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Westinghouse Capabilities in Nuclear Flight Safety

- ① Decker - no
- ② S. P. O. - no
- ③ suggest to Ralph
- ④ think along

MASTER

Westinghouse Electric Corporation
Astronuclear Laboratory
WANL-MP-006

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The schlieren on the front cover depicts a force test on the NERVA reactor which was conducted in the helium wind tunnel at NASA-Langley for Westinghouse.

INFORMATION CATEGORY

UNCLASSIFIED

John P. Sullivan
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I. INTRODUCTION

This brochure describes the capabilities of the Safeguards Engineering Department of the Westinghouse Astronuclear Laboratory (WANL). This Department is concerned primarily with evaluating all safety aspects of nuclear propulsion and has performed safety evaluations in the areas of manufacturing, assembling, ground testing and flight operation. These evaluations require a wide range of experimental and analytical capabilities, all of which are currently available at Westinghouse. It is significant that a number of these studies have had sufficiently important implications with respect to the ROVER Program to have resulted in changes in its course of development.

For example, the need to prevent a nuclear excursion following an accident on the launch pad or a very early mission abort, has lead to the development of the technology needed for a poison wire system. Studies of the oxidation of NERVA fuel materials have indicated that an intact reactor re-entry may be preferable to explosive destruct. The potential need for intact re-entry is leading to changes in materials of construction and control system design. Fission product diffusion studies in conjunction with ground test release data indicate that radioactive dose levels which off-site population could receive may soon limit testing capability or require development of methods to reduce release rates.

The following sections discuss in greater detail the department's capability in the fields of safety studies, radiochemical analyses, and related experience. The computer programs used by the Department and the experimental and analytical equipment are included. While many of the computer programs and experimental facilities are for the ROVER Program, they are, in general, readily amenable to other reactor or isotope systems.

II. ADVANCED NUCLEAR ROCKET SAFETY STUDIES

1. Safety Evaluation for Ground Operation

Westinghouse has provided the major portion of the safety analyses for ground testing of NRX type reactors. These analyses either assured that the reactor tests could be conducted safely

or outlined procedures to be followed to maximize the safety of on-site and off-site population in the event that a "credible" accident occurred.

This capability can be applied to assess safety problems associated with other type nuclear power units or ground nuclear power plants.

2. Diffusion Rate of Fission Products

One of the prime factors, either in establishing the safety of operating test reactors at NRDS or in determining the radiological doses received by a population after the abort of a flight mission, is the rate at which fission products diffuse from the fuel. The ground safety and flight safety considerations are opposite in their requirements. Projected nuclear rocket testing at NRDS may be limited by the release of fission products. In order to test carbon-type cores at higher temperatures than those experienced in NRX-A3 testing, either fission product diffusion must be reduced by limiting the integrated power or by improving the fuel, or the effluent gases must be scrubbed (or contained) to remove fission products. On the other hand, in the event of flight operation, safety is enhanced by maximizing fission product diffusion for those situations in which a reactor or reactor debris re-enters the earth's biosphere subsequent to operations. Present analyses indicate that substantial reductions in fission product inventory may be possible if nuclear after-heat is utilized to enhance diffusion in the event of a mission abort.

An intensive experimental program to determine the diffusion rates of individual isotopes under controlled laboratory conditions was conducted to evaluate the fission product diffusion anticipated under these conditions. These data were then applied to detailed analytical models to evaluate fission product losses under both normal operational and after-heat conditions, and thereby assess radiation hazards to the earth's population from NERVA reactors. Similar evaluations may be performed for other reactor concepts.

3. Loss of Flow Studies

The temperature attained following loss of coolant flow to the reactor is important in determining both the fission product release in orbit and the construction materials required to maintain the reactor intact in orbit is the temperature attained following loss of coolant flow to the reactor. A computer program (NOFLOW) has been developed at Westinghouse to study temperature/time relationships within various components of the reactor. With minor modifications this program can be utilized on other reactor designs.

The studies would determine the temperature/time relationships of the reactor components following loss of coolant as a function of full power operating time. These studies would be useful in determining adequacy of conceptual designs of high specific impulse engines, reactor power plants, or isotopic converters.

4. Re-Entry Ablation Studies

One of the basic technological problems associated with safety of flight operations of nuclear rockets involves evaluating the ablation (including oxidation) of reactor fuel and other engine components during re-entry through the earth's atmosphere. Three problems must be evaluated in light of ablative processes: (1) dispersion of radioactive components and fission products on the earth's surface where they could result in excessive radiological doses to the population; (2) the ability of the reactor components (primarily external) to withstand re-entry heating if intact re-entry is deemed desirable; and (3) the potential physical hazard of large masses impacting upon the earth.

Early in the development of the ROVER Program, it was thought that the biological hazard associated with the flight of a NERVA reactor could be eliminated by destructing the core in a number of small fragments with the use of explosive devices, and it was presumed that the fragments would burn up during re-entry.

Experimental and analytical investigations performed at WANL indicated that NERVA type fuel undergoes little ablation during re-entry. These results indicate that destruct may not be an adequate countermeasure in reducing hazards due to flight operation. As a result, WANL is investigating the safety implications of re-entry of a failed or spent reactor in an intact configuration.

Similar studies should be performed for other nuclear fuel systems to determine if it is desirable to bring nuclear devices intact to the earth or if destruct mechanisms would be adequate to disperse fuel bearing materials in the atmosphere. The re-entry behavior of a number of metals and alloys have been studied and these findings could be extended to other isotopic or reactor systems.

5. Orbital and Re-entry Dynamics

The evaluation of the behavior of an intact reactor requires extensive analytical capabilities in the field of orbital and re-entry dynamics. Westinghouse has an extensive capability in a number of computer programs. For example, the NERO-F1 program was developed to determine orbital lifetimes as a function of engine operating time and ballistic parameter. Another program developed at WANL is WEREC, a point mass trajectory program, which includes solution of ablation and heating equations. This program was used to evaluate the re-entry behavior of fueled material of nuclear debris.

A third program used by WANL is MASS, an optional three or six degree of freedom code which computes the trajectory of a re-entering body and, if desired, its attitude history during any portion of the re-entry trajectory. Thus, details of the aerodynamic loads to which the re-entering vehicle is subjected, are readily obtained.

6. Nuclear Excursion Program

An important facet of rocket safety is determining the magnitude of a nuclear excursion under accident conditions such as compaction on hitting earth, or water immersion of an intact core. The Safeguards Engineering Department has developed a two-dimensional computer program (NERVEX) to study this problem for NRX type reactors. This program can be modified to be sufficiently general to analyze any type of nuclear reactor. Studies with this type program will define the energy release under accident conditions and will give a basis for countermeasures required to minimize hazards to the population.

III. RADIOCHEMICAL ANALYSES SERVICE

The Physical Science Laboratory has provided extensive radiochemical analyses of NERVA fuel in the fission product diffusion program. In addition, radiochemistry analysis has been used to power calibrate the NERVA reactors. The Laboratory has a modern counting room with all the latest solid state beta, gamma and alpha counting equipment. Computer techniques are used to resolve individual isotope decay curves.

IV. PERSONNEL EXPERIENCE

Complementing the Departmental capabilities is an experienced staff qualified in the following related fields:

1. Chemical reaction kinetics, in particular, catalytic reactor rates. Existing equipment can be modified to study chemical reaction rates other than the oxidation rate studies in progress.
2. Flow field analyses about bodies of revolution.
3. Nuclear power plant application evaluation.

V. AVAILABLE COMPUTER PROGRAMS AND LABORATORY EQUIPMENT

1. Computer Programs

There are 17 computer programs available.

1. NERO D-4 (WEREC-1). This is a two degree of freedom re-entry program which solves the trajectory, re-entry heating and ablation equations for bodies re-entering the atmosphere from orbital and suborbital configurations.
2. NERO F-1. This program solves the orbit lifetime equations for a body in a circular or elliptical orbit.
3. Planetary Escape Code. This code determines the trajectory associated with thrusting a vehicle through a planetary gravitational field with the assumption that the planet is a sphere.
4. MASS. The Missile and Satellite Systems Program solves the equations of motion of a body in the earth's gravitational field and atmosphere. Solutions using either three or six degrees of freedom for any desired body shape, provided its aerodynamic characteristics are known, are available. Bodies undergoing thrust, ablation, and center of mass changes can be handled. Information in any of at least six earth, body, and inertial reference frames can be printed out or set up on tape for subsequent problems at the option of the user.
5. Source Term Computer Program. This is a comprehensive computer program used to evaluate the radiological hazards on the ground resulting from re-entry of the reactor, reactor fragments, or nuclear power supply of a nuclear powered rocket vehicle following normal and abnormal modes of operation.
6. Fission Product Inventory Program (FPIP). This program calculates the U-235 fission product activity resulting from a specified reactor operating and shutdown history. The individual activity of up to 499 fission product nuclides and the beta and gamma emission rates (source strengths) of these nuclides or of group sums of these nuclides in any of five chosen energy groups as a function of time is available as output from the program.

The source strength data can be used to determine biological dose and radiation hazards.

7. FIPDIF. A computer program used to determine the fission product inventory retained and the inventory diffused out of an arbitrary mass of NERVA fuel during and subsequent to its exposure to any desired fission density history under any desired series of temperature conditions. Computations are carried out using the 80 largest contributing decay chains of the FPIP program.

8. NOFLOW. This computer program determines fuel and structure temperatures following loss of coolant and as a function of reactor operating time.

9. NOFLOW - FIPDIF Coupled Programs

This is a chain program of three links combining the features of the FIPDIF and NOFLOW programs. It is capable of computing the fission product inventory produced by an arbitrary reactor operating profile, the quantity of fission products lost during the power operation, the fuel and reactor component temperatures following loss of coolant, and both the inventory retained and the inventory lost by diffusion at any time following loss of coolant and reactor shutdown.

10. NURODAC. A computer program to determine the earth deposition area following a nuclear rocket destruct in orbit.

11. NEFOD. A computer program to determine polynomial fit to data.

12. NERVEX. A two-dimensional nuclear excursion analysis program.

13. Thermal and Nuclear Transient Program (TNT). This is a heat transfer program which calculates the temperature of various nuclear powered rocket engine components as a function of operating power and position within the engine. Engine components considered include the reactor core, core support and structural members, reflector, containment vessel, nozzle, etc.

14. Gamma Dose from Cloud. This program determines gamma doses due to passage of a cloud containing fission products released from a reactor.

15. Gamma Fallout Dose. This computer program evaluates the gamma dose due to ground deposition resulting from the passage of a fission product cloud.
16. RISC. The radiation inhalation safety code determines the internal radiation doses which result from breathing air from a fission product cloud.
17. RAC. The reactor accident code is a one-dimensional program used for reactor excursion analysis.

2. Available Laboratory Experimental and Analytical Equipment

The following equipment is available for experimentation and chemical analysis.

1. The Laboratory is equipped with two bell jar test stations; one is coupled to a 15 kw, the other to a 20 kw radio frequency induction heating system. These test stations can maintain static gas pressures from 10^{-5} torr to 14.7 psia. The heating systems can achieve temperatures up to 3000°C and can be modified for higher temperatures. These systems can be used for tests such as heat treatment of test specimens or solid state diffusion studies.
2. A dynamic flow, induction-heated, gas handling apparatus has been constructed in the Laboratory. This apparatus is primarily used to study fission gases released from irradiated reactor fuels. The test samples can be dissolved and prepared for analysis without removing them from the apparatus.
3. An ultra-high vacuum test station capable of reaching 10^{-9} torr can be coupled to the 20 kw radio frequency generator for thermal testing at reduced pressures. This apparatus is used to simulate high altitude pressures for material tests.
4. Temperatures in all the heating systems are measured with two, 2-color recording pyrometers with a range of 1000° to 3500°C . An L&N optical pyrometer is used for lower temperature measurements.

5. A "hot" disassembly area has been set up for recovery of irradiated materials from test capsules or for the preparation of irradiated materials for testing. In this area, there is a shielded gamma box with two castle-type manipulators and a cut-off apparatus capable of handling samples reading up to 50 R/hr on contact.
6. A stainless steel glove box with hand tools and a jeweler's type lathe are located in the same area for radioactive sample preparation.
7. An oxidation apparatus capable of heating samples in controlled oxidizing atmospheres in a range of pressures from 14.7 to 1×10^{-5} Torr is used to measure oxidation rates of test materials. This apparatus, shown in Figure 1, is equipped with a recording, vacuum-micro balance (Figure 2) to measure weight changes under dynamic conditions. An analytical apparatus for measuring absolute (BET) surface areas on samples used in the oxidation test rig, or other experiments, is also available.

Figure 1. Metal Oxidation Apparatus

Figure 2. Recording, Vacuum Micro Balance

8. The Laboratory is equipped to perform all types of radiochemistry and counting room analyses. The counting room has the following equipment with which relative and absolute measurements of materials containing α , β and γ radiations can be made:

<u>Description</u>	<u>Radiation Measured</u>
512 Multichannel Analyzer	γ
Single Channel Analyzers	γ
4 π Counter	α , β
Window-Less Flow Counter	α , β
Thin Window Flow Counter	β
Automatic β Counter	β

9. The Laboratory has a Beckmen B Spectrophotometer, a Fisher Automatic Titrimeter, and a Fisher Electropode Polarograph which extend the capabilities of the Physical Sciences Laboratory to include analysis of inorganic materials to the 1 per cent concentration levels. A Flame Photometry Attachment for the Model B Spectrophotometer permits analysis for many trace elements.