subcritical core

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Figure 11. Water Submersion Scheme

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for the water immersion-water flooding case ($\text{Cd} + \text{H}_2\text{O} - \text{H}_2\text{O}$). If experimental results do not verify this for the S-2-DR core, L/D ratio modifications should yield an appropriate system.

TABLE I

ESTIMATED REACTIVITIES FOR VARIOUS CONDITIONS IN S-2-DR

Core \ Reflector	Be	Cd + Be	H ₂ O	Cd + H ₂ O	Bare Core
NaK	1.040	1.028	0.988	0.907	0.858
H ₂ O	1.127	1.115	1.070	0.989	0.956

A decision to conduct a study of spectral poison will await the evaluation of the tests discussed above. The difference¹¹ in characteristic spectra for water and hydride moderated systems is shown in Figure 12.

2. Experimental Program

The same general approach will be used as described in Section II-B. Selected clean geometry configurations will be tested in water assemblies to verify predicted results and to improve analytical models.

If this experimental effort fails to confirm the expectation of a practical-weight core configuration, an investigation of possible mechanical or chemical removable poison schemes will be undertaken. Telemetry or vacuum-operated removal of poison materiel (or insertion of fuel) from a re-entrant core thimble, constructing the core in halves, vacuum boiling or sublimating poisons, reducing excess reactivity by "burnable" poisons (poison removal by neutron capture), etc., are examples of possible methods which could be combined with the techniques described above.

D. THERMAL AND CHEMICAL EFFECTS

Digital computer techniques may be used to calculate reactivity insertion due to temperature effects such as LOX immersion, heat input due to propellant fires, and heat generated by the fission process. Reactivity effects due to

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Figure 12. Neutron Spectra in Water and Zirconium Hydride

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chemical interactions between the core structural materials, reactor coolant, propellants, sea water, will also be investigated with the digital codes.

Experimental measurement of the prompt and delayed temperature coefficients of reactivity have been carried out in the normal course of prototype reactor operations. If further criticality measurements are required to predict the effects of the presence (or corrosive removal of) chemical agents in the nuclear system, the tests can be carried out in conjunction with the poison investigations suggested above.

E. POWER AND THERMAL TRANSIENT BEHAVIOR

1. General Studies

The results of digital computer code and experimental studies of the reactivity presented by external agents are commonly combined with analog studies of generalized reactivity step and ramp insertion effects. Examples of such generalized analog studies are shown in Figures 13 and 14 which apply to the S-2-DR prototype reactor. Such studies will be performed for the flight system designs with particular emphasis on possible reactivity feedback effects and physical effects on the satellite launch vehicle. These studies, as well as those listed below, may indicate desirable design changes or need for additional critical assembly measurements.

2. Combined Studies

In distinction to fixed nuclear power installations, an increased emphasis on combination nuclear-non-nuclear accidents is required for the SNAP flight reactors. Both the initiation and augmentation of nuclear power excursions by launch vehicle accidents become important due to the large energy storage of the propellant chemicals. An example of such an accident study might require analog representation of a ramp reactivity insertion due to cooling by LOX immersion, mechanically forced control element insertion, and delayed RP-1 immersion, followed by fuel temperature heat transfer effects from both nuclear heat and an external LOX-RP-1 fire.

A search for maxima among such combinations (guided by credibility) will be carried out to provide a basis for the radiological studies in Section III.

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Figure 13. Power and Temperature vs Time for 2 cents/sec Ramp Insertion at Startup (Fuel Temperature Coefficient = 0.1 cent/°F, Upper Grid Plate Coefficient = -0.1 cent/°F)

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Figure 14. Power and Temperature vs Time for One Dollar Step Insertion at Startup

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3. Impact Effects Experiments

As a portion of the experimental program under Launch Abort Experiments, Section III-B-2, reactivity insertion effects due to impact forces will be studied. High speed photography and other measurement techniques will be used to determine:

- a) Relative positions and velocities of control system and core components during impacts
- b) Post-impact geometries
- c) System damage and chemical effects.

Based on these studies, further experiments may be required.

F. SUMMARY OF NUCLEAR STUDIES

<u>Area of Study</u>	<u>Status</u>
Geometric Studies	Preliminary analyses completed, experimental studies starting
Thermal Poison Studies	Computer runs started, experimental studies starting
Water Submersion Effects	Preliminary calculations completed, experimental measurements in progress
General Transient Behavior	In progress
Combined Effects Transients	Await non-nuclear test results (Section IV)
Impact Effects Experiments	Proposal in preparation

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III. RADIOLOGICAL SAFETY STUDIES

A. BASIC ANALYTICAL STUDIES

Preliminary analytical studies have been performed in the areas of nuclear accident hazards, radiological doses, launch abort contamination due to radiological, toxic and chemical agents and atmospheric contamination due to re-entry burnup and dispersal of SNAP fuel elements. The preliminary data and results have been released in several pertinent reports (References 3 to 5 and 12 to 16).

1. Nuclear Accident Hazards

As described in Section II, digital and analog computer study results will be used as input data for analyses of the radiological consequences of nuclear accidents. This data will allow determination of the total energy release, the system temperatures, and the resulting fission product quantity and quality. Several hazard parameters may then be calculated directly as a function of the nuclear system behavior: prompt gamma and neutron dose as a function of distance and shielding, decay of the ensuing radiation levels, etc.

2. Radiological Doses and Contamination

In connection with the engineering-design studies and the experimental launch abort studies listed in this section, the power excursion data will be used to predict the release of the fission products and the resulting contamination levels and possible inhalation doses in nearby areas.

Each operational phase for the APU such as, transportation, assembly, checkout, vehicle integration, launch, and re-entry, will be characterized by a set of maximum credible accidents. The possible inhalation doses and contamination levels will be calculated (with the usual diffusion equations) for the appropriate source containment, source dilution, accident site, release height, and meteorological parameters. Several digital computer codes (CLOUD, D-43, etc.) are used for these calculations.

Radiation levels and possible contamination or chemical toxicity problems to be encountered in the normal (accident-free) handling of the SNAP units will also be analyzed. These studies combined with the accident studies will define

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permissible "zero-power" test runs, "contact maintenance" practices, transport methods, launch site facility requirements, etc.

Preliminary results for these types of analyses are given in References 3 and 15.

3. Effects of Launch Abort Environment

In addition to the nuclear accident, launch vehicle abort interaction studies described in Section II, the consequences in the form of toxic chemical concentrations, of launch pad abort accidents not involving nuclear power excursions will be examined with the calculational methods used for the radiological studies. The principle chemical agents involved are:

- a) Uranium-235 zirconium hydride
- b) Sodium potassium alloy eutectic
- c) Lithium hydride
- d) Unsymmetrical dimethyl hydrazine
- e) Fuming red nitric acid
- f) RP-1 (kerosene)
- g) Liquid oxygen
- h) Beryllium and beryllium oxide
- i) Mercury (SNAP 2 only)

Interactions of these chemicals, besides producing toxic airborne material, will result in damage to the APU, vehicle system, launch pad and environs due to explosions, fires, impact forces, overpressures, etc. Analytical investigations of this chemical system must be strongly based on experimental data. Salvage practice, chemical hazard monitoring, launch pad (or ground impact area) reclamation, and general launch and handling practice information will be obtained.

B. BASIC EXPERIMENTAL STUDIES

Preliminary experimental studies have been performed in the area of re-entry burnup and dispersal of SNAP fuel elements. The reference data and results have been released in several pertinent reports (References 17 to 19).

1. Fission Product Release Studies (Laboratory)

Experiments are to be performed on slugs of SNAP fuel elements to determine the types and percentages of fission products released under various

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transient temperature conditions. The temperatures used in laboratory apparatus will simulate the possible heat inputs expected from various launch abort fires. The low-level fission product inventories used in the fuel samples will have the quality of power excursion fission products. In addition, an experiment will be performed in which the temperature history expected during re-entry of a SNAP fuel element will be simulated with a slug of long-irradiated SNAP fuel. The type and percentage of fission products remaining with the slug will be analyzed to study the atmospheric and fallout contamination due to re-entry heating.

2. Launch Abort Studies

Experiments will be performed to determine the possible effects of launch abort environments on the SNAP systems. Such experiments will include shock, impact and explosives tests on SNAP system mockups. Temperatures and heat transfer values will be measured during tests which simulate the various types of fires possible for launch aborts and/or accidents. These tests will be performed on mockups of the entire SNAP system, models of the various subsystems and components and full size fuel elements. The chemical system listed in Section III-A-3 will be investigated.

Information expected from these tests will include:

- a) Mechanical and thermal effects on control system, core vessel, and reactor core
- b) Identities and quantities of toxic materials released
- c) Dilution and lofting of released toxic materials (including possible fission products) due to thermal updraft and reaction gas evaluation effects
- d) Hazard effects from ground fallout or residues.

3. Re-entry Heating

A fundamental investigation of re-entry heating phenomena pertinent to SNAP reactor systems was undertaken by AVCO RAD for the Air Force Ballistic Missile Division in the Spring of 1960. The results to date are summarized in References 20 and 21.

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Laboratory re-entry simulation has been, or will be, carried out by shock tubes, arc-jets, and high-velocity guns. The measurements obtained will involve heating rates and heat transfer, construction materials and their degradation products, shape factors, oxidation and nitriding, ablation particle sizes, etc. A simultaneous analytical program is developing parameters for re-entry heating codes, studying vehicle altitude stabilization, determining orbital re-entry paths, evaluating the effect of air stream exposure delays, and studying test designs.

Basic investigations of SNAP 2 and 10A fuel element re-entry heating characteristics have been carried out by the Plasmadyne Corp. (References 17 to 19). These tests, and further work planned by Plasmadyne and the Stanford Research Institute, are described in Appendix A.

C. FLIGHT SYSTEM SAFETY EXPERIMENTS

1. Fission Product Field Release Studies

These studies will determine the type and quantity of fission products released from a SNAP type fuel element under various heating and air exposure conditions and the resulting meteorological dispersion on a field test range. The release conditions will include cladding failure, fuel meltdown, and fuel vaporization. The temperatures associated with such failures will be chosen to correspond to the fires, explosions, and re-entry heating that might be possible during SNAP re-entry. Evaluation in respect to quality of fission products, i. e., burst or power inventory, will also be made. Particle size, specific activity and the contamination concentration in respect to distance from release point will also be evaluated during these tests.

2. Ballistic Trajectory Re-entry Tests

These studies are designed to demonstrate the re-entry burnup capability of SNAP fuel elements in actual missile re-entry tests. Also, the release mechanisms, i. e., reactor separation and fuel element ejection systems, will be tested to determine if fuel elements can be released to the atmosphere at sufficient altitude during the re-entry trajectory to assure re-entry burnup and high altitude dispersal of the SNAP fuel elements. In addition, re-entry heating code validity will be checked by use of the experimental re-entry heating data obtained from these tests.

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Depending on the available ballistic trajectories, samples will be included in the flight tests to measure ablation and temperature characteristics of beryllium, BeO, zirconium, ZrH, Hastelloy C, Hastelloy N and lithium hydride during re-entry. The ablation characteristics of the CRU, reflector assembly, NaK piping, reactor grid plates and core can materials will be evaluated. Several types of experimental difficulties are inherent in the flight tests: the high costs require multipurpose rocket flights resulting in nonoptimum trajectories, schedule problems, interference problems, etc., because the SNAP tests will be only one participant. In addition, measurements of burnup from tracking ships or aircraft may be of such marginal practicality that land impact may be required.

3. Shipping and Handling Mockup Tests

These tests will determine the ability of the SNAP system and its shipping container to withstand the possible shipping and handling accidents. The tests will be performed on the SNAP system within the shipping configuration as well as separately. Also, the possible handling accidents will be evaluated under simulated conditions. A portion of these tests will be performed in conjunction with the launch abort experiments as described in Section III-B-2.

D. PROCEDURAL RADIATION SAFETY PLANNING

1. Personnel Training Program

The objective of the personnel training program from the standpoint of radiation safety will be to familiarize the operations personnel with the operational safety procedures and emergency procedures and with the reasons for such procedures. The main concern of this study will be to formulate and conduct a training program in respect to SNAP safety procedures for personnel. Use of one of the mockup systems as a training aid is probable.

2. Operational Procedures

Safety contributions to the preparation of detailed operational procedures will be based on the results of all of the analytical and experimental safety programs. As the procedures are established for each step in the normal operational sequence, the accompanying safety implications must be examined and explained. In addition, complete emergency, salvage, and decontamination procedures will be prepared. These procedures will cover the APU handling from

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shipment to orbital startup and will constitute a portion of the documentation submitted to approval and review agencies.

It must be emphasized that the preparation of the operational procedures is a joint effort between the launch vehicle and nuclear contractors. In order to develop radiological information required for the procedure preparation, early compilation and analysis of vehicle handling procedures is necessary.

3. Safety Report Preparation

Section V lists a total of 13 safety reports and three films planned for the SNAPSHOT program. The reports, in conjunction with reports by the vehicle contractor and others, will be submitted to review and approval agencies within, or advisory to, the USAEC, USAF, USN (Range Safety), and others. Complete identification of all of these agencies has not been established. The listing in Section V is intended primarily for AEC review.

The goal of the safety report preparation effort is to accurately define the hazards for the SNAPSHOT flights, establish the intended safeguard methods, report the progress of the safety test and analytical programs leading to demonstration of effective hazard control, and to obtain the contributions of review authorities toward the program safety.

4. Radiological Instruments and Equipment Evaluation

Based on the results of the analytical and experimental safety programs, the type, number, and locations of radiological instrumentation, personnel protective and monitoring equipment, decontamination equipment, etc., necessary during the SNAP operational sequence will be specified. This specification will be based upon the range safety, SNAP safety and off-site safety requirements.

5. Health Physics Program Requirements

In cooperation with the launch facility personnel, an operational Health Physics program will be instituted. Environmental sampling, routine surveys, hazard control procedures, personnel monitoring, reporting, etc., will be planned. The general nature of the Health Physics program will be based on the hazards studies described in this report.

6. Nonradioactive Safeguard Requirements

Information on the procedures for controlling hazards due to liquid metals, beryllium toxicity, mercury spills, and other chemicals in the SNAP

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systems will be developed and provided for LMSD, test program subcontractors, AFSWC, and the launch site personnel. This material will also appear in operating manuals, emergency procedures, decontamination procedures, etc.

E. SUMMARY OF RADIOLOGICAL SAFETY STUDIES

<u>Area of Study</u>	<u>Status</u>
Nuclear Accident Hazards	Preliminary calculations completed
Radiological Doses and Contamination	Preliminary calculations completed
Effects of Launch Abort Environment	In process at AI
Launch Abort Studies	Proposal in preparation by subcontractor
Re-entry Heating Studies	In progress
Fission Product Field Release Studies	Proposal made
Ballistic Trajectory Re-entry Tests	Suggested
Shipping and Handling Mockup Tests	Proposal in preparation by subcontractor
Personnel Training Program	Not initiated
Operational Procedures	Preliminary work only
Safety Report Preparation	4 reports issued, 1 safety film in progress
Radiological Instruments and Equipment	Not initiated
Health Physics Program Requirements	Not initiated
Nonradioactive Safeguards Requirements	Not initiated

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IV. ENGINEERING DESIGN STUDIES

A. PROGRAM REQUIREMENTS

SNAP 2 and 10A design, fabrication and testing schedules for complete reactor systems are set in References 22 and 23. These schedules will require analytical efforts and component development efforts to be carried out in advance of complete system tests.

For the SNAP 10A system development, 8 individual systems will be built and tested. These include: 1 non-nuclear mockup system to test power conversion components, 2 non-nuclear flight-system mockups to be used by LMSD for vehicle compatibility studies, 2 non-nuclear mockup flight systems for environmental simulation and performance qualification tests at AI, and 3 nuclear flight machines, one of which will undergo qualification testing at AI and the other two used for the SNAPSHOT flight tests.

The SNAP 2 development program consists of a similar series of test systems, the first of which, S-2-DS, is currently undergoing initial nuclear operation in the SETF.² Safety studies concerning the developmental apparatus must then be scheduled to be compatible with the prototype development schedules.

In the establishment of the schedule and program for safety equipment development, it is necessary to provide functional descriptions for the equipment; a continuing reassessment of these functional requirements will be carried out as safety program data accumulates. With particular reference to the nuclear tests (Section II) and liaison with the vehicle contractor or other agencies, functional requirements may change.

B. REACTOR CONTROL SYSTEM EQUIPMENT

1. Telemetry Scram System

a. Description

The primary scram or safety element separation system for the reactor from the launch time lasting through initial operation must be under ground control. Secondary scram systems will be operative when telemetry control is inoperative. Upon receipt of a ground signal via the satellite telemetry

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command receiver, the reactor must assume a configuration which remains subcritical when submerged in water. The scram system must withstand launch environment tests appropriate to a telemetry system, but with a higher order of reliability.

Credible launch accidents which cause failure of this system must be of a class which cannot cause failure of the Launch Abort Shutdown System described in Section C-1 below.

b. System Tests

When controlled by cable-transmitted signals (and snubbers), this scram system will be the principle test safety element control for the SNAP 2 and 10A nuclear ground test reactors operated in the SETF. The system will also be represented on the non-nuclear mockup systems and undergo tests beginning March 1962. System tests with the prototype flight machine must verify the system adequacy by the flight delivery date. Tests of telemetry equipment will presumably be carried out by the vehicle contractor.

c. Component Design and Development

To be ready for fabrication of the mockup and flight system reactors the component development must finish by the November 1961 milestone (Section V). This will also allow fabrication of the initial control assembly for SNAP 2. A portion of the component testing will be done as a part of the nuclear studies (Section II).

2. Safety Element Drive

a. Description

A flight safety element drive system will be required. The exact nature of the drive cannot be specified until the nuclear and design studies have continued for some time. The general system requirements are:

- 1) Move elements from fully scrambled position to launch (cocked) position after personnel evacuation
- 2) Fully insert elements upon orbital startup telemetry command
- 3) Compatible with telemetry scram (Section B-1)

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- 4) Remove elements to "out" positions in case of mission "scrub" (reverse of No. 1) to obtain sufficient shutdown for personnel approach.

b. System Tests

That portion of the safety element drive that is included in the flight apparatus must be included in the SNAP 10A and 2 non-nuclear mockup system tests beginning February 1962.

c. Component Design and Development - November 1961

(Similar to Section B-1, Telemetry Scram System)

3. Power Shutdown System

a. Description

In the absence of complete verification of high altitude re-entry burnup predictions, the reactor must be shut down upon the end of the APU's useful life to allow decay of the fission products prior to re-entry. A type of passive, high reliability thermomechanical device actuated by temperature decay to accomplish this has been suggested. Whatever device is used should have the following properties:

- 1) Require no power
- 2) Be reliable even after APU lifetime
- 3) Cannot unlatch spuriously.

The need for a power shutdown device diminishes considerably if only missions such as MIDAS are considered where the expected orbital lifetime is in millions of years; however, for lower perigee orbits (planned or unplanned), the device will allow APU fission product decay.

b. System Test

Although verification of the operation of this device is a small portion of the system tests, the shutdown system must be shown to stay "unscrammed" during the environmental, mechanical, and nuclear tests of the developmental APU's. As in Section B-1-b, these tests begin March 1962 and must end October 1962.

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c. Component Design and Development

(Similar to Section B-1-c; ready for system fabrication on November 1961).

4. Re-entry Shutdown Separation System

a. Description

For the SNAPSHOT flights, impact of the APU anywhere outside the controlled-access range safety area, must be accompanied by positive action to produce irreversible subcriticality. This must apply to the impact itself or any ensuing action by natural forces. To obtain this goal, both for orbital re-entry or any launch vehicle failures after the aerodynamic heating shields have been ejected, the action of re-entry heating must be employed.

As presently envisioned, two separation processes are used to provide an irreversible shutdown:

- 1) Separation of the core vessel from the reflector assembly, radiation shield, and NaK piping
- 2) Ejection of the individual fuel elements from the core vessel.

Design information for this system will be obtained from the re-entry simulation studies described in Section III. Initial results of these tests and analytical re-entry heating analyses performed at AI and AVCO RAD^{20,21} will be used to fabricate actuation mechanisms for laboratory heating tests.

Providing fusible links and other devices in the reactor mounting apparatus can accomplish shutdown for orbital re-entry and certain classes of ballistic re-entry, but the telemetry and launch abort shutdown systems must be made effective for orbit injection failures prior to separation of the aerodynamic heating shrouds.

b. System Tests

Structural design features imposed by this requirement are included in portions of the non-nuclear mockup control systems beginning test March 1962. Special system tests may be included in the re-entry flight tests described in Section III.

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(1) Component Design and Development

Component laboratory tests must yield a basic design ready for test system fabrication November 1961.

C. EXTERNAL EQUIPMENT

1. Launch Abort Shutdown System

a. Description

A lightweight explosive charge (or other device), capable of quickly rendering the reactor core irreversibly subcritical, and attached to, and/or jettisoned with, the aerodynamic heating shields, is actuated by the following conditions:

- 1) Vehicle explosion
- 2) Impact, incipient impact, or loss of altitude
- 3) Re-entry heating for second stage failures
- 4) Optional: telemetry signal.

Condition (1) necessarily leads to condition (2), and in this situation not only the telemetry system but the "destruct" system itself may be inoperative due to the vehicle explosion; however, these situations occur over evacuated areas (as controlled by the vehicle flight termination system). Condition (3) is discussed under Re-entry Shutdown System, above.

b. System Tests

Responsibility for operation of this system as a part of the flight vehicle would best be the vehicle contractor's. Tests of the "fuse" or actuation sensing devices should be carried out with the Agena static firing and other environment tests starting with the SNAP 10 flight system mockup about March 1962.

c. Component Design and Development

Because the launch abort shutdown system is likely to be an ordnance device, appropriate subcontractors are being investigated to develop the system. Fusing development tests should be complete by about March 1962 to allow the system tests with the completely assembled apparatus ready for final fabrication by about April 1962.

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2. Shipping Equipment

a. Description

A shipping cask will be necessary for the APU which will protect the contents from normal transportation shock and vibration and from water immersion. In addition, the cask must provide containment required by federal, state, and local regulations for the chemically hazardous materials as well as the low-level radioactivity.

A spacer sleeve fitted in place of the removed reflector will keep the reactor subcritical even if the outer container is breached in a transportation accident and the assembly falls in water.

A protective container for reflector assembly to preserve control calibration will also be required.

b. System Tests

Current plans are to ship a SNAP 10A non-nuclear flight system mockup to LMSD using this equipment (about July 1962). Prior to this date, "road tests" with the nuclear flight system test reactor to determine the effectiveness of preserving the nuclear calibration may be carried out. SNAP 10A nuclear flight system test checkout begins July 1962 and the road tests must be carried out after initial criticality. The entire system must be satisfactory by the flight machine delivery date. SNAP 2 equipment is required for mockup shipment October 1962.

(1) Design and Component Development

Any effect that the shipping equipment design has on the APU design must be established by the October 1961 fabrication start for the SNAP 10A flight system mockup machines and January 1962 for SNAP 2. Further completion of equipment development is not required before June 1962. Vibration and shock test apparatus used for the test reactors will also be used for the shipping equipment.

3. Control and Safety Element Mechanical Locks

a. Description

Mechanical retaining devices, held in place by a lock and key system, must prevent insertion of the control and safety elements in the event of crane

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accidents, etc., during the assembly, vehicle integration, and launch preparation periods. Materials of construction must not add significant reactivity. In general, the retaining devices must be so constructed that they are "stronger" than the control and safety element mountings.

b. System Tests

Actual employment of these devices will not be required until after the SNAP 10A flight system test critical assembly. Their use, and "system test" with this reactor will start about July 1962 (later with SNAP 2). Satisfactory performance should be demonstrated prior to flight reactor shipment. This demonstration will consist of a series of drop tests with mockup cores.

c. Design and Component Development

Initial design and development should be sufficiently definitive by October 1961 to allow final reflector system fabrication to begin for the flight system mockup and nuclear test and reactors.

D. SUMMARY OF ENGINEERING DESIGN STUDIES

<u>Area of Study</u>	<u>Status</u>
Telemetry Scram System Development Safety Element Drive	SER and S-2-DS ground systems tested, flight system designs beginning
Power Shutdown System	Preliminary design completed
Re-entry Shutdown Separation System	Preliminary design completed
Launch Abort Shutdown System	Preliminary study initiated
Shipping Equipment	
Control and Safety Element Mechanical Locks	Awaits system design information

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V. PROGRAM MILESTONES

A. REPORT AND PROCEDURES PREPARATION

1. SNAP 10A

Flight Safety Criteria Report	July 1961
Preliminary Flight Safety Report	July 1961
Accident Study (Hazards) Report	January 1962
Final Safeguards Report	July 1962
Flight Safety Procedures Report	September 1962
Completion of Flight Personnel Training	December 1962

2. SNAP 2

Preliminary Safety Evaluation Report	January 1960 (Issued)
Flight Safety Criteria Report	January 1962
Interim Flight Safety Report	January 1962
Accident Study (Hazards) Report	July 1962
Final Safeguards Report	July 1963

3. General

Topical Report: Safety Evaluation of SNAP Space Reactor Systems	September 1960 (Issued)
Re-entry Hazards Report	January 1962 (Issued)
Flight Safety Program Report	April 1961
Preliminary SNAP Safety Film	June 1961
Interim SNAP Safety Film	January 1962
Final SNAP Safety Film	June 1962

B. COMPLETION OF ENGINEERING STUDIES

Safety Criteria	June 1961
Flight Control System Safety Requirements	July 1961
Initial Re-entry Separation System Description	August 1961
Initial Flight Scram System Description	September 1961
Initial Launch Abort Shutdown System Description	October 1961
Shipping and Handling Equipment Initial Specifications	October 1961

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C. COMPONENT TEST COMPLETION

Core Immersion Nuclear Measurements	April 1961
Re-entry Separation Tests	September 1961
Flight Scram Equipment	November 1961
Launch Abort Shutdown System	December 1961
Shipping Equipment Environmental Tests	March 1962

D. SYSTEM TEST QUALIFICATION OF SAFETY EQUIPMENT

1. Flight Control and Scram System

Environmental Development

S-2-PSM-2 (Non-nuclear Component Test)	April 1962
S-10-FSM-1 and 2 (Non-nuclear Mockup)	August 1962
S-2-PSM-6 (Non-nuclear Component Test)	September 1962

Nuclear Tests

S-10-FS-1 (Test Flight Machine)	November 1962
S-2-PS (Nuclear Component Test)	April 1963

2. Launch Abort and Re-entry Separation Shutdown System

Environmental Development (Passive)

S-10-FSM-1 and 2	August 1962
S-10-FS-1	November 1962
Mockup System (Active)	December 1962

3. Shipping and Handling Equipment

Environmental Development (Shipment of Mockup Systems)

S-10-FSM-2	July 1962
S-2-PSM-6	September 1962

Nuclear Tests (Preservation of Reactivity Calibrations During Environmental Tests)

S-10-FS-1	July 1962
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APPENDIX A

POST-SNAPSHOT CONTINUATION SAFETY STUDIES

A. ARC-JET RE-ENTRY SIMULATION STUDIES

A series of three investigations of SNAP fuel element behavior in simulated re-entry heating conditions have been planned. Two of these studies have been completed and are reported in References 18 and 19.

The completed studies have determined the ablation properties of reduced-scale SNAP fuel elements during re-entry heating. The studies employed burnup rate measurements of fuel elements exposed to arc-jet exhausts under re-entry conditions. Experimental verification of calculated ablation energy values for the SNAP hydride fuel material has resulted. High-speed photographic studies have provided a clearer understanding of the mechanisms involved during sample burnup.

The results of the completed series of studies will be used to evaluate the feasibility of re-entry burnup and high altitude dispersal of full-scale SNAP reactor cores. Application of these results will primarily apply to SNAP missions involving low perigee orbits leading to orbital re-entry prior to fission product decay.

Both stable and tumbling re-entry of full-scale SNAP elements will be simulated in the forthcoming tests.

B. OXIDATION - IGNITION STUDIES

A subcontracted study of the fallout hazards from the high altitude burnup of fission-product-containing SNAP fuel elements is in progress at the Stanford Research Institute. The principle area of investigation concerns the ablation particle sizes and their oxidation. These studies will allow assessment of possible population dose levels by yielding information concerning biological half-life, critical organs, plant and animal uptake, solubility, upper atmosphere residence times, etc.

C. GROUND STARTUP ANALYSES

In preparation for SNAP missions which will require nuclear-electric power generation during the launch period, preliminary analyses of the radiation levels

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accompanying ground startup have been completed.³ A post-SNAPSHOT hazards study of this operating mode is planned. Because the expected levels at the normal launch exclusion radii or in existing blockhouse structures are low, the chief problems involve countdown holds or "scrubbed" launches.

D. SAFETY SPECIFICATIONS FOR ADVANCED SYSTEMS

1. Electrical Propulsion

Station-keeping for 24 hour orbits, lunar missions or interplanetary missions are viewed as possible applications for advanced SNAP systems. The implications of flights with rapidly varying orbit parameters pose new safety problems, particularly concerning orbital fission product decay, re-entry burnup, lunar and alien planet contamination, and long-term control reliability. A study program on the radiological aspects of these problems is being carried out.

2. Manned Missions

Application of SNAP units to supply power for manned missions has been studied.²⁴ To date, nuclear safety criteria peculiar to the manned mission (other than shielding studies) have not been extensively studied; however, information developed in the SNAPSHOT program will be examined for this purpose.

3. Others

Planned safety studies, not currently in effect, will concern power supplies for lunar and planetary surface exploration and orbital space stations.

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