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TO : W. P. Gammill, Chief
Health Physics Branch

DATE: October 16, 1963

FROM : Norman F. Islitzer, MIC
U. S. Weather Bureau

SUBJECT: SAFETY ANALYSIS REPORT - SNAPTRAN 2/10A-3 WATER IMMERSION TESTS - IDO 16929

SYMBOL : NFI:LGT

A review of the safety analysis section of this report has been made by this office, and outside of minor errors the methods of computing the various radioactive doses in the environment for the proposed tests are satisfactory. Independent checks of the cloud dose, inhalation dose, and deposition dose at the nearest site boundary during lapse conditions have been made and agree fairly well with those presented in the report. It follows that the calculations of the doses at other distances are probably also correct.

The assumption of the release of all of the noble gases, 50% of the halogens, and 50% of the other fission products to the atmosphere during the destruct test is probably overly pessimistic as mentioned on page 79. However, the reference to the computed release of less than 1% during the SPERT I destructive test probably should not be weighed too seriously, since this estimate was based upon rather inadequate field data. Furthermore, the release fractions for different isotopes could not be ascertained during the SPERT I Destruct.

Calculations for the inversion hours were not checked because this is not considered to be a credible occurrence if meteorological controls of the SNAPTRAN experiment are properly implemented. A wind shift carrying the effluent away from the designed test grid is credible and emergency procedures should be established for this occurrence.

The ingestion dose calculation made on pages 95-96, which indicate a maximum of 25 mr ingestion dose to the thyroid of a child from drinking contaminated milk, appears to be low. Our calculations indicate that it should be more like 100 mr even with a reduction factor of 20 based upon previous data of the relative activity of milk contamination and air concentration of I-131. The results of the Controlled Environmental Radioiodine Test (CERT), support this reduction factor of 20; however, this may not be valid for all terrain and different forms of I-131. Since the tests are planned for the winter season where grazing outdoors of cattle is largely restricted, it does not appear that the ingestion of milk will be a problem.

Since test conditions call for a 3-hour period of temperature lapse conditions this means that the test will probably have to be initiated no later than 2 o'clock in the afternoon in the winter months, since the inversions usually set in by 5:00 PM in the afternonn during that season.

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cc: Don Pack, EMRP

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SAFETY ANALYSIS REPORT - SNAPTRAN 2/10A-3
WATER IMMERSION TESTS

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SUMMARY

As part of the nuclear safety research program sponsored by the AEC, Phillips Petroleum Company will conduct a series of experiments to evaluate the hazards associated with the use of the SNAP 2/10A reactors. The SNAPTRAN 2/10A-3 series is directed toward a determination of the consequences of a nuclear accident approaching the maximum credible which would result from the immersion of a SNAP 2/10A reactor core in water. This simulated accident, which is expected to completely destroy the reactor core by a nuclear excursion, will be preceded by static physics measurements and a few long-period transient tests.

The potential hazards associated with conducting the SNAPTRAN 2/10A-3 program have been evaluated and are presented in this report. The report contains a description of the experimental program, a description of the reactor test package and control system, a discussion of the results of previous water immersion experiments, a discussion of the operating philosophy and test procedures, and an evaluation of the potential hazards attendant to the experimental program. The areas of consideration in the safety evaluation include materials handling, possible operator error and system failure, radiation levels associated with the various tests, and consequences of the maximum nuclear excursion.

On the basis of the safety analysis conducted, it is concluded that the test program can be conducted without undue hazard to operating personnel, other personnel within the NRTS, or the general public.

FIGURES

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FIGURES

I. INTRODUCTION

One of the important aspects in the utilization of nuclear reactors for aerospace auxiliary power systems is the evaluation of potential hazards unique to such an application. The Atomic Energy Commission has therefore initiated, as a part of its overall nuclear safety effort, an aerospace nuclear safety program to obtain information relevant to the evaluation of these hazards. That portion of the program concerned with determining the kinetic behavior of the SNAP reactors and the consequences of certain nuclear accidents involving these reactors has been designated as SNAPTRAN. The SNAPTRAN tests, which will be conducted by Phillips Petroleum Company at the Test Area North (TAN) site of the National Reactor Testing Station, will initially involve the SNAP 2/10A type reactor. These reactors, approximately 9 inches in diameter by 12 inches long, are composed of a core containing 37 rods of fully enriched uranium in a zirconium-hydride matrix. The core is contained in a thin stainless-steel vessel surrounded by a fixed beryllium reflector and controlled by four beryllium drums which vary the neutron leakage from the core. During assembly, launch, and ascent into orbit these reactors are maintained sub-critical by mechanical interlocks and administrative procedures. Once the reactor is in orbit the control drums are programmed for insertion until the desired operating power is attained.

The dynamic nuclear behavior of the reactor and in particular the consequences of a nuclear accident are the principal considerations to be investigated in the SNAPTRAN program. Two potentially hazardous situations could occur: (1) the accidental rotation of the control drums into the reactor during assembly or launch, and (2) immersion of the reactor core in water or moist earth. The kinetic behavior of the beryllium-reflected reactor and associated radiation hazards resulting from the first situation will be examined in the SNAPTRAN 2/10A-1 and SNAPTRAN 2/10A-2 programs. The safety considerations involved in conducting the SNAPTRAN 2/10A-1 tests are discussed in IDO-16825, "Safety Analysis Report - SNAPTRAN 2/10A-1 Safety Tests" [1]. The power excursion behavior and radiological consequences resulting from the second situation, i.e., immersion of the reactor in water will be investigated in the SNAPTRAN 2/10A-3 program. It is the purpose of this report to present

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an evaluation of the safety measures to be taken during conduct of the SNAPTRAN 2/10A-3 tests.

Non-nuclear tests to investigate the physical behavior of reactor components upon impact with water [2] have shown that the beryllium reflector and other components external to the reactor vessel will probably separate from the reactor vessel with the core remaining intact. The SNAPTRAN 2/10A-3 tests will, therefore, be conducted utilizing only the fuel and reactor vessel. The experiments to be conducted during the SNAPTRAN 2/10A-3 program consist of loading the reactor with fuel, measurement of the reduced prompt neutron generation time $[(\Lambda/\beta)_{eff}]$ by noise-analysis techniques, operation of the reactor at low power to calibrate nuclear instrumentation, nondestructive transient testing initiated by step or ramp additions of reactivity, and the conduct of a final transient test which models an accident approaching the maximum credible as a result of water immersion.

The reactor vessel containing fuel will be mounted on a pedestal in a 14-ft-diameter open tank rigidly mounted on a railroad flatcar (dolly). The reactor vessel will be surrounded by a poison sleeve capable of maintaining the reactor subcritical when the reactor is immersed in water. The poison sleeve, actuated by a drive mechanism, can be withdrawn either slowly or rapidly and can be scrammed. Extensive instrumentation will be located within the reactor vessel (in-core) and external to the reactor vessel to provide information regarding the nuclear and mechanical behavior of the reactor during the transient tests. In addition, instrumentation is available for obtaining extensive radiological measurements to a distance of several miles following the final test. Upon completion of the final test the remains of the reactor will be transported via the railroad car to the hot shop facility where physical, chemical, and metallurgical examination will be performed.

This report includes a brief summary of the test program, a description of the test package, and an analysis of the potential hazards involved in performing the tests. Site and facility descriptions are not included since detailed descriptions were previously included in the safety analysis report for the SNAPTRAN 2/10A-1 test series [1]. On the basis of the safety analysis presented herein, it has been concluded that the SNAPTRAN

2/10A-3 test program can be conducted without undue hazard to operating personnel, personnel at other NRTS installations, or to the general public.

II. PROGRAM

A. Purpose and Objectives

In the sequence of operations necessary to launch a SNAP reactor into space, once conceivable mechanism for the initiation of a nuclear accident is the immersion of the reactor in water. Such an event which could occur during transport, as an aftermath of fire or explosion on the launch pad or during a launch abort over water could result in a nuclear power excursion accompanied by the release of radioactive products to the surrounding environment. An experimental program, SNAPTRAN 2/10A-3, has been proposed to scope the potential hazards of such an accident and provide information relevant to safety assessment, to design the reactor system with respect to safety, and to the development of procedures and controls to ensure safety during launch. All of the available reactivity in the reactor will be inserted by a step insertion for the purpose of intentionally simulating the worst type of accident. As far as the system is concerned this condition corresponds to the "maximum credible accident". It is recognized that the probability of such an event occurring unexpectedly is low; however, for the purpose of safety analysis the radiological consequences have been presented for both controlled and uncontrolled meteorological conditions. The theoretical upper limit of the energy release (170 Mw-sec) associated with insertion of the total excess reactivity available has been used in the radiological computations inasmuch as little is known regarding the kinetic behavior of these reactors, and in fact, one purpose of the test program is to determine the energy release. On the other hand, the maximum theoretical energy is not expected to be released. The expected energy release associated with the addition of about $2.50 of reactivity above prompt critical is about 20-40 Mw-sec. It must be assumed that an accident releasing this energy could occur either during predestructive or destructive testing. Primary experimental program objectives are:

(1) to provide information concerning the nuclear and mechanical energy release during a power excursion approaching the maximum credible,

(2) to provide qualitative and quantitative information concerning the fission product release and transport, and

(3) to provide physics and engineering information which will assist in understanding the kinetic behavior of the reactor and which will assist in assessment of the reactor design with respect to safety.

The program will include the following: (1) mechanical, electrical, and hydraulic checkout, (2) fuel loading, (3) static physics measurements, (4) long-period transient experiments, (5) destructive test, and (6) post-test examination.

B. Mechanical, Electrical, and Hydraulic Systems Checkout

Prior to the loading of fuel, a mechanical, electrical, and hydraulic systems checkout will be conducted on the complete reactor system. This checkout will include determination of proper operation of the control console and measurement of the speed of the slow poison-sleeve drive, the drop time when the sleeve is scrammed, the removal time of the sleeve fast-removal mechanism (pyrotechnic actuator), and the water fill-and-dump times.

C. Fuel Loading

During fuel loading the reactor vessel will be placed within and clamped to the poison sleeve to provide a safe and convenient loading environment. The fuel will be loaded one element at a time. Following completion of the full core loading, the reactor vessel head will be clamped in place and seal-welded to the vessel. The instrumented fuel lead penetrations in the head will then be seal-welded. Next, the integrity of the vessel will be checked with a helium leak detector. Finally, the vessel will be filled with NaK through a special charging system and sealed off. Sufficient space will be left for expansion of the NaK in the vessel for conditions of increased temperature resulting from long-period transient tests and power calibration. The loaded reactor will then be mounted on the pedestal within the environmental tank.

D. Static Physics Measurements

After performance of a mechanical checkout with the reactor loaded, a watertight calorimeter will be mounted around the reactor vessel. With the poison sleeve surrounding the vessel the water height in the calorimeter will be increased in small increments. After each addition the poison sleeve will be withdrawn. This procedure will be continued until the critical water height is obtained. Following this determination the calorimeter will be filled with water and the poison sleeve will be slowly raised until criticality is attained. Once the critical sleeve position has been found, the reactivity worth of the sleeve will be determined by the period method. Excess reactivity will then be measured using soluble poison as a reactivity shim.

After the sleeve and water height reactivity calibrations have been performed, the reactivity effect of water in the environmental tank will be determined by varying the water level in the tank.

The reduced prompt-neutron generation time will be determined both with the reactor slightly subcritical and with the reactor critical but at low power.

By means of the calorimeter technique, the sensitivity of the ion chambers to the nuclear power generated in the core (power calibration) will then be determined for chambers in the various locations in the core, in the water, and below the flatcar and flight tube. The nuclear power level will be kept as low as possible in order to avoid large temperature gradients within the core.

E. Long-Period Kinetics Tests

A series of approximately ten long period power excursions may be performed to aid in the checkout of the instrumentation and the determination of the self-limiting behavior of the system. These excursions will be initiated by withdrawal of the poison sleeve and terminated either by scramming or by nondestructive self-shutdown mechanisms. The temperature rise will be the determining factor for the amount of reactivity inserted. In no case, however, will an experiment be conducted in which the predicted temperature of the fuel exceeds 1000°F.

F. Destructive Test

Following the long-period kinetics tests, final preparations for the destructive test will be made. Startup, operational, and safety channel detectors will be removed from around the reactor and final installation of special transducers will be completed. The sleeve propellant charge will then be loaded into the remote charging mechanism of the pyrotechnic actuator ~~and~~ the calorimeter removed. When preparations are complete and the appropriate meteorological conditions prevail, the sleeve removal mechanism will be armed and the final test initiated. The following measurements will be made: (1) fission product buildup and spread, (2) reactor components kinetic energy and dispersal, (3) reactor power, period, and energy release, and (4) heat deposition and pressure buildup.

Redundancy of detectors, location, ranges, and recorder channels will be provided. In addition, extensive photographic coverage of the event will be made with ground and aerial cameras using both black-and-white and color film.

Expected results of the destructive test have been outlined in IDO-16971 "Analysis of SNAPTRAN 2/10A-3 Destructive Test"[17].

G. Post-Test Examination

Upon completion of the destructive test, an area survey will be made to determine the extent of contamination spread and the distribution of reactor materials. Fuel and reactor structural component fragments will be collected and moved with the reactor remains to the examination area. An extensive analysis of these fragments will be made to determine the thermal, chemical, and, mechanical energy release.

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III. TEST PACKAGE DESCRIPTION

A. General

The SNAPTRAN 2/10A-3 test package design reflects certain basic criteria of the experimental program. These criteria include the provision that the water immersion destructive test be conducted in a body of water sufficient in size to assure that the ultimate reactor shutdown is not caused by water expulsion, i.e., the reactor must be in an essentially infinite water environment. In addition, the test package design must allow the conduct of static physics measurements, including a power calibration, and must facilitate cleanup of the test area and examination of the reactor remains following the destructive test.

To accomplish these objectives the reactor, enclosed in the calorimeter, has been located within a large environmental tank mounted on a 4-rail railroad dolly. The top of the reactor is located at a depth of 3.5 ft below the water surface. A pictorial representation of the test package is given in Figure III-1. The environmental tank has been fabricated from steel and is backed by concrete to assure tank integrity during destructive disassembly of the reactor core and vessel. To facilitate removal of the test package following the destructive test, all operational and experimental leads have been routed from the dolly through a facility plug into the shielded coupling station.

Control of the reactor can be accomplished either by movement of a neutron absorbing sleeve around the reactor vessel or by varying the water level in the calorimeter. The control sleeve is moved by two separate in-line systems: (1) a motor drive system which provides slow speed movement and precise positioning of the sleeve, and (2) a pyrotechnic actuator which provides rapid removal of the sleeve. The pyrotechnic actuator will only be used to initiate the destructive test. During the static physics measurements, the calorimeter will permit precise temperature and water level control in the water immediately surrounding the reactor.

A description of the reactor package, support structures, control system, and experimental and operational instrumentation is presented in this section.

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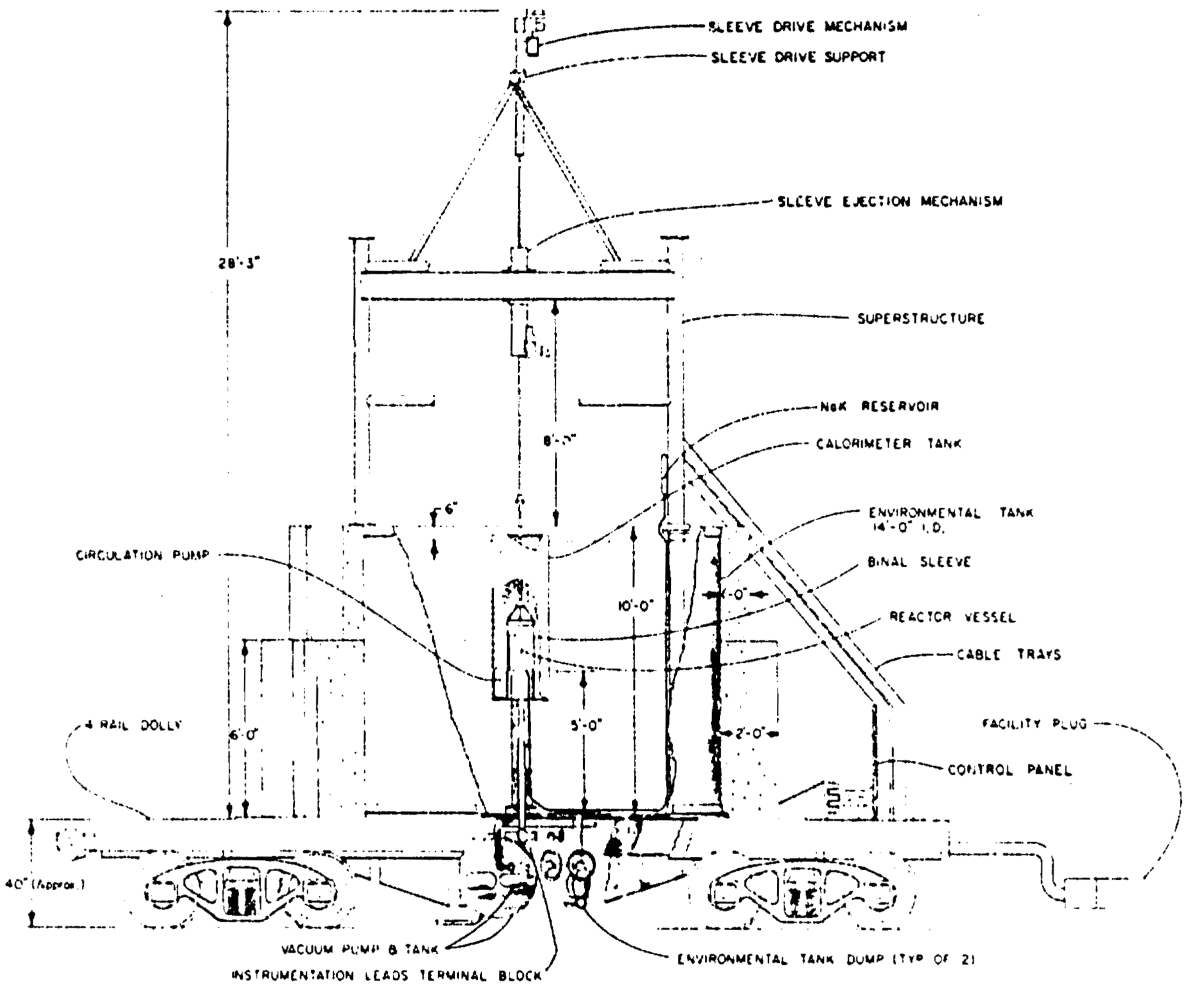

Figure III-1 - SNAPTRAN 2/10A-3 Test Package

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B. Core and Vessel

1. Core

A cross section of the reactor core and vessel assembly is shown in Figure III-2. The core is a right cylinder which consists of 37 fuel rods arranged in a triangular array on 1.260 inch centers to form a hexagon 8 inches across the flats. The fuel rods are held in this array by upper and lower grid plates with beryllium filler pieces used to adapt the hexagonal core to the cylindrical vessel described below. The fuel-moderator for the reactor is an alloy of zirconium-hydride and 10 wt% of 93% enriched uranium. The fuel-moderator density is 6.08 g/cm^3 and its volume is 520 in^3 (8540 cm^3). The reactor core contains 4.75 kg of U-235 and 464 gram-moles of H_2. The fuel-moderator is clad with Hastelloy-N having a wall thickness of 0.015 inch. The outside diameter of each fuel element is 1.250 in. and its length is 12.25 inches. A gap of approximately 0.001 in. exists between the cladding and the fuel-moderator. The ends of the fuel rods have caps and grid plate indexing pins welded to each end. The upper and lower grid plates, which are fabricated from Hastelloy-C provide precise positioning of the fuel rods with respect to the vessel and to each other.

2. Vessel

The reactor vessel, fabricated from type 316 stainless steel, is cylindrical in shape, 8.94 in. OD, with a 0.032 in. wall thickness. Holes are provided in the head for the penetration of detector lead wires to the interior of the reactor vessel. Support lugs are welded to the head for mounting the vessel in the environmental tank. An extension has been affixed to the upper end of the vessel to ensure the proper alignment of the Binal sleeve with the reactor during the lowering of the sleeve.

C. NaK Fill System

The reactor head has a tubing lead welded into place for convenience in NaK loading. This NaK inlet is connected via a 23 ft length of

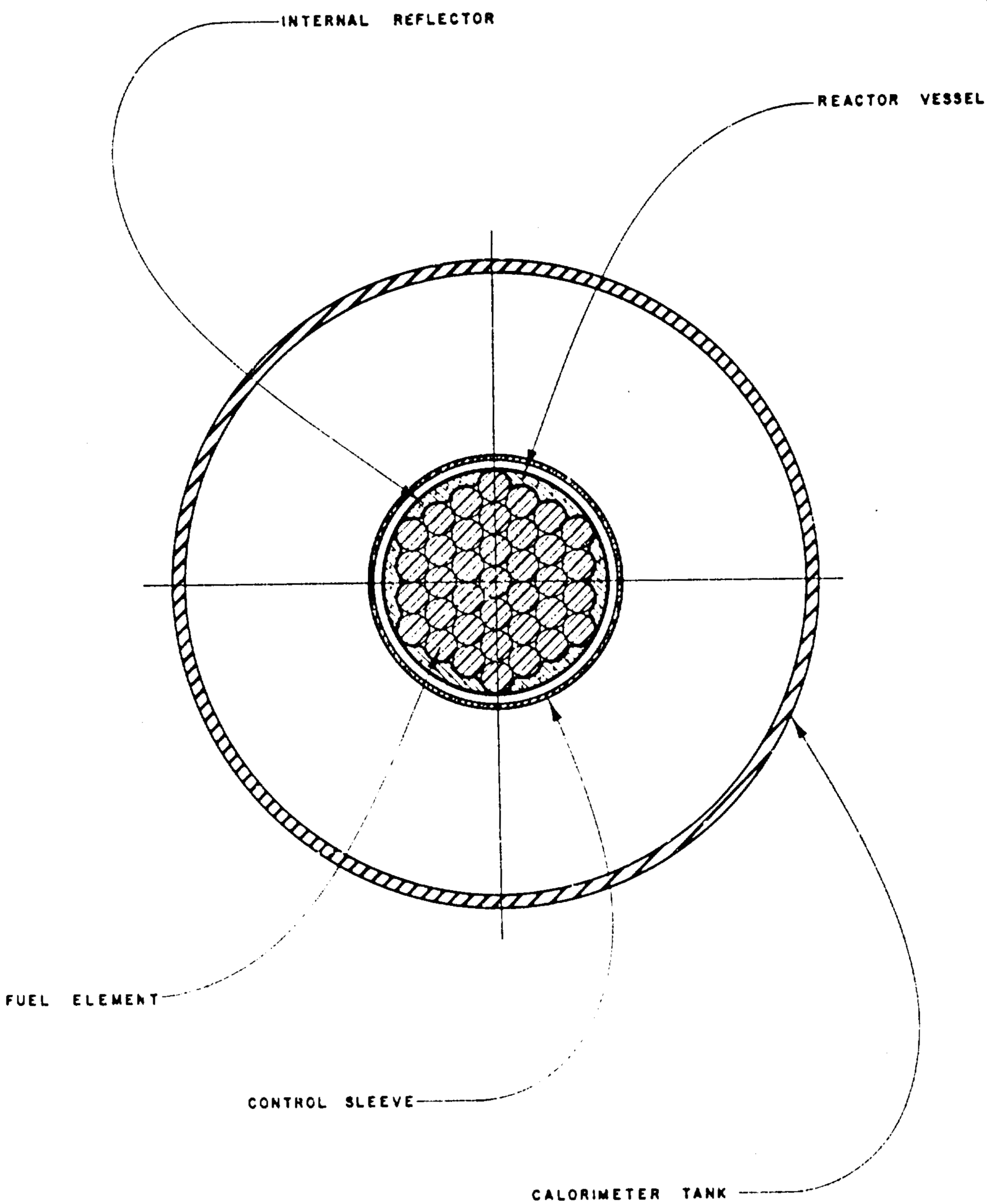

Figure III-2 - SNAPTRAN 2/10A-3 Reactor Cross Section flexible stainless steel tubing to a 30 cubic inch expansion tank which will be mounted on the environmental tank superstructure.

After the reactor system has been helium purged and evacuated, the NaK is valved into the system at the expansion tank. After a minimal amount of NaK is charged to the system, it is once again evacuated to remove any air that might have been in the NaK bottle. When the system is liquid full, including the expansion tank, the vacuum and overflow line on the vessel are crimped and seal-welded. The NaK in the expansion tank is forced out by a helium purge and the expansion tank is evacuated before it is seal-welded. A pressure transducer on the expansion tank permits continuous monitoring of the integrity of the system by recording the negative pressure of the reactor system.

A pictorial view of the system is shown in Figure III-3.

D. Support Structure and Environmental Tank

Support of the reactor vessel, calorimeter, and auxiliary test equipment is provided by a pedestal fabricated from 8-in. schedule-40 stainless steel pipe. A cross section of the pedestal, vessel and calorimeter is shown in Figure III-4. The reactor centerline is positioned 5-1/2 ft above the bottom and 4-1/2 ft below the top of the environmental tank.

During the static physics measurements and kinetics tests, the calorimeter will be in place around the vessel and will be supported by a 1-in. thick stainless steel flange which is attached to the pedestal. The calorimeter, which is fabricated from Plexiglass, has an internal diameter of 2 ft and a wall thickness of 1 inch. An electrical heater, an agitator, temperature measuring instrumentation, and water level measuring equipment are also located on the support flange. The calorimeter, which will be removed for the destructive test, is held together by tension bands placed around the periphery to enable removal without disturbance of the control sleeve or drive system. The bands and the calorimeter can be removed by means of extension tools.

All experimental and operational instrumentation leads within the calorimeter and reactor vessel are routed inside the support pedestal to

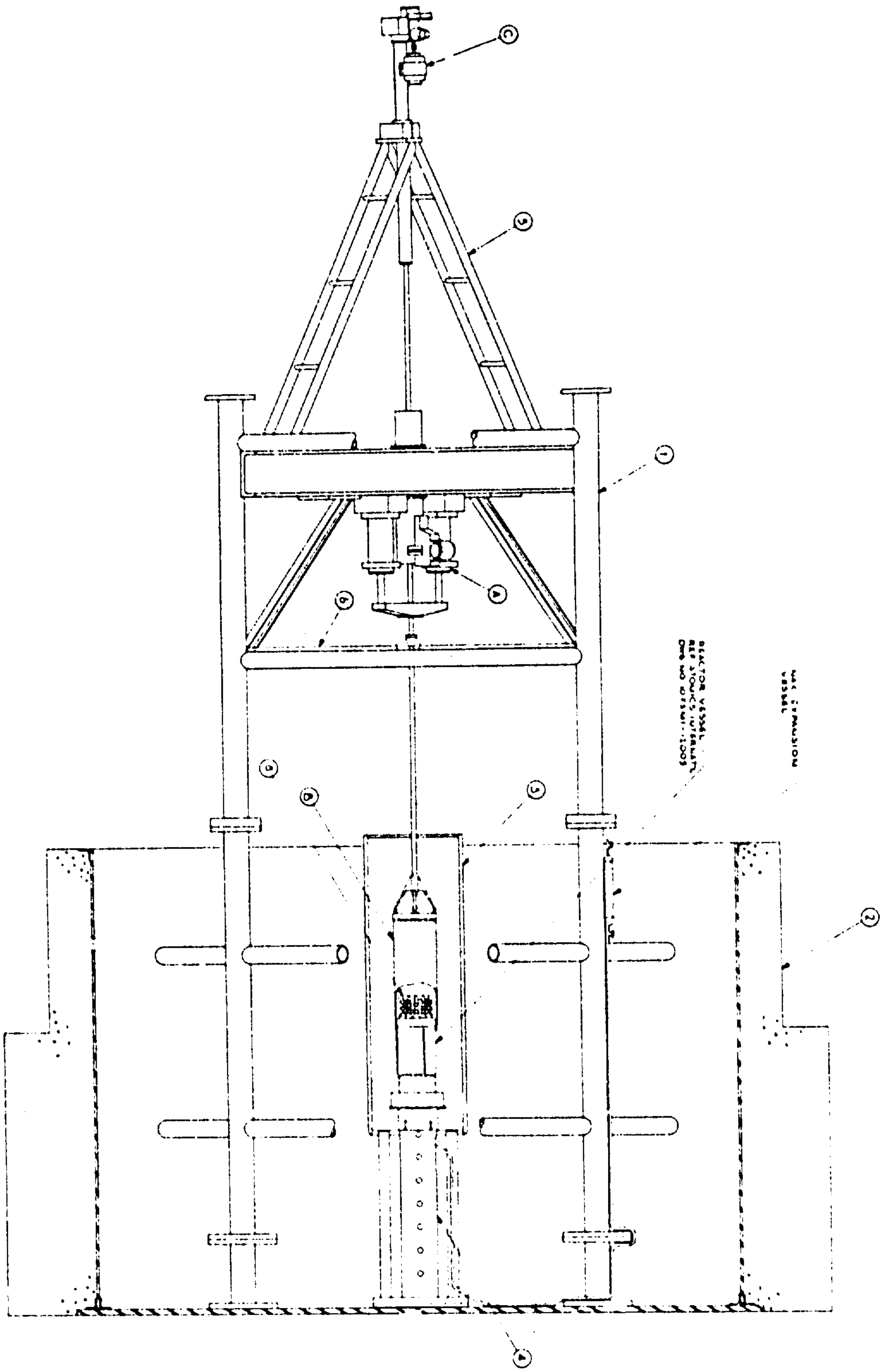

Figure III-3 - SNAPTRAN 2/10A-3 Assembly

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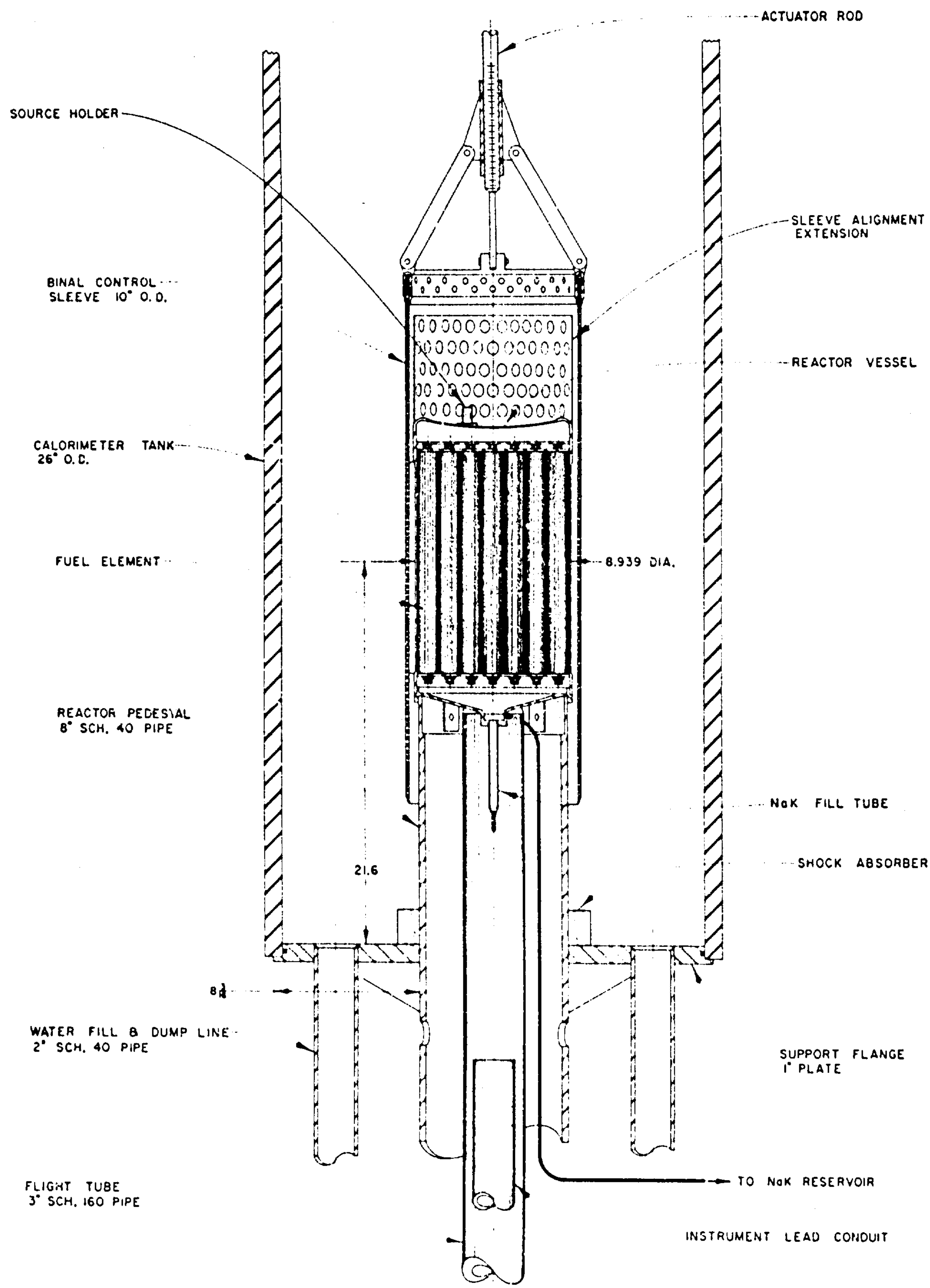

Figure III-4 - SNAPTRAN 2/10A-3 Calorimeter Configuration

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an instrument lead conduit which penetrates the bottom of the environmental tank. The leads are then brought into a coupling box below the dolly and out through waterproof penetrations.

The environmental tank has an internal diameter of 14 ft and a height of 10 feet. The tank walls are fabricated from 0.75-in.-thick carbon steel and the base from 1.5-in.-thick carbon steel. In order to maintain integrity during high pressure surges which may be generated during the destructive shutdown of the SNAPTRAN 2/10A-3 reactor, the tank is backed on the sides by concrete, 1 ft thick at the top and 2 ft thick at the base.

Mounted within the tank is a steel structure which supports and aligns the sleeve motor drive mechanism and the transient drive system.

E. Water Fill and Dump

A schematic diagram of the demineralized water storage and supply system is shown in Figure III-5. A distribution manifold in this system permits the use of a single pump for pumping water from two 12,000 gallon storage tanks to the dolly and from the dolly to the storage tanks or to either the hot waste system or the leach pond. The controls for the manifold valves and pump are located in a facility panel in the control room. This makeup and drain system has the capability of pumping water to or from the dolly at a maximum rate of 350 gpm.

The SNAPTRAN 2/10A-3 test package water fill and dump system, shown in Figure III-6, has been designed to allow individual control of the water level in both the environmental tank and the calorimeter. The filling rate through the single inlet line to the environmental tank is regulated by means of a pneumatic valve. The maximum filling rate is approximately 350 gpm. Drain capability for the tank is provided by a tee between the pneumatic inlet valve and the tank, which allows the inlet line to serve a dual function. From the tee, the drain line leads to a return header. A second drain line in the environmental tank also leads into the return header. This header is routed back through the facility plug and connects to the storage tanks. A normally-open auxiliary drain leads from the return header on the dolly to the hot

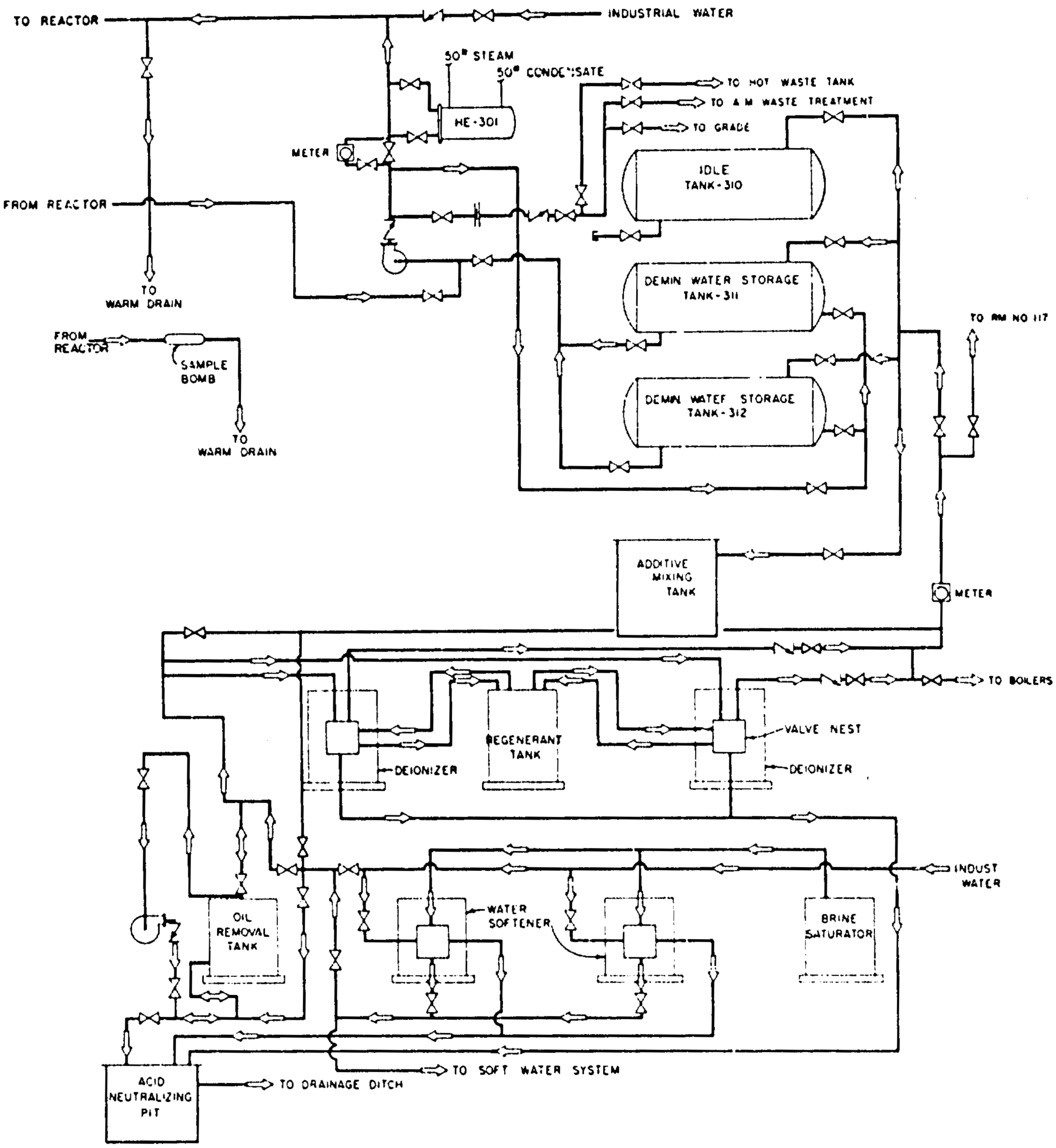

Figure III-5 - Demineralized Water Storage and Supply System

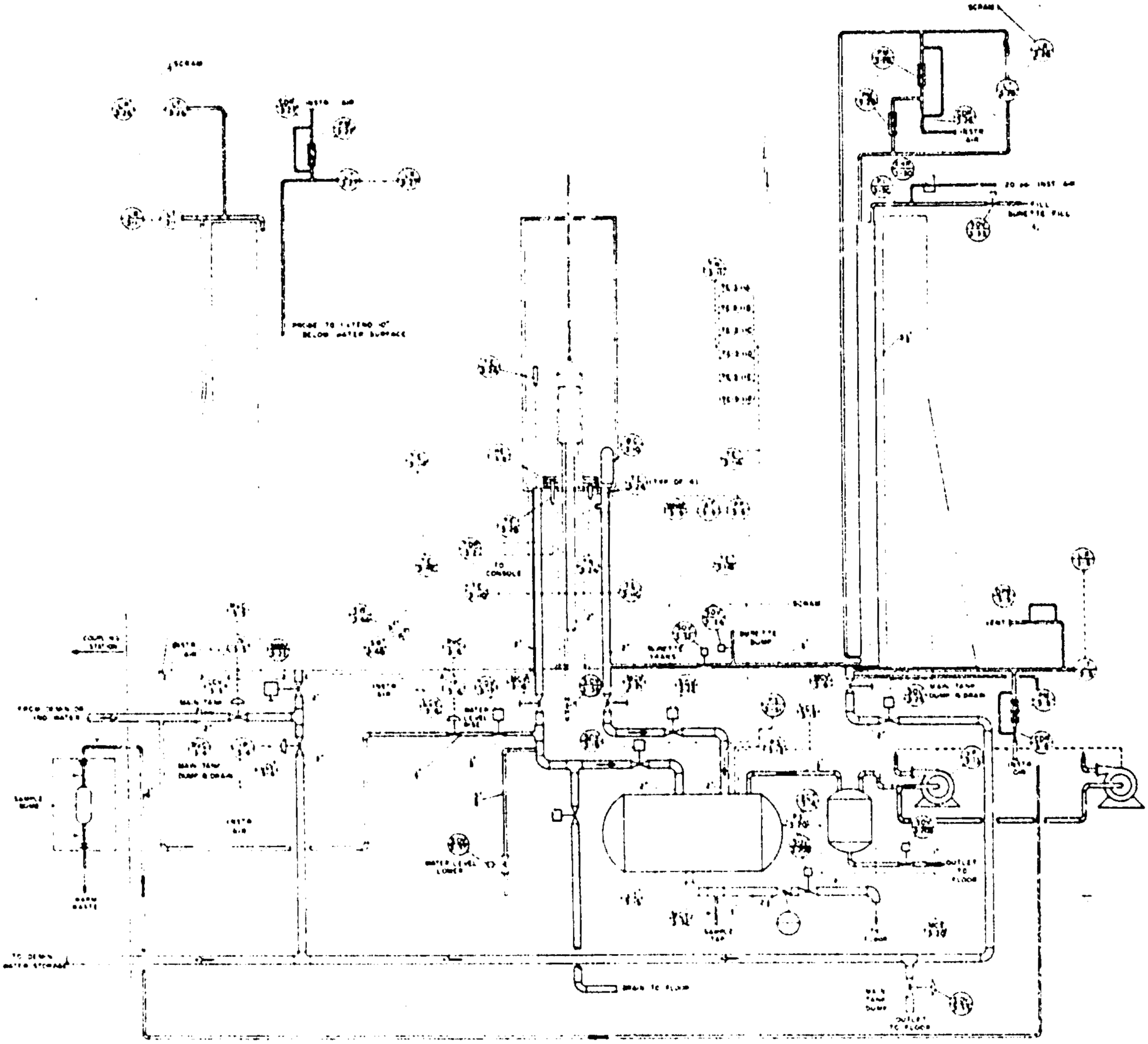

Figure III-6 - Water Fill and Dump System

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drain trench in the cell floor, giving drain capability in the event of pump failure. Solenoid valve control of these drain lines is provided at the console but is not included in the scram circuitry.

Two pumping systems are available to empty the environmental tank at a rate of 1100 gpm. The total volume of approximately 10,000 gallons of water can be removed in less than ten minutes. Direct gravity drainage to the floor can be accomplished at a rate of 50 gpm.

Filling and draining of the calorimeter is accomplished through a pair of lines leading through the environmental tank and calorimeter support flange on the pedestal. One line, used for normal filling and draining, branches into three parallel lines; an inlet, an outlet, and a scram dump line. The flow in the inlet and outlet lines is controlled by pneumatic valves and a solenoid valve which are operated from the console. Flow through the scram dump line is actuated by a solenoid valve which is opened when a scram signal occurs. The second line is used for scram dump and also for fine level control. Fill control is automatically switched to a burette fill system when the reactor level reaches a conductance probe located in the calorimeter 1 in. below the bottom of the reactor vessel. The burette is a small diameter cylinder in which a water column is air-driven to raise the level of water in the calorimeter. Precise control of the water level is thus obtained since a large change in the burette water height results in a small change in calorimeter water level. To operate the burette, the top of the cylinder is charged with air to 20 psi. A solenoid operated valve is used to admit burette water into the calorimeter.

In order to lower the level in the calorimeter, water is drained through a console operated pneumatic throttling valve into the drain header. When water is drained, it is necessary to return the level to the probe height in order to obtain a precise reference level.

When a scram signal is obtained, the inlet water control valves are closed and solenoid valves located in the two calorimeter lines are opened. This action allows the water in the calorimeter to be dumped. In order to reduce the drain time, the dump lines are connected to a vacuum tank with a larger volume than that of the calorimeter. It has been estimated that the time required to lower the water 1 in. is approximately 325 msec. At this rate the reactivity of the system will be reduced at about \$6/sec at the critical water height level.

The vacuum in the tank is controlled by a preset pressure switch and automatically actuated vacuum pump. When the pressure in the tank rises to atmospheric, as in a scram dump, a pressure switch actuates a solenoid valve which allows the calorimeter contents to empty into the floor drain.

Prior to the destructive test all manual outlet valves from the environmental tank will be locked open to assure drainage capability.

F. Poison Sleeve Drives

Reflector poisoning is accomplished by the use of a cylindrical poison sleeve which can be positioned vertically around the reactor vessel. The sleeve has an internal diameter of 9.5 in. with a wall thickness of 0.25 in. and an overall length of 30 inches. The sleeve contains 10.5 wt% natural boron in the form of B_4C dispersed in aluminum. The sleeve is essentially "black" to thermal neutrons and, in the seated position, causes the reactor to be far subcritical as discussed in Section IV. Attached to the top of the control sleeve is a yoke which couples the sleeve to the actuator rod through a spider mechanism. The control sleeve is shown in the partially withdrawn position in Figure III-4.

Slow movement of the sleeve is effected by a precision motorized drive mechanism. Rapid removal of the sleeve is accomplished by means of a pyrotechnic actuator. Both systems are coupled to the sleeve through the actuator rod. Figure III-1 includes a pictorial representation of the two drive systems and their physical relationship to one another.

The sleeve drive mechanism is powered by a 1/4 hp, variable speed, 32 volt, DC motor. The motor rotation is transferred through a gear train to a ball=screw mechanism as shown in Figure III-7. The rotational motion is then translated to vertical motion by means of a ball nut which travels on the screw. The gear train and ball-screw reduction is sized to provide 1 in. of travel for each 750 revolutions of the drive motor. At the maximum motor speed of 1725 rpm, the sleeve withdrawal rate is 2.3 in/min. Connected to the ball nut is a draw bar which extends through the drive housing to an electromagnet. The armature which mates with the electromagnet is the pyrotechnic actuator piston. When the electromagnet and armature are in contact and the electromagnet is energized, the draw bar is coupled to the actuator rod. With the entire assembly coupled, the weight of the sleeve and movable portion of the drive mechanism will not drive the worm gear backwards when the motor is stopped.

Sleeve position indication is provided by a synchro transmitter which operates a digital indicator on the console. Upper and lower limit switches are mounted on the drive housing and are actuated by the movement of the ball nut within the housing, limiting the travel of the sleeve drive mechanism to 23 inches.

To reduce sleeve alignment problems, the upper limit position maintains the bottom of the control sleeve approximately 1.0 in. below the top of the active fuel. Administrative interlocks in the control system prohibit withdrawal of the sleeve beyond the upper limit switch during the static physics and kinetics measurements. However, prior to the destructive test the draw bar is raised to the fully withdrawn position, approximately 31 in. above the normal upper limit of travel.

When a scram signal is obtained the electromagnet is de-energized, thereby breaking contact with the armature and decoupling the draw bar from the actuator rod and control sleeve. The sleeve assembly is then accelerated downward around the reactor vessel by gravity until the sleeve contacts a shock absorber located on the support flange. A seat indicating switch is located in the shock absorber and is actuated by the sleeve assembly when it is in the fully down position.

In order to rapidly withdraw the sleeve from around the reactor vessel to initiate the destructive test, a pyrotechnic actuator is provided. This system is designed to remove the sleeve at a velocity of

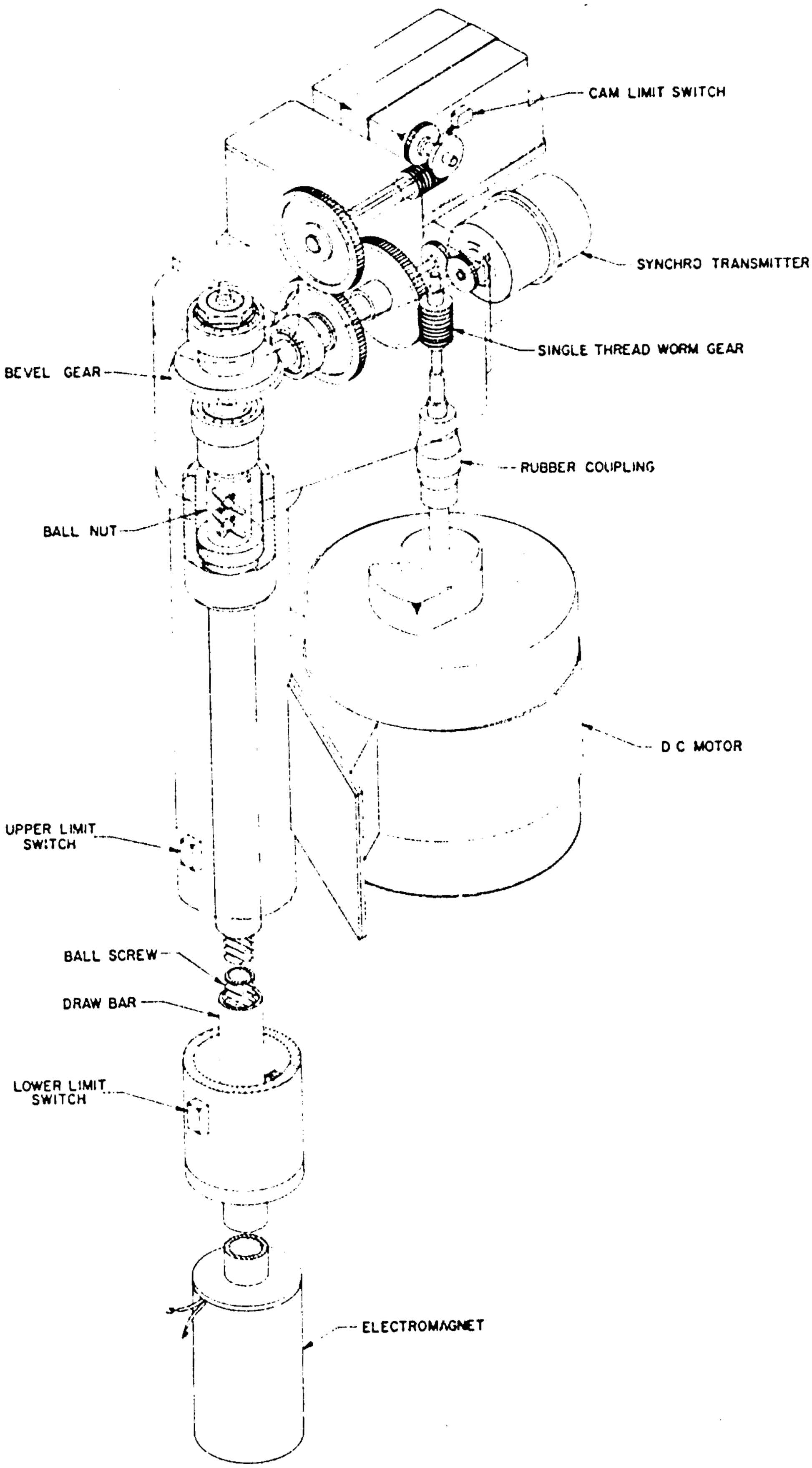

Figure III-7 - Sleeve Drive Mechanism

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100 fps which results in an effective reactivity insertion time of approximately 10 msec. A pictorial representation of the pyrotechnic actuator is presented in Figure III-8. To accomplish the sleeve removal, the draw bar is withdrawn to the uppermost position placing the electromagnet approximately 54 in. above the top of the actuator rod. The pyrotechnic actuator is then free to move the sleeve independent of the sleeve motor drive mechanism. The actuator piston moves within a cylinder which is fabricated from cold rolled steel bar stock, 7 in. in diameter and bored to an inside diameter of 5.0 inches. A 0.030 in. clearance is provided between the piston and cylinder wall to allow free movement of the entire assembly during static physics measurements and kinetics testing.

A rotating chamber is located at the bottom of the cylinder. This chamber is designed to contain a black powder charge of approximately 50 grams and two electrical firing squibs or detonators. The chamber is remotely rotated into the firing position by means of a motor and worm gear assembly. A hydraulic shock absorber is located below the barrel to stop the sleeve assembly at the upper limit of its travel. In this position the bottom of the sleeve is approximately 31 in. above the top of the active fuel.

During static physics and kinetics tests, pressure relief for the actuator piston and cylinder assembly is provided through the rotating powder chamber to eliminate air damping of the sleeve assembly during scram.

G. Reactor Control System

1. Control Console

The reactor will be operated from the SNAPTRAN 2/10A-1 console in the control room of the IET facility [1]. The two center control panels and the left hand "pie section" panel of this console have been equipped with controls for the SNAPTRAN 2/10A-1 experiment. Other sections of the console contain startup instrumentation, power level recording instrumentation, period and level safety instrumentation, television monitors and a program sequence timer. This instrumentation

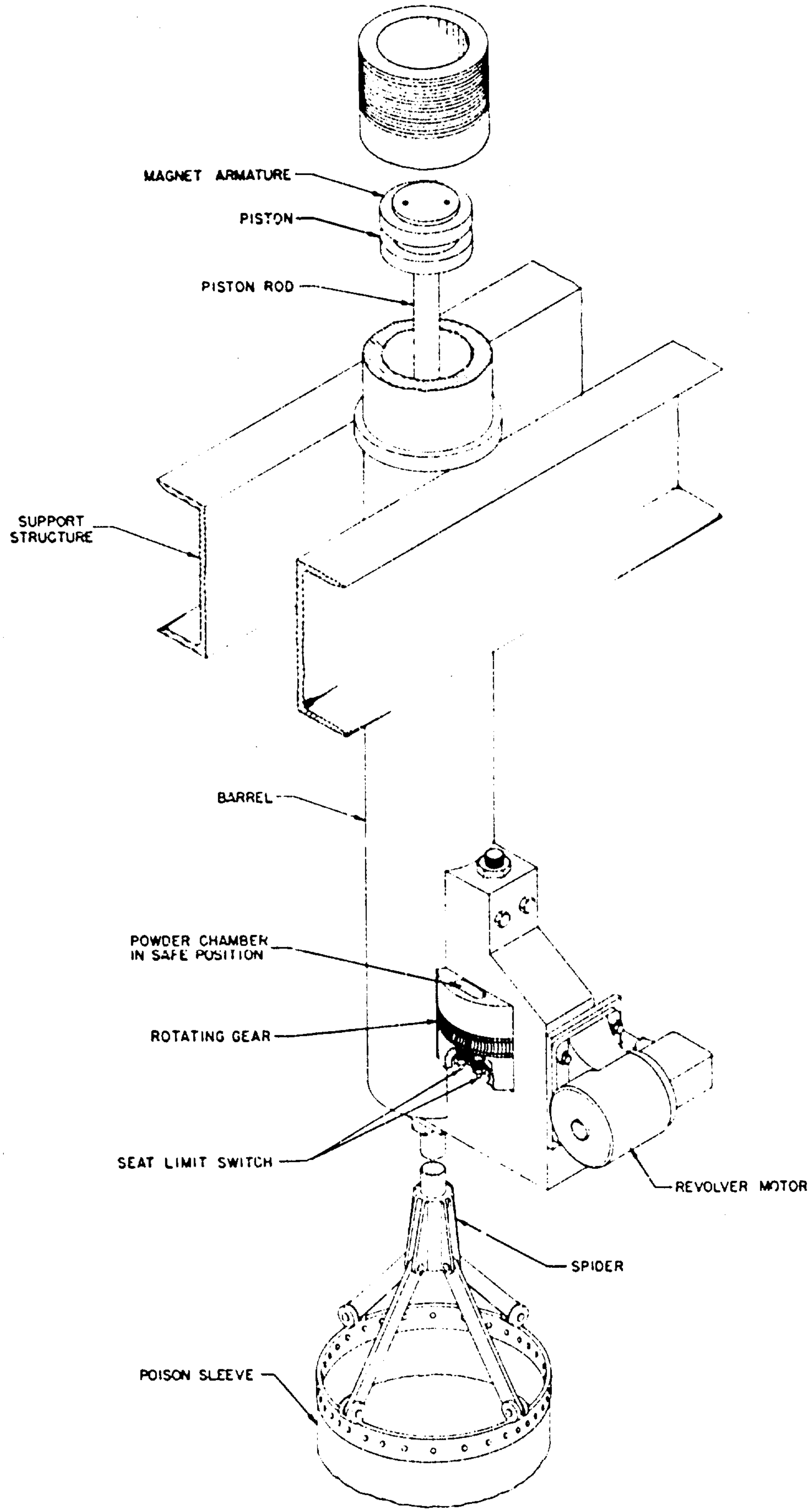

Figure III-8 - Sleeve Ejection Mechanism was installed for the SNAPTRAN 2/10A-1 tests, but will also serve for the water immersion tests. The controls for the SNAPTRAN 2/10A-3 reactor are installed on the panel adjacent to the left hand pie section of the console. A layout drawing of this panel is shown in Figure III-9.

The operator-indicators shown in Figure III-9 are miniature rectangular pushbutton units which can accommodate up to four 28 volt independently wired incandescent bulbs, and a choice of spring returned or ratchet held switches with as many as four double throw circuits. In the SNAPTRAN control system applications these indicators are wired such that every indication is served by two bulbs in parallel. Thus, burnouts are evident and result in erroneous indication only in the improbable event of simultaneous burnout. All indicators are illuminated white, depending upon on or off modes, and printed legends are used to convey information to the console operator.

Each keyswitch has a different key, thus facilitating flexible administrative control of operations without necessitating undue delegation of responsibility. All keyswitches except one are maintained in the on position by a detent. A spring return keyswitch is used on the transient safety bypass.

The pistol grip drive motor control switch is detent maintained in the counterclockwise position which is used for sleeve lowering, and spring-returned from the clockwise position, which is used for sleeve raising.

Five water level recorders are installed on the facility panel within view of the console operator. These instruments record burette water level and a coarse and fine level indication from both the environmental tank and calorimeter. Two of these recorders, vis., the burette level and the fine calorimeter level, have slave indicating meters on the console panel. A contact closure at the upper end of the fine environmental tank level recorder scale operates a relay and an indicator light at the console. A conductance probe in the calorimeter, 1 in. below the bottom of the core, operates another interlock relay and a light, providing a reference level indication for burette operation.

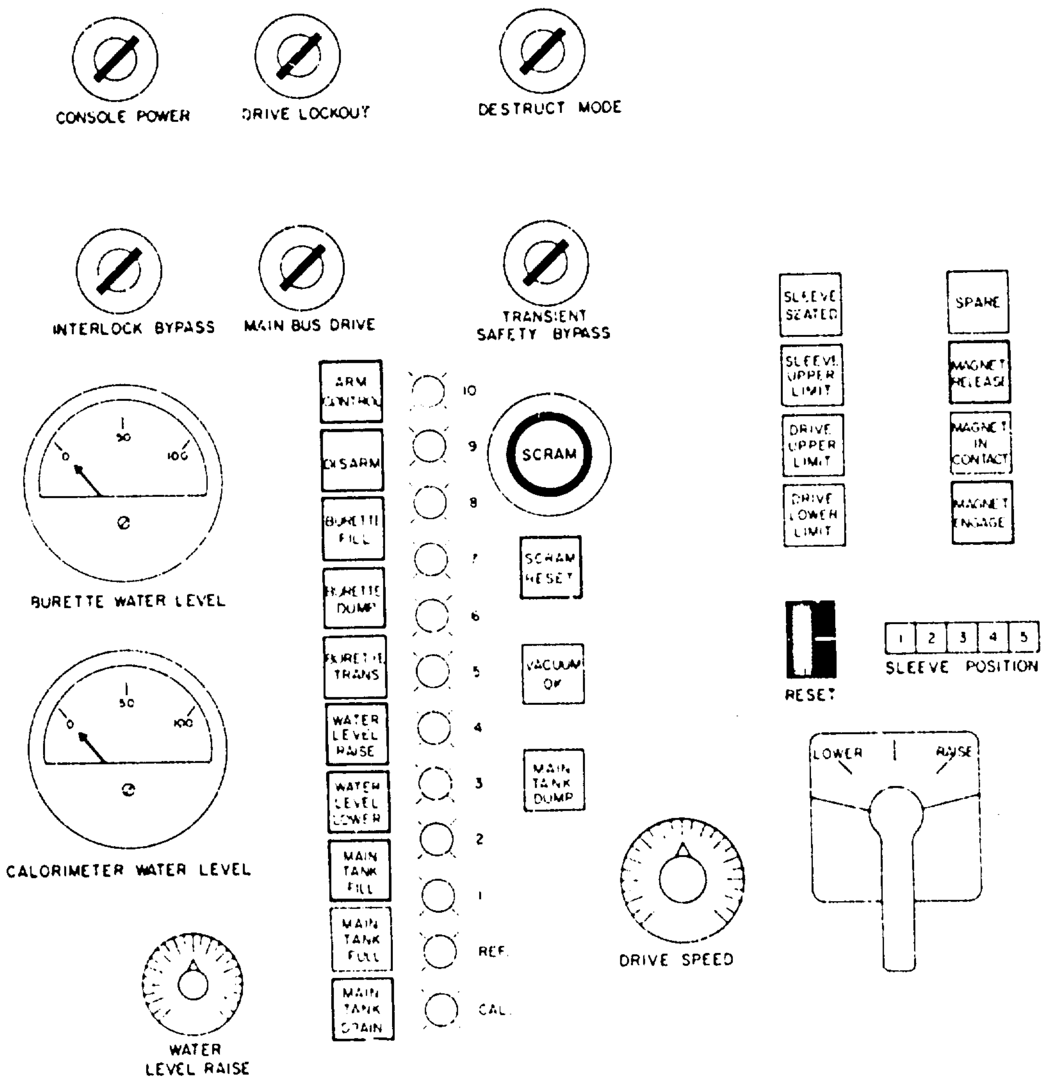

Figure III-9 - Control Console Panel Layout

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All control circuits operate directly from the console which contains the 16 relays necessary for interlocking circuitry. The basic power supply to the console is a 150 ampere hour, 26 volt lead-acid storage battery which supplies power for the reactor control system and the reactor instrumentation that requires 28 volt DC power. This battery is made up of 39 cells connected such that individual cells can be removed and replaced without interruption of service and is installed in a corrosion-free wooden enclosure for mechanical protection, providing a virtually failure-free source of power. A motor-generator set using commercial power is regulated at precisely 28 volts and continuously maintains battery charge.

All other reactor instrumentation requiring standard 120 volt AC power is supplied through an automatic transfer switch either from commercial power or from a 50 kilowatt gasoline driven alternator. Because the engine driven unit generally shows warning symptoms prior to failure, whereas commercial power outages generally occur with no warning whatsoever, the alternator will be considered the primary power source during nuclear operation.

Instrumentation is continuously supplied with power and can be turned off only at the breaker box or by pulling power plugs from receptacles inside the instrument enclosures.

All control power is brought through the Health Physics console power keyswitch on the SNAPTRAN 2/10A-1 panel. The Nuclear Test Section control power keyswitch is located on the SNAPTRAN 2/10A-3 console.

The area scram button network, the portable scram button, the AC power scram relay, and the period and level trip safety scrams of the SNAPTRAN 2/10A-1 system are utilized for the SNAPTRAN 2/10A-3 system. Auxiliary contacts on the SNAPTRAN 2/10A-3 power keyswitch remove these elements from the SNAPTRAN 2/10A-1 circuitry and incorporate them into the SNAPTRAN 2/10A-3 system.

The program sequence timer of the SNAPTRAN 2/10A-1 system will be used for the SNAPTRAN 2/10A-3 destructive test and may be used during the kinetics testing.

To minimize the probability of inadvertent detonation of the propellant charge, the leads from the pyrotechnic actuator detonator are kept separate from the remainder of the control system. These leads will be shunted, taped, coiled, and appropriately marked at the dolly junction box, safe from damage or being inadvertently energized.

2. Scram Control

Scram shutdown of the SNAPTRAN 2/10A-3 reactor may be accomplished either by dropping the poison sleeve from the raised position it must occupy during reactor operation or by draining water from the calorimeter by opening the dump valves. Dropping the sleeve is accomplished by de-energizing the electromagnet which couples the poison sleeve to its raising mechanism and draining the water is accomplished by de-energizing the solenoids which hold the dump valves closed.

The scram circuit is shown on the logic diagram, Figure III-10. As previously mentioned, power from the console power keyswitch is taken through the external scram circuitry of the SNAPTRAN 2/10A-1 control system. Re-entering the SNAPTRAN 2/10A-3 console, the circuit then passes through the main-bus-drive keyswitch, the console scram button, and the scram relay holding contacts, finally energizing the four parallel connected scram relays. When voltage is present at the scram button, as evidenced by the red lighted scram reset button, the scram relays may be picked up by pressing the reset button. This momentarily shunts the scram holding contacts which close when the relays are energized, whereupon, the reset light turns white. Two normally open contacts connected in series, one each from two of the scram relays, serve as the scram holding contacts. When the scram circuit is interrupted in any manner, these contacts open thus maintaining the interruption.

The sleeve magnet receives current from the scarm circuit. Thus the magnet can be de-energized by the scram button or any other of the above mentioned scram interlocks even if all of the contacts on all of the scram relays become welded closed.

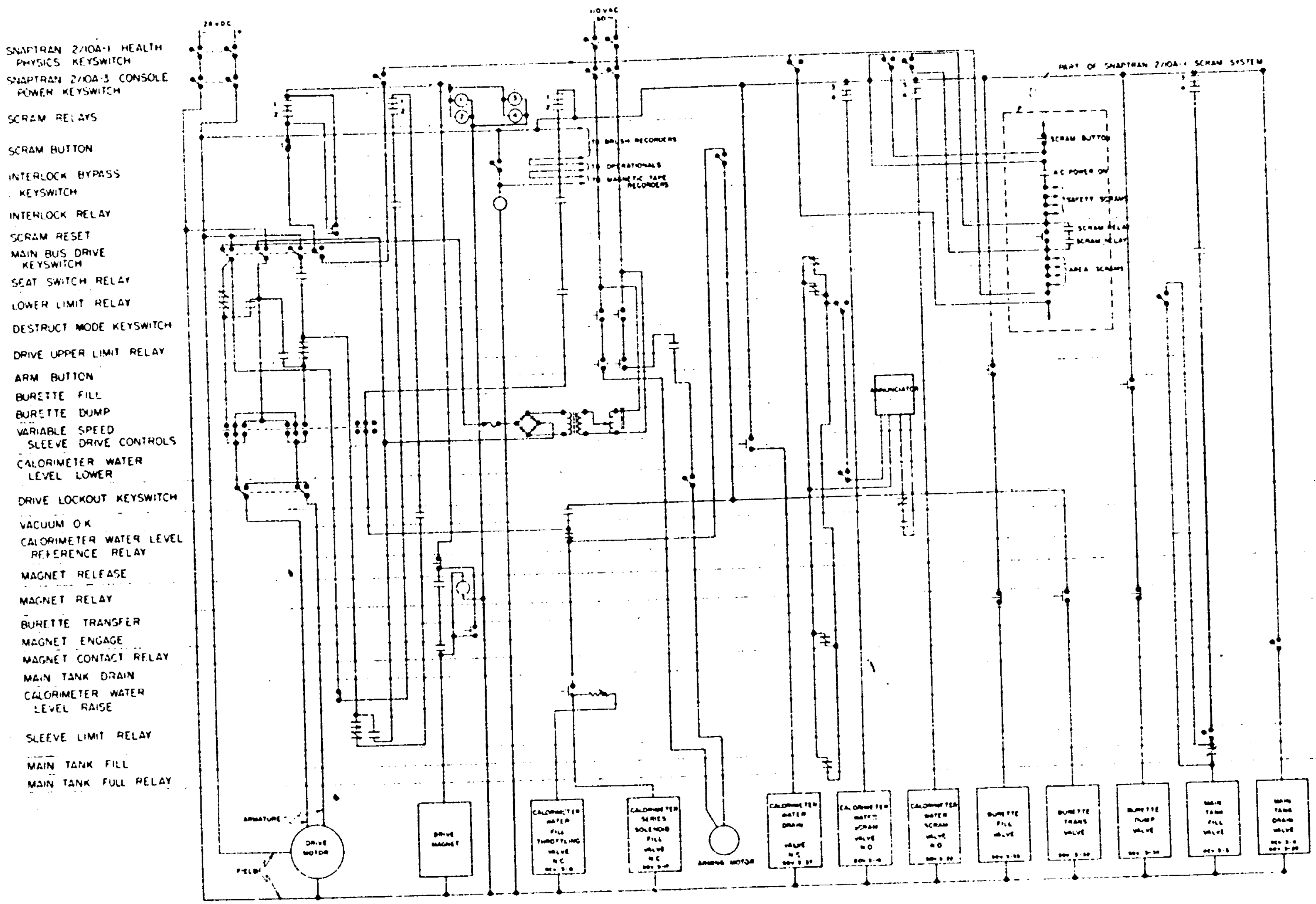

Figure III-10 - Control System Logic Diagram

The two 2-inch dump solenoid valves on the calorimeter are operated direcly by scram relay contacts, with no other control save the console power keyswitches. These valves are wired separately, having a contact from each of two scram relays connected in series similar to the scram holding contacts.

The sleeve-drive-motor withdraw circuit and the calorimeter fill circuit contain scram relay contacts which prevent operation when the scram relays are not energized. In every case a pair of relay contacts is used, one from each of two different relays, to decrease the probability of hazard from relay malfunction.

3. Water Level Control

a. Environmental Tank

Filling and draining the environmental tank is accomplished by a 350 gpm centrifugal pump which is controlled from the facility panel. Remotely controlled 3-inch valves will direct the water transfer. These valves are controlled by the main-tank-fill and main-tank-drain switches on the console.

Two level recorders provide indication of water level in the environmental tank. The range of one recorder covers the entire depth of the tank while the other covers only the top two or three feet. The upper-level recorder is provided with electrical contacts which actuate the main-tank-full indicator light and a relay which activates an alarm circuit if the water level falls below the setpoint.

b. Calorimeter

In addition to the scram-dump valves, the calorimeter has a throttled inlet, a throttled outlet, and a burette device for adding precisely measured amounts of water. The throttled inlet valve has a solenoid valve in series with it to reduce the hazard of inadvertent raising of the water level around the reactor. As in the environmental tank, there are also two level recorders - a coarse level recorder, the range of which includes the full depth of the calorimeter, and a fine level recorder which spans only the reactor vessel. A conductance probe is provided to indicate a fixed-reference water level one inch below the reactor core.

The water-level-raise switch on the console furnishes power to the calorimeter inlet solenoid and to the pneumatic controller of the calorimeter inlet throttle valve, if: (1) the sleeve-drive-control switch is in the off position, (2) the interlock relay is energized, (3) the scram relays are energized, and (4) the water level reference relay is not energized. The water-level-raise switch is a spring-return switch which must be held in the active position by the console operator.

The water-level-reference relay stops the filling process at a precise reference point just below the reactor core. Above this point, filling will normally be done by transferring measured quantities of water from the burette. However, if desired, the water-level-reference relay may be bypassed by the interlock-bypass keyswitch and filling from the inlet valve continued. No filling above the reference level is possible, whether by the burette transfer or the inlet valve, if the pressure in the scram discharge tank is greater than 10 psig. The vacuum tank effectively quadruples the available head for discharging water from the calorimeter when the scram valves open.

The burette is filled by actuating the burette fill switch on the console which opens a small solenoid valve. No interlocks are required to be satisfied. If the burette is overfilled or level adjustment is required for some other reason, the burette level may be reduced by pressing the burette dump switch, opening another small solenoid which releases water from the burette without changing calorimeter level. All calorimeter and burette water level switches are spring-return type.

4. Electromechanical Sleeve Drive

The mechanism for vertically positioning the poison sleeve with respect to the reactor core, is a modified Advanced Reactivity Measurement Facility (ARMF) control rod drive, consisting of a Saginaw ball-screw and nut, a pair of bevel gears, and a worm-gear set driven by a 1/4 hp electric motor. The motor is a two-pole, compound-wound, 32 volt, commutator-type DC motor modified for armature voltage speed and direction control and dynamic braking. Static braking is provided by the worm-gear set which has a 50:1 ratio and is non-overhauling.

The series field of the motor is disconnected to allow remote reversing of the armature current. The shunt field is connected directly through a cable to the console power switch and is continuously energized by the 26-volt bus. The armature voltage is provided through a reversing switch from a 0-26 volt rectifier power supply. This power supply is mounted in the console and consists of a 0-135 volt variable transformer, a 5:1 step-down transformer, and a full-wave silicon-diode bridge, all conservatively rated with respect to the loading of the sleeve drive. Resistance of the motor circuit limits the maximum starting current to 25 amperes.

A synchro transmitter, geared to the drive, is electrically connected to a synchro receiver on the console. The receiver drives a digital indicator which shows drive position in hundredths of an inch.

Cam operated switches are provided to give indication at limiting drive positions: (1) mechanical lower limit, (2) mechanical upper limit, and (3) the position at which the bottom of the raised sleeve is one inch below the top of the reactor vessel (upper limit). The lower limit and upper limit switches are redundant pairs of microswitches actuated by a cam on the draw bar. The mechanical upper limit switch is actuated from one of two worm-driven cams, geared to the sleeve drive mechanism.

When the sleeve draw bar is driven down, a 390 ohm electromagnet on the lower end of the draw bar extends into the pyrotechnic actuator cylinder where it engages the actuator piston which serves as the magnet armature. Contact with the piston is indicated by a miniature microswitch within the magnet solenoid. The piston rod extends from the bottom of the pyrotechnic actuator and attaches to the binal sleeve. A microswitch actuated by the bottom of the sleeve gives indication when the sleeve is seated in its lowermost position around the reactor vessel.

To enable the drive to be raised to the mechanical upper limit where it will not interfere with the pyrotechnic actuator for the destructive test, a main-bus-drive keyswitch is provided on the control console. With this keyswitch the main-bus power may be substituted for the variable voltage power for the motor drive. The main-bus-drive keyswitch de-energizes the scram bus and a seat-relay interlock requires that the sleeve be in the seated position for the drive to operate from the main bus.

In addition to the mechanical-limit switches, the sleeve-raising circuit contains the following operational interlocks: (1) water-level-raise switch, (2) interlock relay, (3) vacuum-indicating relay, and (4) scram relays. These interlocks prevent the sleeve from being raised while water is being admitted by the inlet valves, while insufficient vacuum is available for scram discharge, or until the scram circuit is energized. In addition, the interlock relay which indicates that the power level monitoring instrumentation is in operation must be energized.

For termination of sleeve withdrawal during ramp reactivity insertion tests, a cam operated adjustable limit switch, driven by a synchro receiver in the position-indication circuit, is provided. This switch will energize the sleeve-limit relay to stop the sleeve at a precisely preset position. Ramps will be initiated manually by means of the drive control switch. There are no operational interlocks in the sleeve lowering circuit.

The sleeve drive magnet derives current from the scram circuit. A spring-return, magnet-engage pushbutton energizes the magnet relay which is then held by one of its own circuits, provided the magnet-contact relay gives indication that the magnet is in contact with the armature. Pressing the magnet-release pushbutton, a normally closed spring-return switch, breaks the circuit to the magnet relay, thus de-energizing the magnet.

5. Pyrotechnic Actuated Sleeve Drive

A pictorial representation of the sleeve ejection mechanism showing the powder chamber and detonating squibs in the safe position is shown in Figure III-8. Arming for the destructive test will consist of running the electromechanical drive to its upper limit, rotating the powder chamber into the actuator cylinder, and activating the squib detonating circuits.

The destruct-mode keyswitch on the console will activate the powder-chamber rotating circuit, deactivate the drive-lockout alarm, and close the normally open solenoid valves on the reactor tank drain. The main-bus-drive keyswitch will enable the draw bar to be driven to the mechanical upper limit, clear of the pyrotechnic actuator. The drive will be immobilized in the upper limit position by the drive-lockout keyswitch. When these conditions have been established, interlocks in the arming circuit will be satisfied and enable the powder-chamber rotating motor to be operated by the arm switch (a spring-return pushbotton). The final step in the arming procedure will be to connect the detonator leads to the appropriate sequence timer terminals.

6. Alarms and Auxiliary Circuitry

Two facility panel annunciator alarms, the drive-lockout alarm, and the insufficient-vacuum alarm are connected to the control system. The drive-lockout keyswitch, in addition to its use in the destructive test, serves to ensure the safety of any personnel who may be required to enter the test cell following the power calibration. This switch disconnects the drive motor from all other circuitry and activates an alarm circuit which gives warning if: (1) the sleeve-seat switch is not actuated, (2) the magnet-contact switch is not actuated, (3) the lower-limit switch is not actuated, and (4) the environmental tank and calorimeter level recorders do not indicate that the tank is full.

During transient tests, reactor periods and power levels may be expected to reach values above the setpoints of the safety-scram circuit. To permit transient testing, it is therefore necessary to incorporate a keyswitch into the control system which will temporarily bypass the safety circuits. The transient-safety-bypass keyswitch (spring-return) energizes a relay which bypasses the safety trip portion of the scram circuit and remains energized until the manual reset button is pushed, the scram circuit is de-energized, or the console power is turned off.

For transient tests and for the destructive test, the sequence timer of the SNAPTRAN 2/10A-1 control system may be used to start recording instruments, to energize firing circuits, and to terminate tests by scramming.

H. Operational Instrumentation

For effective surveillance of the nuclear state of the reactor, the reactor operator will have control of and indication from at least:

(1) Two channels of neutron pulse counting equipment, covering in overlapping ranges, the source level to one watt.

(2) One channel of linear power recording equipment covering 10 mw to 100 kw.

(3) One channel of log power recording equipment covering 100 mw to 10 Mw.

(4) Two channels of log n period and level transient safety equipment covering 1 watt to 1 Mw with period trip set for 10 sec and level trip set for 2 kw.

(5) One disaster channel of log power covering 100 kw to 100 Gw.

The detectors for the low-level startup and linear power channels will be placed beneath the reactor so as to minimize the variable shielding effect of changing water level and sleeve position. The threshold of sensitivity for these detectors will be 1 cps for 10^2 nv at the reactor for the startup channel and 10^{-12} amps for 2×10^5 nv or 10^{-2} watts at the reactor for the power channel. A block diagram of the operational instrumentation is shown in Figure III-11.

A neutron source will be placed above the reactor so as to be seen through the reactor by the startup channel detectors. For initial startup and operation a 0.3 curie Po-Be source will be used.

I. EG&G Equipment

The mechanical equipment employed by Edgerton, Germeshausen, and Grier (EG&G) for photographic coverage of the SNAPTRAN 2/10A-3 destructive test has been evaluated and it is Phillips Petroleum Company's conclusion that the installed hardware does not require further safety analysis. The EG&G equipment installed in the environmental tank consists of three periscopes, two sets of flash lamps or "back-lights" all of which are installed on the internal periphery of the environmental tank, and a 24 in. square metal screen "target" placed between the reactor

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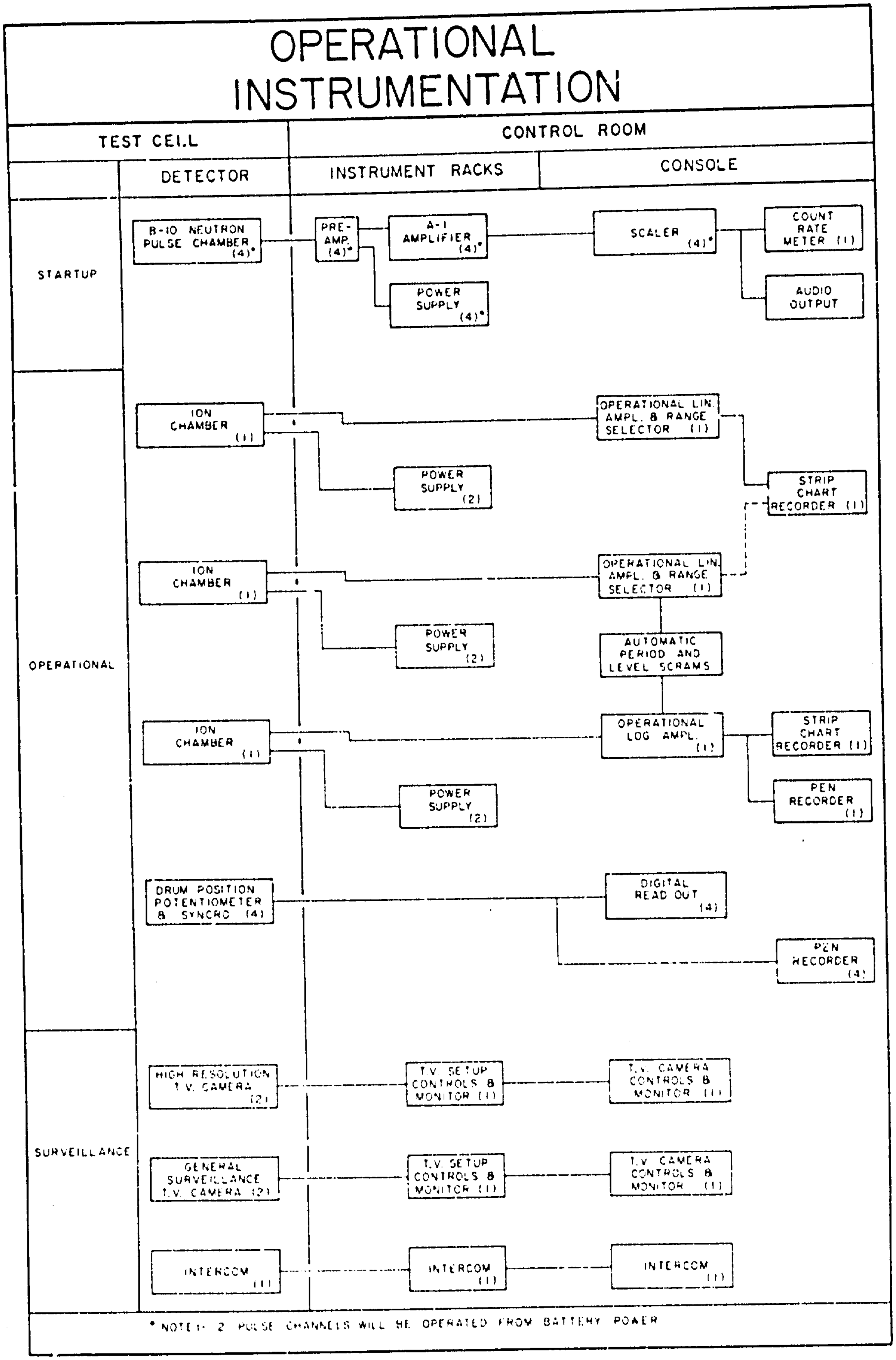

Figure III-11 - Operational Instrumentation Block Diagram

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vessel and the "back-lights". The periscopes, which are fabricated from aluminum, each measure 19 in. by 27 in. in cross-section and are filled with demineralized water whenever there is water in the environmental tank. When the water is removed from the environmental tank the periscopes will also be drained.

The "back-lights" are located on the opposite side of the environmental tank from the periscopes at the approximate elevation of the reactor vessel. Each of the lights measures approximately 18 in. by 24 in. by 6 in. thick.

This "in-tank" equipment does not constitute a perturbation to the nuclear characteristics of the system and therefore will not affect the safety of the system.

J. Experimental Instrumentation

The experimental program encompasses particular objectives, each of which prescribes specific measurement requirements. To acquire the maximum amount of meaningful information from a planned nuclear excursion, measurements must be made to determine the radiation hazards, reactor kinetic behavior, reactor disassembly behavior, and the extent of physical damage to the reactor system and to the immediate environment.

Measurements will be made to provide information concerning fission product buildup and spread, radioactive component spread, and direct radiation doses[3]. Reactivity, nuclear power, period, and nuclear energy deposition measurements, including space-time flux measurements, will be made to determine the presence of shutdown mechanisms due to mechanical, thermal chemical, and nuclear effects. Measurements of nuclear heat deposition, pressure, and component kinetic energy will be made to indicate the physical processes occurring during disassembly.

The number and types of measurements which can be made is dependent on the detector and recorder capabilities. Therefore, to provide optimum utilization of the transient measuring and recording capabilities, all measurements will be made on the basis of the relative importance of the test objective, the applicable measurable phenomena, the phenomena generation time and duration, and the dynamic range.

Measurements will be made to provide dynamic range and spatial gradient coverage as well as amplitude, event-time, and time-history accuracy. Redundancy of detectors, location, ranges, and recorder channels will also be provided. The experimental measurements and the type of detectors which will be used in the destructive test are as follows:

Within the Reactor Vessel

(1) Miniature flux monitors for determining the radial and axial neutron flux distribution during the power rise and for correlating the destructive power rise with the power calibration data.

(2) Energy probes for determining energy deposition as a function of time and the determination of the onset of hydrogen release.

(3) Fuel-clad strain gauges for determining the time-history of radial and axial fuel rod rupture during disassembly.

(4) Fuel-grid strain gauges for determining pressure propagation behavior of reactor disassembly.

(5) Strain gauges on the vessel shell and head for determining vessel rupture behavior.

(6) Pressure transducers for determining the pressure buildup before vessel rupture.

Within the Environmental Tank

(1) Neutron and gamma detectors for determining the power behavior as seen through several feet of water.

(2) Miniature flux monitors for determining the power behavior as a function of distance from the core.

(3) Fast neutron detector and flight tube arrangement for determining the nuclear power time-history.

(4) Active pressure transducers for determining the time-history of the total mechanical energy development (nuclear and chemical) and the directional and source size characteristics of the pressure generation.

(5) Passive pressure detectors for determining peak pressures.

(6) Time-of-arrival detectors for determining peak pressure if phenomena rise-times are shorter than the response-time of the pressure detectors.

(7) Water surface velocity and displacement detectors for additional measurement of mechanical energy development.

(8) Strain gauges on the reactor support pedestal for additional measurement of the disassembly forces.

External to the Environmental

(1) Air pressure detectors for determining the effective mechanical energy transferred from the environmental tank to the environment.

(2) Time-of-arrival detectors for determining the peak air pressure.

(3) Fast response temperature detectors near the environmental tank for determining the possible chemical reaction time-history.

(4) Strain gauges on the environmental tank for determining the strain energy absorbed.

(5) Displacement detector on the pyrotechnic actuator for determining the reactivity insertion rate.

(6) Strain gauges and accelerometers on the flatcar and actuator bridge for determining the impulse transferred to these structures.

(7) Blast protected gamma detectors beneath the flatcar for determining the near-field dose and dose rate.

(8) Gamma detectors at various radii from the tank for determining the far-field dose and dose rate.

(9) Photographic equipment in a quasi X-Y-Z array using color to 300 f/sec, black and white to 10,000 f/sec, and rapid sequence cameras to 25 f/sec for both data acquisition of the destructive phenomena and documentary coverage of the test. A block diagram of the experimental instrumentation is shown in Figure III-12.

(10) Extensive downwind radiological measuring equipment located on a monitoring grid [1].

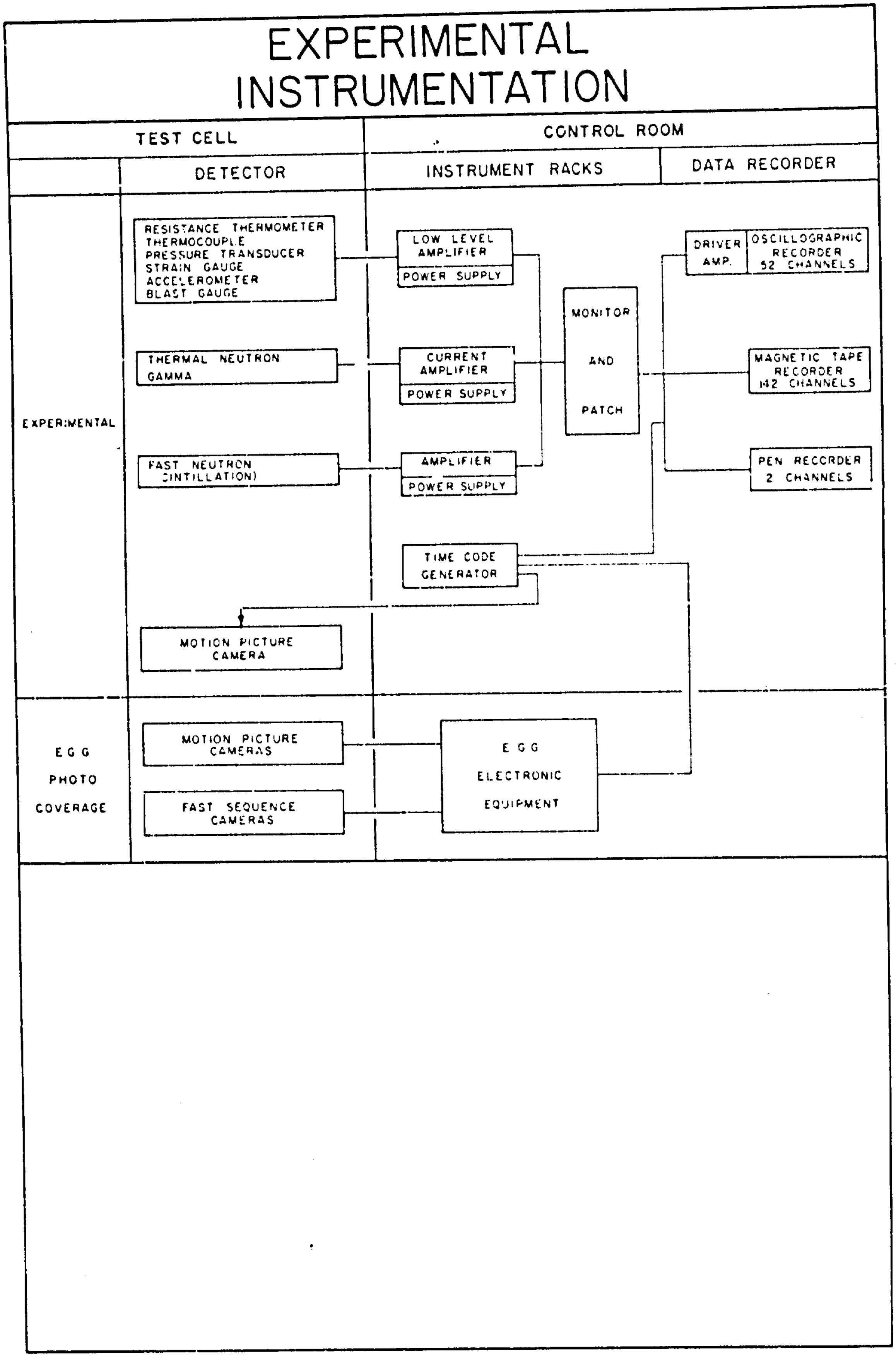

Figure III-12 - Experimental Instrumentation Block Diagram

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IV. NUCLEAR CRITICAL EXPERIMENTS AND CALCULATIONS

A. Introduction

Critical experiments were performed by Atomics International using the SNAPTRAN 2/10A-3 fuel. The experiments were carried out in the SNAP critical assembly (SCA-4B). The objectives of these experiments were to:

(1) determine the critical loading and excess reactivity of the water-reflected SNAPTRAN 2/10A-3 core for comparison with other SNAP 2/10A core loadings, and

(2) determine the feasibility of utilizing a poison sleeve to control the reactor.

The pertinent results of a preliminary analysis of these experiments are that the excess reactivity of the water-reflected SNAPTRAN 2/10A-3 core is at least $3.60, and that the poison sleeve can maintain the water-reflected SNAPTRAN 2/10A-3 core far subcritical. The critical sleeve height with the reactor fully immersed in water is 7.75 in. above the lower end of the fuel[4,5]. Table IV-A summarizes the experimental results.

B. Comparison of SNAPTRAN 2/10A-3 and SCA-4B Configurations

Figure IV-1 shows the core region geometric configurations in the SCA-4B experiment and the SNAPTRAN 2/10A-3 destructive experiment. The fuel elements, beryllium internal reflectors, and grid plates are identical in these two configurations. These components are coded to permit exact reassembly in the SNAPTRAN 2/10A-3 reactor vessel. The reactor vessel in both configurations was fabricated from 0.031-in.-thick 316 stainless steel.

The SNAP 2/10A design vessel head is used in both configurations. The SCA-4B head is the unmachined forging and does not incorporate the NaK outlet pipe. The SNAPTRAN 2/10A-3 head will incorporate NaK filling and pressure transducer mounting ports. These differences are expected to produce only a minor effect on excess reactivity.

TABLE IV-A

SUMMARY OF SNAPTRAN 2/10A-3 AND SCA-4B CRITICAL EXPERIMENTS

Configuration	Active Core Submersion Level (in.)	Portion of Core Covered by Sleeve (in.)	Fuel Loading[1] (rods)	Excess Reactivity ($)
Reflected only	full	0	32.7 ± 0.2	0
Reflected only	(2)	0	33	0
Reflected only	11.21	0	34	0
Reflected only	10.21	0	35	0
Reflected only	9.45	0	36	0
Reflected only	9.02	0	37	0
Reflected only	full	0	37	3.6 ± 0.20
Reflected 1/4" Binal 1/4" from core	full	all	37	< 0
Reflected 1/4" Binal 1/4" from core	full	8.55	37	< 0
Reflected 1/4" Binal 1/4" from core	10.41	2.69	37	0
Reflected & Flooded, 1/4" Binal adjacent to vessel	full	all	35.5 ± 0.2	0

(1) Lucite rods are located in vacant fuel positions.

(2) Water partially covered vessel head.

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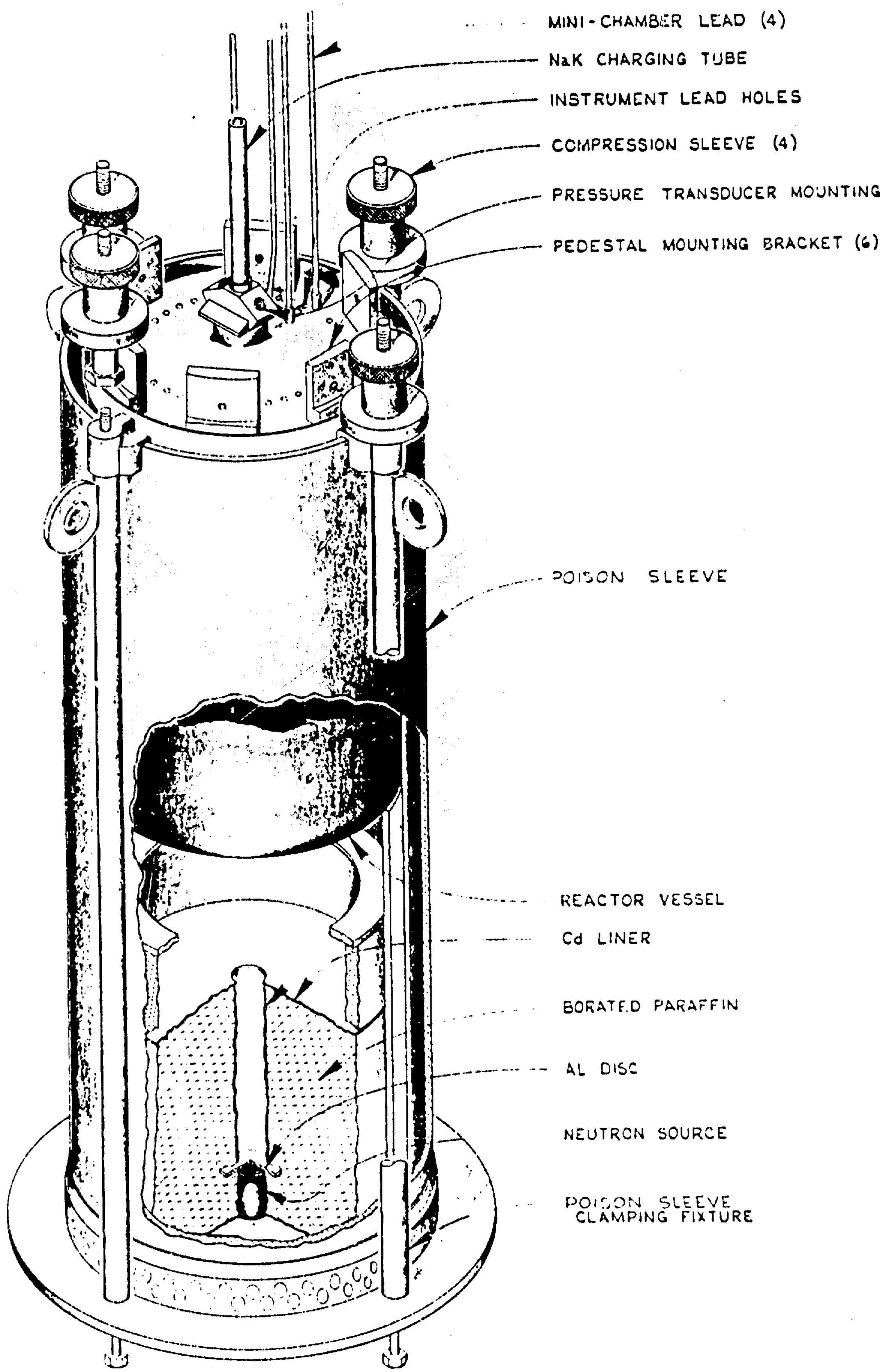

Figure IV-1 - Geometric Configurations of the SNAPTRAN 2/10A-3 and the SCA-4B Critical Experiments

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The main differences in configurations occur in the tops and bottoms of the vessels. The bottom water reflector is slightly closer to the fuel region in the SCA-4B configuration. It is estimated that the 0.25-in.-thick aluminum plate in the SCA-4B machine does not significantly affect the reactivity. The top water reflector is 0.28 in. farther away from the fuel region in the SCA-4B. This additional distance is a void region, and probably results in the greatest reactivity difference, although small, between the two configurations. The minimum axial water reflection of 3.5 inches in the SCA-4B in this region is essentially equivalent in reactivity effect to an infinite reflector.

Another difference, expected to result in minor reactivity effects, is that the SNAPTRAN 2/10A-3 core will be filled with NaK whereas the SCA-4B core was not.

C. Experiments

1. Critical Loading

With full water reflection the core was loaded to critical by substituting fuel elements for lucite rods. Lucite rods were located in the vacant fuel positions. Criticality was achieved on the 33rd. fuel element with 1.64 in. of water beyond the end of the fuel element. (In the SCA-4B configuration the water did not completely cover the vessel head.) The extrapolated critical loading (determined from source multiplication at each element loading) was 32.7 $\pm$ 0.2 elements.

Additional fuel elements were substituted for lucite, maintaining criticality by varying the water level in the top tank. With a full loading of 37 fuel elements criticality was obtained with the core submerged in water to 9.02 in. of the fuel element length.

2. Poison Sleeve Experiments

A 1/4-in.-thick cylindrical poison sleeve (binal) was positio around the reactor vessel 1/4-in. from the vessel. With full water reflection, including water between sleeve and core, the fully loaded core was far subcritical with the sleeve covering either all or 8.53 in. of the fuel element length. With the sleeve covering 2.69 in. of the

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fuel element length the core was supercritical by an estimated $1.50, based on criticality when the core was submersed to 10.41 in. of the fuel element length.

The sleeve circumscribed the core vessel. With this sleeve configuration the water-flooded-and-reflected core was critical on an extrapolated fuel loading of 35.5 fuel elements.

3. Reactivity Measurements

The determination of the excess reactivity of the fully-loaded water-reflected core was based on positive period measurements. Starting with a loading of 33 fuel elements, additional fuel elements were substituted for lucite rods, maintaining criticality by either varying the water reflection or poisoning the core with special splines in the element interstices. The incremental reactivity worth of water reflection over a range of full to approximately $1.20 less than full reflection was determined by placing the assembly on positive periods. Utilizing these measurements the reactivity worth of each additional fuel element was determined, always maintaining, by poison splines, nearly full water reflection. The excess reactivity of the fully loaded assembly determined by these techniques is approximately $3.60. The incremental reactivity worth of substituting each fuel element for lucite is $0.80 to $0.85/element.

The reactivity worth of water above the vessel head in the SCA-4B assembly is approximately $0.60. This value should be used only as an indication of the worth of water in this region in the SNAPTRAN 2/10A-3 destructive assembly, because of geometric differences between these two assemblies.

D. Calculations

In order to assess the reactivity state of the reactor during the proposed SNAPTRAN 2/10A-3 experimental program, calculations were performed to determine the reactivity worth associated with reactor environmental changes. These calculations have been normalized to three particular experiments performed on the SCA-4B critical facility at Atomics International[4,5].

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(1) Using a diffusion theory, radial calculational model[6], the reactivity worth of NaK in the core is estimated to be plus \$0.55 with or without the sleeve around the dry reactor.

(2) Placing the plexiglass calorimeter around the dry reactor results in a calculated reactivity increase of plus 26 cents and an additional increase of plus 15 cents when water surrounds the calorimeter. These calculations were also performed using a radial model[7].

(3) The shutdown reactivity of the reactor when surrounded by the poison sleeve and fully immersed in water is estimated to be approximately minus \$7.09. This estimate is based upon the results of two dimensional (R-Z) diffusion theory calculations[8].

(4) Interlocks provided by a poison sleeve seat switch prevents water from being added to the calorimeter unless the poison sleeve is in its inserted or seated position. Thus reactor startups can be accomplished only by withdrawal of the poison sleeve.

A radial transport model[9] was used to describe the reactivity effects of the poison sleeve when surrounding the SNAPTRAN 2/10A-3 reactor. The total reactivity effect of surrounding the water immersed reactor with a 1/4 inch Binal sleeve was calculated to be minus 10.70 dollars. The calculations showed that by surrounding the reactor in air with the poison sleeve the reactivity was increased by 1.30 dollars. The maximum reactivity insertion rate is limited mechanically by controlling the sleeve withdrawal rate which is calculated to be 5 cents per seond during withdrawal of the poison sleeve in water. The scram trips are set for a 10 second or less period and 2 kw maximum power level.

Under the conditions of a reactor scram occurring with the lower edge of the sleeve well below the water surface, the subsequent release of the sleeve will insert negative reactivity and consequently shut the reactor down. The condition of scramming the reactor with the sleeve positioned above the water surface will insert positive reactivity until the lower edge of the sleeve approaches the water surface. Two facets of this condition are:

(1) The maximum amount of reactivity which can be present when lowering the sleeve over the portion of the reactor surrounded by air is the same amount present when the bottom of the sleeve is raised to the level of the water surface. If this amount of reactivity is enough to cause the 10 second period scram to trip (i.e., 42 cents), scram would occur with the bottom of the sleeve at the surface. But, if this amount of reactivity is not sufficient to cause the 10 second period scram to trip (i.e., less than 42 cents), then only that amount (i.e., less than 42 cents) can be inserted when scramming the sleeve in air, even if the water surface has not moved to reduce reactivity. Since the reactivity worth of the sleeve in air is much less than the reactivity worth of the water around the reactor, any reduction in water height during the sleeve travel in air would reduce the total reactivity inserted at scram.

(2) The critical water height with the sleeve raised above the reactor was measured by Atomics International to be 9.02 in. above the lower end of the fuel. The increase in reactivity resulting from lowering the sleeve around that portion of the reactor above the water surface (3.23 in.) is calculated to be plus 33 cents.

Under either of the two conditions presented above, the reactivity before, during, or after scram will never exceed the levels which are allowed during normal reactor operation.

V. OPERATING PHILOSOPHY AND NUCLEAR TEST PROCEDURES

A. Introduction

The objective of the SNAPTRAN 2/10A-3 test program is the modeling of the maximum credible accident which may conceivably occur as a result of the reactor falling into water during launch or ascent. The operating philosophy and test procedures which promote the safe conduct of these tests are discussed below.

B. Organization

1. AED Organization

The responsibility for conducting the SNAPTRAN 2/10A-3 experimental program has been assigned to the Atomic Energy Division of Phillips Petroleum Company. The four major subdivisions of the AED are Administration, Engineering, Operations, and Technical. The Reactor Projects Branch, which is a part of the Technical activity, has the responsibility for all reactor safety testing within the Division. That portion of the safety testing which involves the SNAPTRAN 2/10A-3 program will be carried out by the STEP Project. The relationship of the STEP Project to other branches of the AED is shown in Figure V-1.

2. STEP Organization

The STEP organization is shown in Figure V-2. The organization consists of four sections: Engineering, Nuclear Test, Experiments, and Data Reduction and Analysis. The functions and responsibilities of the four sections are summarized below.

a. Engineering Section

This section is responsible for providing engineering service to the STEP organization. These services include: assistance in planning, design, and conduct of engineering type experiments; the design of new facilities, modification of existing facilities, construction liaison, systems acceptance testing and plant engineering; and nuclear engineering, including core and containment design, radiological evaluation, and hazards analysis.

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PHILLIPS PETROLEUM COMPANY

ATOMIC ENERGY DIVISION

ORGANIZATION OF THE ATOMIC ENERGY DIVISION

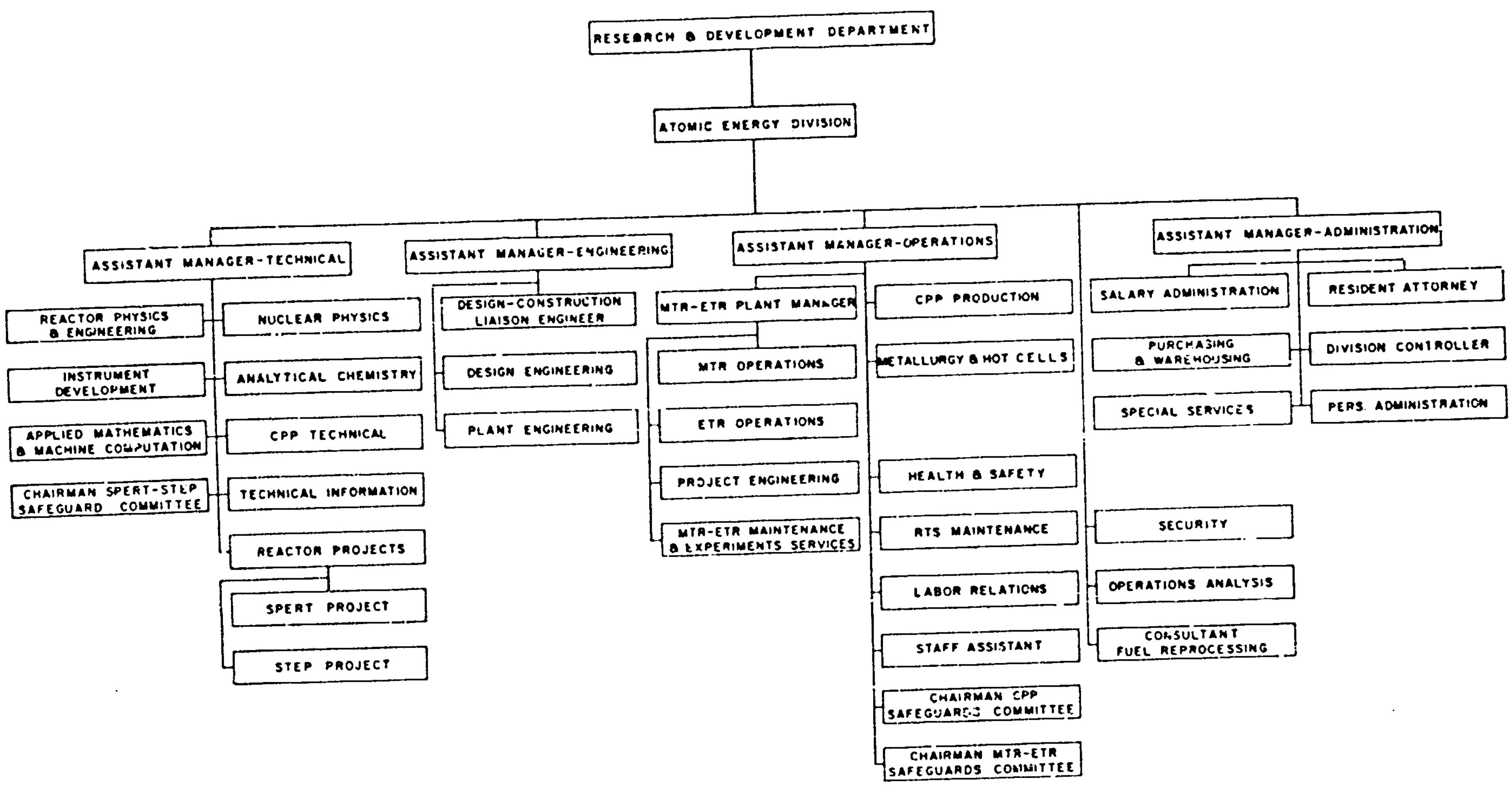

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Figure V-1 - Phillips AED Organization

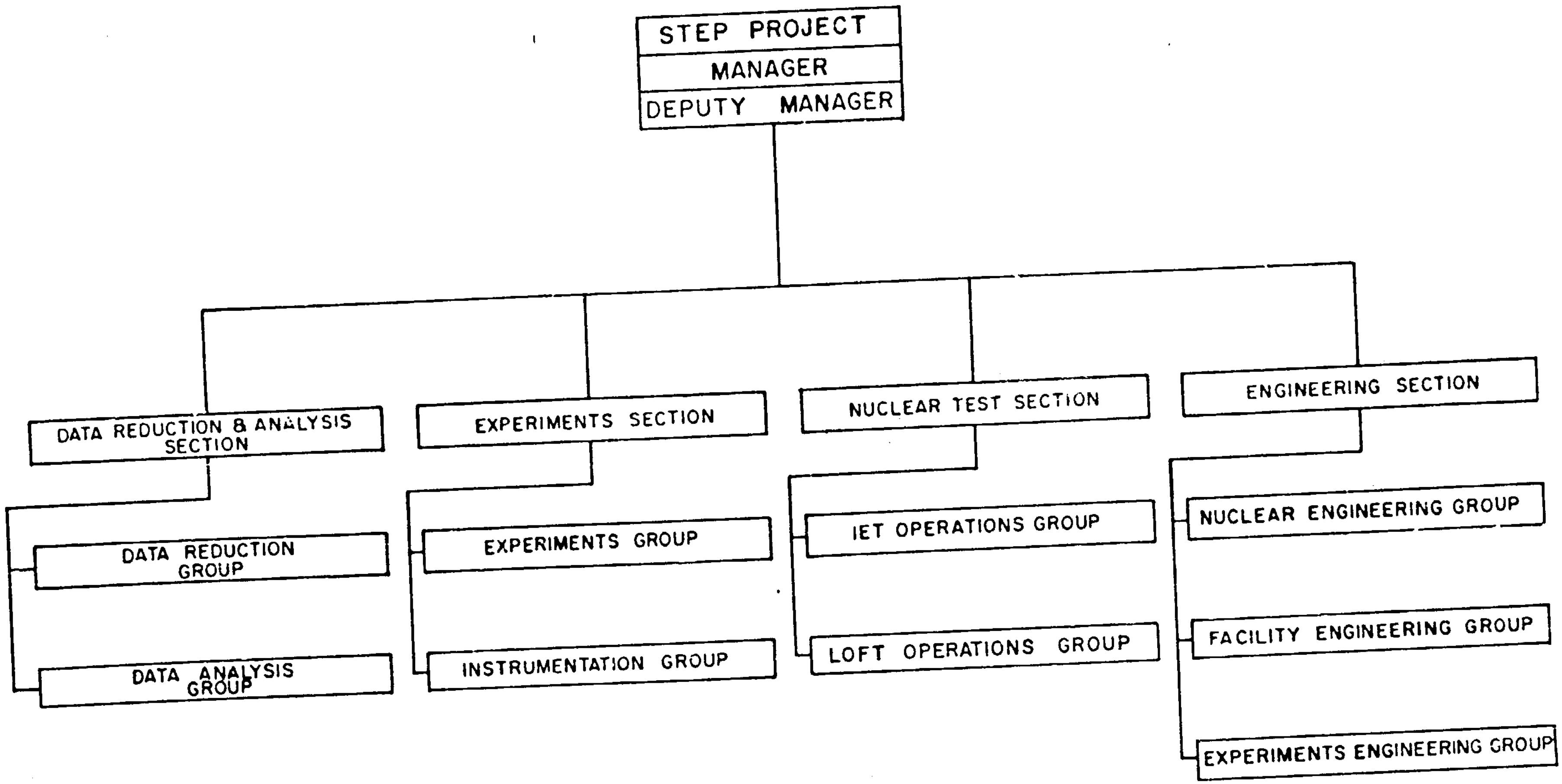

Figure V-2 - STEP Organization

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b. Nuclear Test Section

This section is responsible for carrying out all reactor and plant operations and for the coordination of all maintenance activities in the respective facilities.

c. Experiments Section

This section is responsible for planning, initiation, and routine analysis of all experiments to be performed. This section is also responsible for nuclear surveillance of all operations in the reactor area and during transportation of the reactor to and from the examination area. In addition, the section is responsible for the design, installation, calibration, and maintenance of all operational and experimental instrumentation and data processing equipment.

d. Data Reduction and Analysis Section

This section is responsible for the reduction, handling, and storage of experimental data. In addition, the section is responsible for the analysis and interpretation of the experimental data and for development of analytical models and calculational techniques which will assist in correlating experimental data with the physical theory.

3. Supporting Organizations

Supporting services are supplied to the STEP Project by other branches of the AED. Other branches supplying service include: Reactor Physics and Engineering, Applied Mathematics and Machine Computation, Instrument Development, Analytical, Engineering, Health and Safety, and Maintenance. In addition, a number of special committees appointed by the Division Manager are responsible for assuring the safe conduct of all operations by reviewing policies and procedures and evaluating hazards attendant to the operations. These committees include the following:

(1) The Safeguard Review Committee, which is responsible for determining that all operating policies and procedures are safe, current, and complete.

(2) The Nuclear Safety Committee, which is responsible for review, for providing consultation services, and for searching out of areas in which there could be a criticality hazard.

(3) The SPERT-STEP Safeguard Committee, which is responsible for review and approval of all reactor core loadings and control systems, operational procedures, and experimental programs from a nuclear safety viewpoint.

C. Planning and Approvals

The method of operation and scope of the test to be performed on the SNAPTRAN 2/10A-3 reactor necessitate thorough planning and extensive review of the proposed procedures employed by the STEP Project. These procedures are reviewed once each year by the Safeguard Review Committee.

The Experiments Section Chief is responsible for the preparation of a written Test Series Proposal. This proposal will include a statement of the objectives of the test series and its relation to the overall program, the expected results, any potential hazards to be expected, and the approximate time schedule.

The Test Series Proposal will first be reviewed in detail by the STEP senior staff. Following this review a presentation of the Test Series Proposal will be made to the SPERT-STEP Safeguard Committee.

After the Safeguard Committee's approval has been obtained, the Reactor Projects Manager will note his approval and the Test Series Proposal will be forwarded to the Assistant Manager, Technical, for his approval. Following approval by the Assistant Manager, Technical, the report will be transmitted to the Idaho Operations Office for review and approval.

Prior to conducting a test, the Experiments Section Chief will call a planning meeting. The attendance of Experiments Group Leader, Nuclear Test Section Chief and Group Leader, and any additional persons designated by the Experiments Section Chief will be required. The Test Series Proposal will be reviewed and detailed plans for performance of the tests will be made.

It is then the responsibility of the Nuclear Test Section Chief to prepare the test procedures that are to be followed. He will also be responsible for informing all operating personnel of the test objectives, the procedures to be followed, the expected results, and any unusual procedures which may be required as a consequence of the test results. Each person will be made aware of his individual responsibility and his working assignment for the test series.

In addition to the specific operating procedures necessary for the performance of a particular test, certain basic nuclear test procedures will apply during the entire SNAPTRAN 2/10A-3 program. These basic procedures are discussed below.

D. Operating Philosophy

Since the objective of the SNAPTRAN 2/10A-3 experimental program necessitates operation of the reactor under conditions normally considered hazardous, extensive administrative controls must be relied upon to minimize the probability of nuclear incidents, to insure the safety of STEP personnel and the NRTS, and to eliminate hazard to the general public. Safety of operating personnel is assured by the requirement that all personnel in the test area be in the control and equipment building and no closer to the reactor than the control room during any nuclear operation. Safety of other than operating personnel is assured by the requirement that meteorological control be exercised during all tests in which fission product release can be reasonably expected. Protection of the reactor system from excursions which could cause premature damage is assured by administrative control, interlock systems, and by automatic period and level scrams to be used during poison sleeve positioning operations and critical water height measurements.

E. Nuclear Test Procedures

1. Administrative Control

Administrative control of the STEP program is outlined in the Standard Practices Manual, a written reference containing the basic rules and instructions regulating the safe and efficient operation of the STEP

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facilities. Each person connected with the test program is responsible for becoming thoroughly familiar with those instructions which pertain to his particular phase of the operation.

The STEP Nuclear Test Section is responsible for all nuclear operations including static physics measurements and kinetics tests, and for all non-nuclear operations in the IET including plant modifications, maintenance, and fuel handling. During those periods when the reactor is in transport between TSF and IET, the Nuclear Test Section is also responsible for all operations involving the reactor.

2. <u>Reactor Assembly Procedures</u>

Prior to nuclear operation of the reactor, a number of operations involving nuclear hazards must be completed. These operations include fuel loading, welding the top head to the vessel, seal welding the instrument leads, helium leak testing, charging the system with NaK, making the final seal weld, and installing the loaded reactor vessel in the environmental tank. Procedures for accomplishing these operations in a safe manner have been written and will be distributed to those personnel involved in the operations.

During most of the above mentioned operations, the reactor vessel will be attached to a stand which is mounted on one end of the SNAPTRAN 2/10A-3 railroad dolly and at all times it will be surrounded by a Binal poison sleeve. Only one person at a time is to approach closer than six feet to the reactor, except with the express permission of the Nuclear Test Section Chief or his designated alternate.

The minimum neutron instrumentation to be in operation while work is in progress on the reactor will be one linear power recorder, one log power recorder, and two pulse systems. The detectors for the neutron instruments will be placed in close proximity to the reactor vessel and will be used until the normal instrumentation in the water tank is put in service.

Any operation on the reactor which could possibly affect the reactivity of the system (e.g., loading fuel, charging with NaK, etc.) will be monitored with the neutron pulse counting systems and in the case of operations involving permanent reactivity changes, 1/M plots will be maintained. The information from these 1/M plots in conjunction with the information gained from the SNAPTRAN 2/10A-1 critical loading experiment will be used to determine the subcritical state of the reactor.

3. <u>Work Procedures with Reactor Shut Down</u>

Nuclear safety considerations dictate that several procedures be followed concerning work in the reactor building and work on or very close to the reactor. Approval must be obtained from the Nuclear Test Section Chief or his designated alternate prior to any entry into the reactor building. Prior to and entry to the test cell, the responsible supervisor will ascertain to the best of his judgment, that the reactor is shut down and that the environmental tank is also dry with no significant moisture remaining and that no foreseeable circumstances will cause the tank inner surfaces to become wetted during the shut down period. A surveillant physicist must be present when any personnel are on or above the railroad dolly. No portable reflector-moderator material will be present in the building without the approval of the Nuclear Test Section Chief or his designated alternate and no large amounts of reflector-moderator material will be present without the approval of both the Experiments Section and Nuclear Test Section Chiefs.

Administrative control of the various control console keys will be maintained by the Health Physics and Nuclear Test supervisors. The following is a listing of these keys and their functions:

(1) Console power - Two console power keys are used; one on the SNAPTRAN 2/10A-1 control panel and one on the SNAPTRAN 2/10A-3 control panel. These keys control power to the console, with the key on the SNAPTRAN 2/10A-3 console serving the additional function of transferring the AC power scram relay and the safety trip circuits from the SNAPTRAN 2/10A-1 control system to the SNAPTRAN 2/10A-3 system.

(2) Main bus drive - Prior to the power calibration, this key will be used to keep the environmental tank and calorimeter drained of water while people are working in the test cell and still permit console power to be on for checkout of various control circuits. For the destructive test this key permits withdrawal

of the sleeve draw-bar to the mechanical upper limit. These functions are accomplished by connecting the sleeve-drive motor directly to main bus power, bypassing the variable voltage power supply, and de-energizing the scram bus. The circuit is interlocked so that the draw bar cannot be withdrawn unless the sleeve remains in contact with the seat switch.

(3) Drive lockout - This key must be actuated to permit rotation of the arming cylinder. The key immobilizes the sleeve drive to prevent inadvertent withdrawal of the sleeve with water around the reactor. Also, this key activates an alarm circuit which gives warning if the draw bar is not at lower limit, and if the sleeve is not seated with the magnet in contact.

(4) Destruct mode - This key will be used only during the destructive test. It activates the powder chamber insertion circuit, deactivates the drive lockout alarms since it will be necessary to have the draw bar at mechanical upper limit for the test, and closes the motor driven drain valve in the environmental tank.

(5) Transient safety bypass - This key bypasses the safety trip circuits during the kinetics and destructive tests. De-energizing the magnet current and scram circuit or turning off console power will reactivate the safety circuits.

(6) Interlock bypass - In the event of malfunction of one of the operational power recording channels during a test, this key will permit replacement or repair of the unit without aborting the test.

(7) Timer - This key activates the sequence timer on the SNAPTRAN 2/10A-1 console. The timer may be used to turn on and off recording devices and scram the reactor for the kinetics tests as well as start the recording devices and fire the pyrotechnic actuator for the destructive test.

To insure health physics cognizance of any manipulation of the reactor control system, the Health Physics Supervisor will maintain administrative control of one console-power key. The health physics console-power key, necessary for any operation of the control system, will be obtained from the Health Physics Supervisor as needed. In addition, prior to the power calibration when non-nuclear operation of the reactor control system is necessary, the main-bus-drive keyswitch will be locked on and the key to this switch surrendered to the Health Physics Supervisor. Following the power calibration it will be necessary to keep the reactor core covered with water while personnel are in the reactor area. This will require that the environmental tank and calorimeter be filled with water at the beginning of each working shift. During these periods of time, to insure that no nuclear operation of the reactor takes place unless proper evacuation procedures have been completed, the drive-lockout key-switch will be locked on and this key also controlled by the Health Physics Supervisor.

Prior to the power calibration, the environmental tank and calorimeter will be drained of water and the poison sleeve will be in place around the reactor vessel while people are working in the reactor building. During this period, only one person at a time will be permitted in the environmental tank.

When console power is turned off, as during non-working hours, the environmental tank and calorimeter will automatically be drained of water and the area inside the IET security fence will be classified as a high radiation area.

Failure of some components within the environmental tank following the power calibration may necessitate movement of the test package to the hot shop (TAN 607) for repair or modification.

4. Preparations for Reactor Operations

Prior to reactor operation, the Nuclear Test Section will be responsible for completing check lists to verify operability of operational instrumentation, experimental instrumentation and equipment, and process instrumentation and equipment. Operational instrumentation will include, as a minimum, two pulse neutron counter systems, one linear power recorder system, one log power recorder system, and two period and power level safety circuits. When all check lists have been completed and the Nuclear Test Group Leader has verified the completion of plant and reactor preparations, a note to this effect will be placed in the console log.

5. Routine Evacuation

All personnel entering the test area are required to report to the security area guard house within the test area. The guard will maintain a record of all people within the area.

Prior to any nuclear operations, the Nuclear Test Group Leader will initiate a routine evacuation of the test area in the following steps:

(1) The reactor operator will actuate the evacuation horn at periodic intervals for not less than twenty minutes. All those people not directly concerned with the immediate operation of the test will evacuate through the TSF area gate, notifying the security guard. During those tests in which fission product release can reasonable be expected, a check of the area lying downwind of the reactor building between the test area and site boundary will be made in cooperation with ID Health and Safety. The Phillips Health Physics Supervisor will be notified when the downwind area has been cleared of personnel. At this time, the guard at Post 707 (TSF access gate) will be notified that no more entry to the reactor area will be permitted.

(2) Twenty minutes after the initial test area evacuation order, the reactor operator will announce over the public address system the order for all personnel inside the security fence (security area) to proceed to the control and equipment building. This will include all those people in the test cell and coupling station.

(3) A health physicist will leave the test cell last, closing the tunnel shielding doors, checking the shielding doors in the coupling station, and verifying that the passageways are cleared of personnel. He will then lock the access door behind him.

(4) The health physicist will move Guard Post 705 from the security fence gate to the turnaround room and will then check the

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security area, including all outside buildings, to verify that all personnel have been evacuated.

(5) The health physicist, upon completion of the security area check, will obtain the names of all personnel remaining in the control and equipment building. He will verify, via telephone, that the list of people in the control and equipment building checks with the record maintained by the guard at Post 707 and will also verify that the test area has been cleared.

(6) The health physicist will then receive verification from the Health Physics Supervisor that the area downwind of the reactor building between the test area and the site boundary has been cleared of personnel if fission product release is expected.

(7) The health physicist will report to the Responsible Supervisor in the control room and transfer the health physics key for the console power switch to the reactor operator.

6. Reactor Operation

When all pre-operational procedures have been completed, including the routine test area evacuation, the reactor is ready for startup. During operation the Nuclear Test Section Chief or his designated alternate is the Responsible Supervisor in the control room and in charge of all operations. The minimum personnel requirements in the control room during reactor operations are the Responsible Supervisor, a Surveillant Physicist, a Reactor Operator, an Assistant Reactor Operator, and two Instrument Technicians. All other personnel must have the specific approval of the Responsible Supervisor to remain in the control room during the test.

Before the reactor is brought critical, checks of the scram mechanism will be made. As the reactor is being brought to critical, the control sleeve position or water height will not be changed more than an amount equal to $0.50 reactivity, without stopping the movement long enough to ascertain the criticality state of the reactor. If any indication of a hazardous or potentially hazardous condition exists, the reactor will be scrammed and the condition will be investigated and corrected. It is

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the responsibility of each member of the STEP organization to scram the reactor if he believes that a potentially hazardous condition exists. In the event of a scram from malfunction or indication of hazardous condition, the Nuclear Test Section Chief must approve the resumption of nuclear operation.

The amount of sleeve withdrawal during kinetic tests will be controlled by a limit switch which will be positioned by finding the critical position of the sleeve and calculating the amount of sleeve withdrawal desired. The magnet will be turned off and the sleeve drive withdrawn to this position. The limit switch will be set and the setting checked for correct operation.

During kinetics tests it will be necessary to bypass the automatic period and power level trip circuits. These trips will be bypassed by a momentary contact keyswitch, the key to which is controlled by the Nuclear Test Section Chief. This bypass will only be used during kinetics tests and will be the last step in the test sequence just prior to initiation of sleeve withdrawal. At the termination of the test, actuation of the magnet release switch, any scram button, or turning off console power will automatically reset the trip circuits.

After final preparations of the reactor and data gathering equipment have been completed, evacuation of the test area, including clearing of the downwind area to the site boundary, will be initiated. After evacuation procedures have been completed the explosives crew will reenter the test cell and, with the poison sleeve drive at lower limit, will install the propellant charge and blasting caps in the remote insertion mechanism. The squib firing circuit will be shunted and disconnected from the activating source until ready for use.

All static and kinetics testing will be performed with the calorimeter in place around the reactor vessel. The removal of this tank will be the last step in the test cell preparations for the destructive test and

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will not be removed until after the pyrotechnic actuator has been loaded. Following removal of the calorimeter tank, the test cell will be cleared and the remainder of the test preparations completed in the control room.

To initiate the destructive test the poison sleeve drive will be raised to its upper limit, the destructive mode key and pushbutton switches will be used to insert the propellant charge, and the blasting cap circuit will be made operable. The remainder of the sequence (turning on recorders, bypassing the trip circuits, and firing the propellant charge) will be initiated with the timer.

7. Routine Reentry Procedures

When instrumentation indicates that the reactor is shut down and in the best judgement of the Nuclear Test Group Leader, the reactor is subcritical and no foreseeable events will cause it to go critical, reentry operations will be permitted.

Reentry into the test cell will be under the direction of the Nuclear Test Group Leader with the advice of the Health Physics Supervisor. The equipment available to aid the health physicist in evaluating reentry hazards is discussed below.

(1) The remote area monitoring system will consist of eleven ion chambers which will continuously record the intensity of the radiation field at their respective locations. The locations and sensitivity ranges of these ion chambers are as follows:

(a)	Railroad flatcar	100 mr/hr to 1000 r/hr
(b)	Furnace enclosure of test cell	0.1 mr/hr to 100 r/hr
(c)	Personnel door to test cell	0.1 mr/hr to 100 r/hr
(d)	Coupling station	0.01 mr/hr to 10 r/hr
(e)	Service room below coupling station	0.01 mr/hr to 10 r/hr
(f)	Control room escape tunnel	0.1 mr/hr to 100 mr/hr
(g)	Control room	0.1 mr/hr to 100 mr/hr
(h)	Data reduction room	0.1 mr/hr to 100 mr/hr
(i)	Equipment room	0.1 mr/hr to 100 mr/hr
(j)	Vehicle tunnel entrance	10 mr/hr to 10 r/hr
(k)	Entrance to stairs leading from underground parking area	10 mr/hr to 10 r/hr

The ratemeters and recorders for these ion chambers are located in the fire equipment room of the IET.

(2) One constant air monitor (CAM) will be located in the IET equipment room near the filters of the building ventilation system. This monitor can be quickly modified to sample air from the heating and ventilating system. The other constant air monitor will be located below the coupling station and will be sampling air from the test cell building.

(3) One portal monitor will be located at the end of the tunnel to the test cell near the health physics office.

(4) A laboratory counter will be located in the health physics office for analyzing smears of alpha-particle and beta-particle activity.

(5) A scintillation type well-counter will be located in the health physics office for counting such items as water samples with a low activity level.

(6) A stack monitor readout panel will be located in the fire equipment room. This monitoring system samples air at the 80 ft level of the stack. Measurements are made of gross particulate activity and gross gaseous activity, which includes the iodines collected by a separate charcoal trap sampling system. The collection and detection equipment for this system is located in building 713 below the stack.

(7) In addition to the above equipment, the following equipment is available:

(a) Five portable G-M type radiation monitors (0 to 20 mr/hr)
(b) Five low-range Juno portable radiation monitors (0 to 5 r/hr)
(c) Five high-range Juno radiation monitors (0 to 25 r/hr)
(d) Two Jordan portable radiation monitors (0 to 500 r/hr)
(e) Seven Cutie-Pie portable radiation monitors (0 to 2.5 r/hr)
(f) Three thermal neutron portable radiation monitors
(g) One fast neutron portable radiation monitor
(h) Fifty pencil dosimeters (0 to 250 mr)
(i) Five pencil dosimeters (0 to 5 r)

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(j) Three alpha-particle portable detectors

(k) Three nuclear accident dosimeters

The precautions to be observed prior to entry into the test cell will depend primarily upon two factors:

(1) a determination by the Nuclear Test Group Leader that the reactor is safely subcritical by the virtue of having no water in the environmental tank, and

(2) a pre-entry survey of the area by the health physics section using remote monitoring equipment.

The Health Physics Supervisor at the IET will evaluate the radiological hazards before allowing re-entry into the test cell. A decision will be made on re-entry time limits and protective clothing, respiratory protection, and personal dosimetry requirements. After consultation with the Nuclear Test Group Leader to insure that the reactor is safely subcritical, a re-entry team composed of a health physicist and one or more members of the Nuclear Test Section will be allowed to enter the cell.

8. Post-Destructive Test Re-entry Procedures

Additional procedures to those outlined in the previous section are required for re-entry into the test cell following the destructive test.

The radiation and safety hazards will be evaluated by the STEP Senior Staff and when it has been resolved that personnel may enter the area, the first reentry team will proceed toward the test cell. This team will consist of two health physicists and one person from the nuclear test section. The team members will wear special protective clothing with self-contained breathing apparatus. The health physicist will be equipped with portable radiation survey instruments and a portable radio unit. As the team approaches the test cell they will radio the radiation readings to the control room. The radiation reading in rooms and passageways leading to the test cell will be recorded on a map in the control room. Smears will also be taken of these areas, and the beryllium filters below the coupling station will be recovered if exposure time permits. The team will then remove their protective clothing and return to the health physics office for a personal survey. The radiation data obtained

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by this team and by the roving manipulator, if available, will then be used to determine when and how cleanup procedures may be undertaken.

A second reentry team consisting of two health physicists will be stationed at the TSF test area gate. After this team members have been notified by radio that the reactor is safely subcritical, they will survey the road leading to the IET for contamination. After reporting their results, they will operate as one of the teams of the site monitoring group and will collect samples on the south side of the monitoring grid.

F. Transfer of the Test Package with Fuel in the Core

When the test package and test dolly have been prepared for transfer the Nuclear Test Group Leader will notify the supervisor in charge of the hot shop that the reactor is ready for movement. At that time he will also inform the section chief of the radiation levels surrounding the test package. The Nuclear Test Group Leader will then initiate a routine evacuation of the test area if he believes a potentially hazardous situation could exist during transfer of the test package.

During transfer of the package the shielded locomotive will contain the locomotive operator, a health physicist, a surveillant physicist from the Experiments Section, and one person from the Nuclear Test Section. The Nuclear Test Group Leader will inform the hot shop dispatcher that the package is ready for movement and if partial evacuation of the TSF area has been necessary, the dispatcher will notify the Nuclear Test Group Leader that such evacuation has been effected.

Once the test dolly has reached the examination area, the reactor test package responsibility will be assumed by the Metallurgy and Hot Cells Branch. However, prior to the commencement of any operation in the hot cell, a qualified individual or group of individuals will be assigned the full responsibility for nuclear safety.

G. Examination Area Operations

The general program and procedures to be followed during operations in the examination area will be prepared by STEP Project personnel. The procedures to accomplish this program will be written by Metallurgy and Hot Cells Branch personnel. The nuclear safety considerations involved in these procedures will then be reviewed by Reactor Physics and Engineering Branch personnel and forwarded to the SPERT-STEP Safeguard Review Committee for final approval.

H. Health Physics Support

The health physics staff, in addition to accomplishing its normal duties, will perform the following:

(1) Design and coordinate the installation of a site monitoring grid to obtain data on the release of fission products from the destructive test.

(2) Administer radiological and physical safety control over all participating personnel who will be on or near the test grid and, in conjunction with the AEC aerial monitoring team, determine that the entire area is cleared of personnel prior to the destructive test.

(3) Activate grid equipment prior to the destructive test, recover samples after the test, and deliver all samples to the proper laboratories for analysis.

(4) Establish a Field Access Control Center for assuring that the pre-test setup of equipment has been completed, for clearing the area, for dispatching sample recovery teams, for checking participants in and out of the sampling sector, for decontaminating personnel, and for establishing radio contact with all participants.

(5) Determine when reentry into the immediate reactor area is safe from a radiological standpoint and what protective apparel and precautions must be used.

(6) Monitor for beryllium contamination in cooperation with the Phillips Industrial Hygienist.

VI. SAFETY ANALYSIS OF THE PRE-DESTRUCTIVE TEST SERIES

A. Special Considerations Involving Materials Handling and Storage

The basic safety considerations involved in receiving, handling and storage of fuel, source, and reflector materials are discussed in the SNAPTRAN 2/10A-1 Safety Analysis Report[1]. The following sections, therefore, cover only those aspects which are unique to the SNAPTRAN 2/10A-3 system.

1. Fuel Loading and Preparation of the Reactor System at IET

The loading of fuel into the reactor vessel will be performed at the IET in accordance with the general procedures outlined in the STEP Standard Practices Manual.

A fixture will be used to maintain the reactor vessel in a fixed position during the fuel loading operation. In addition, the fixture serves to position and clamp the control sleeve around the reactor vessel. A drawing of the fixture, control sleeve, and reactor vessel with the head in place is shown in Figure VI-1. During the fuel loading sequence, the fixture will be located on the reactor dolly along with the NaK charging and leak testing equipment.

Although the reactor will have no water reflection during loading and test preparation, and will therefore be subcritical, the fuel loading will be performed in stages and will follow standard techniques. This loading procedure is purely a precautionary measure. since the static nuclear characteristics of the system are well known from critical experiments conducted by Atomics International. The fuel elements and beryllium inserts to be used in the SNAPTRAN 2/10A-3 tests were used in these experiments. The components are coded to permit reassembly in the same configuration for the SNAPTRAN 2/10A-3. The results of the critical experiments are described in Section IV.

In the absence of a hydrogenous reflector, the control sleeve around the reactor vessel represents a slightly more reactive configuration than does the bare vessel. From critical experiments conducted by Atomics International, it has been estimated that the fully loaded bare

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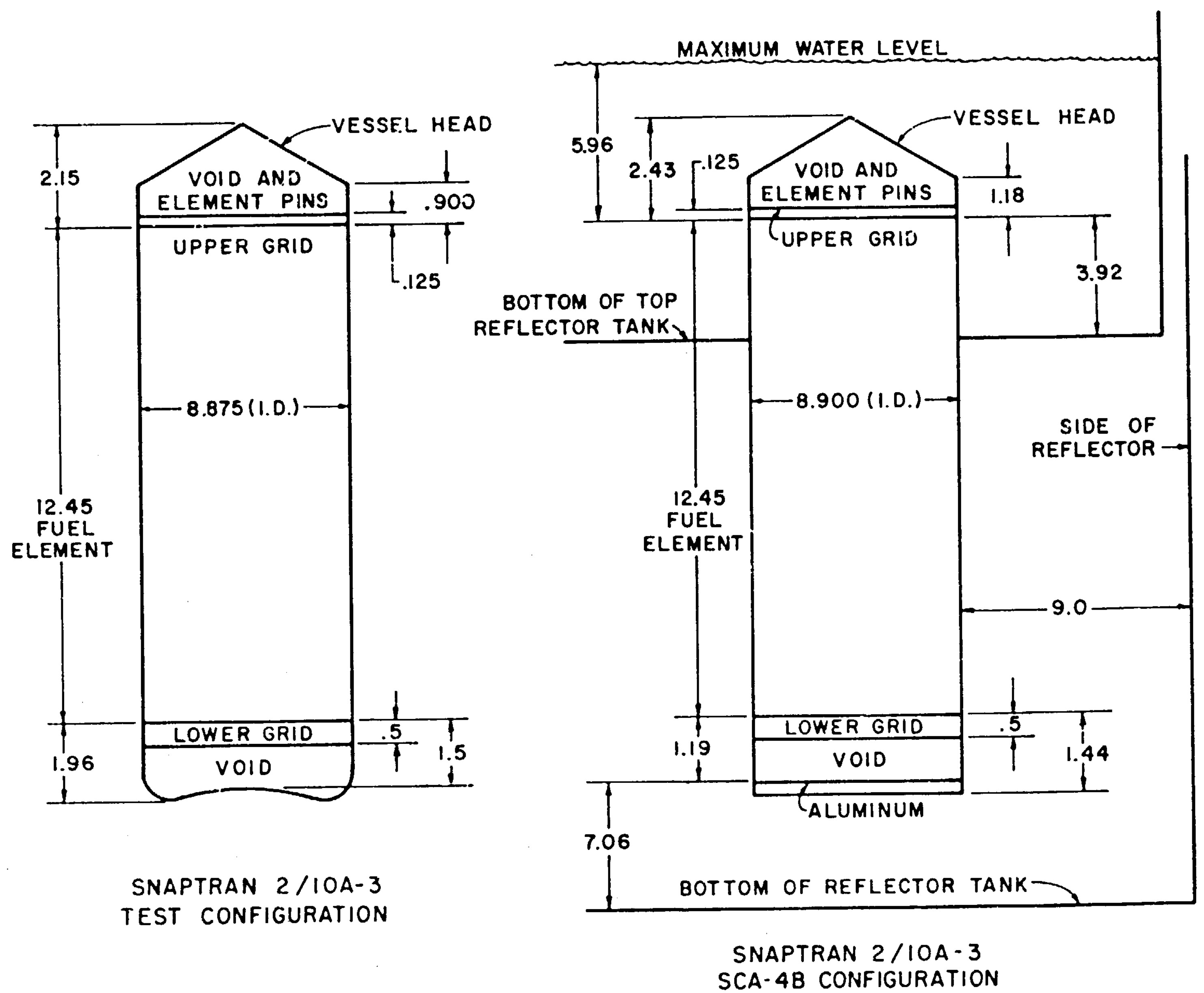

Figure VI-1 - SNAPTRAN 2/10A-3 Vessel Holding Fixture

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reactor is approximately \$20 subcritical, whereas the reactor is about \$19 subcritical with the control sleeve around it. However, the sleeve is designed to maintain the reactor subcritical with any amount of hydrogenous material surrounding the reactor vessel. Thus, by using the control sleeve during the loading and test preparations, the possibility of accidental criticality as a result of personnel or materials being in proximity to the reactor is precluded. Administrative control over the location of personnel and materials in the test cell will be exercised during the loading, as discussed in Section V. As a further precaution, and to avoid the possibility of core flooding, all water systems in the test cell will be deactivated during the fuel loading and test preparations. The two water systems, raw water and demineralized water, leading to the dolly will be disconnected from the dolly at the coupling station. There will also be two closed valves in series in each of these systems. The test cell fire-water system will have three valves in series which are closed.

Two pulse counting systems and two ion chamber systems--one log and one linear--will be operating during the fuel loading. The detectors and a neutron source will be mounted on the fixture in which the reactor vessel is positioned. Audible and visual indication of the count rate will be available in the test cell and in the control room.

In order to facilitate the safe and orderly loading of instrumented fuel elements, the head will be firmly supported approximately four feet above the reactor vessel. The instrument leads from each instrumented element will be passed through penetrations in the head and then the fuel element will be inserted into the reactor vessel. With this procedure, as the fuel is loaded, the head will support the instrument leads in a vertical position and keep them in the position where they present a minimum of interference to the fuel loading sequence.

After the fuel elements have been loaded into the reactor vessel, the head will be lowered over the instrument leads and into position on the vessel and welded in place. The instrument leads will then be seal welded to the head.

2. NaK Loading and Reactor Installation

The possibility and consequences of an accident have been investigated in which the reactor vessel is postulated to rupture or leak when the reactor is loaded with fuel and charged with NaK. Prior to the filling operation, the reactor vessel and fill system will be thoroughly purged with helium and then leak tested. The reactor vessel will then be charged with NaK, after which the NaK filling tube will be crimped and seal welded. Thus, the only conceivable way that NaK could become exposed to the air is if the vessel or fill system is breached either by a direct blow or by dropping the vessel during installation. A chemical reaction involving NaK cannot proceed rapidly unless the leak in the system is of sufficient magnitude to allow a large portion of the NaK to become exposed to water. Since water will not be present in the test cell during this period, NaK leaks should be readily controllable and present little hazard to properly equipped personnel. Mechanical damage to the equipment is the only thing which would be likely to cause a leak or rupture in the system. Since water will not be present, the probability of a NaK fire appears to be low. The maximum damage to the reactor would probably occur if the NaK fire was by some means initiated directly within the reactor vessel. If all the NaK were to react with air, the resultant energy release would be approximately 15,000 Btu. If it is assumed that all of this energy is available for raising the core temperature, the temperature increase would be approximately 1000°F. This increase is not great enough to cause the release of sufficient hydrogen within the fuel rods to burst the cladding. Thus, no potential hazard exists from the possibility of an additional H_2-air reaction. The occurrence of such an accident in the test cell is not considered credible during the NaK filling and reactor installation operations.

In order to provide enough working space to install the reactor package on the support pedestal, it will be necessary to raise the actuator piston rod above its normal upper limit. By means of an overhead crane, the loaded reactor vessel, with the control sleeve still clamped in place, will be lifted above the pedestal and the package slowly lowered into place. The reactor vessel will be bolted to the pedestal. The sleeve will next be unclamped and slowly lowered to the support flange. The

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loading fixture will then be removed from the environmental tank. Next, the actuator piston rod will be lowered, and the spider, at the lower end of the piston rod, will be connected to the yoke on the control sleeve. To complete the reactor system preparation, the calorimeter will be placed over the reactor vessel and secured to the support pedestal.

After the calorimeter has been installed, the control system will be tested with no water in the calorimeter or environmental tank to assure proper mechanical operation of the sleeve and drive components. The water systems will not be activated until the dry checkout is complete and the control sleeve is secured in the lower limit position.

3. Precautions During Non-Working Hours

Certain precautions will be taken to assure the safety of the reactor and personnel in the TAN area during non-working hours or at any time of reactor shutdown. The control sleeve and drive will be driven to the lower limit prior to shutdown and the water in the environmental tank and calorimeter will be pumped to the storage tanks. When the console power keyswitch is turned off, the inlet control valves automatically close and the drain valves in the calorimeter and environmental tank open. The auxiliary drain valve will also open, providing a direct drain path from the calorimeter to the drain trench. With this procedure, no credible chain of events can be postulated which will cause an increase in system reactivity sufficient for the reactor to achieve criticality. For example, should a NaK leak occur during this time, the reaction with air or remaining moisture is expected to be quite slow and probably resemble more closely a non-violent oxidation process. It is not considered credible that any leak during shutdown would result in violent NaK-air reactions which could conceivably damage the reactor or experimental instrumentation.

As a part of the startup procedure, it is required that the pressure in the NaK expansion chamber be compared with the pressure of the previous day to assure that no NaK leak has occurred from the system. In addition, the tank will be visually inspected to assure that no NaK leak has occurred since the last operation. Should a NaK leak occur and go unnoticed, it is possible that during the calorimeter filling operation, water could conceivably enter the reactor core and result in a reactivity insertion sufficient to attain criticality. The complete flooding of the reactor vessel with the poison sleeve in the lower position could cause the system to be approximately $2.50 supercritical. However, the water addition rates are sufficiently low that if it is assumed that only the high power level trip is operable, the energy release would be less than 1 Mw-second. It is concluded that even should multiple failures occur no hazard exists since a 1 Mw-second energy release is not sufficient to cause damage to the reactor.

Security guards will be on duty at all times to prohibit unauthorized entry into the IET area. The dose rate at the guard station, which is located approximately 600 ft from the test cell on the access road to IET, is calculated to be less than 1 mrem/hr. Any entry beyond this point during non-working hours will be under the cognizance of the Nuclear Test Section. It is therefore concluded that the reactor can be safely shut down and secured in a manner such that no potential exists for a hazard from inadvertent criticality or from direct radiation.

4. Preparation for the Destructive Test

After the power calibration experiment and kinetics tests, certain modifications to the test package are required in the preparation for the destructive test. The radiation levels to be expected in the vicinity of the environmental tank are discussed in Section VI-C.

Since the water level in the calorimeter and environmental tank cannot be maintained without control power to the scram dump valves, it will be necessary to have console power on while personnel are in the test cell. Administrative procedures require that the control sleeve drive be at lower limit prior to personnel reentry. Inadvertent reactivity addition by movement of the control sleeve drive is prevented by locking the drive-lockout keyswitch in the "on" position and removing the key. This key will remain under administrative control until such time as routine evacuation procedures have been effected and the reactor is ready for startup.

Final preparations for the destructive test will be conducted under the supervision of the Nuclear Test Section Group Leader and will be under the technical cognizance of a surveillant physicist. Prior to removal of the calorimeter, the powder will be loaded in the revolver chamber on the pyrotechnic actuator and the startup instrumentation and other equipment not required for the destructive test will be removed. These procedures will be taken to prevent damage to the reactor vessel and poison sleeve, thereby reducing the possibility of a criticality accident during final preparations.

5. Transportation of the Loaded Test Package

In the event that an unforeseen situation requires transportation of the reactor system to the examination area, the control sleeve and drive will be secured in the lower limit position. Without power to the sleeve drive motor, the worm drive in the gear train will remain stationary. This will provide a positive means of locking the gear train, thus preventing movement of the sleeve. Calculations indicate that an upward force of more than 400 pounds would be necessary to strip gear teeth and allow the drive rod to be raised. Since there is no credible means of exerting such a force during transportation of the test package, it is concluded that the control sleeve cannot be removed during transportation.

Before transportation, the water will be completely drained from the system and the calorimeter removed so that no hydrogenous reflecting material will be present in the environmental tank. The test package will not be transferred during adverse weather conditions.

B. Operational Error

1. Nuclear Operation

In order to preclude operator error during conduct of the SNAPTRAN tests, automatic protective instrumentation, redundancy in nuclear detectors and recorders, and special design restrictions to assist in administrative control have been supplied. Two channels of automatic protective instrumentation consisting of fast electronic

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scram systems actuated by either a short reactor period (5-10 sec) or a high power level (2 kilowatts) have been provided. In addition, two operational neutron level channels and two channels of startup instrumentation (B-10 pulse counters) are provided. Key-actuated interlocks have been included on the control console to prevent an unauthorized reactor startup and to assist in the enforcement of administrative controls by ensuring that supervision is present during startup. The possibility of operator error is reduced by standard procedures which require that the assistant operator and the responsible supervisor be in attendance at all times and be cognizant of any operations affecting the reactivity of the system.

Should an accident occur as a result of an operator error, the hazards to operating personnel are negligible, since during all nuclear operations operating personnel are located inside the shielded control room. The radiation exposure to other on-site and off-site personnel will also be within acceptable levels.

2. Startup Accident

The startup accident, defined generally as an uninterrupted reactivity addition, was investigated and analyzed. Such an accident can be postulated to occur as a result of increasing the water level around the reactor or as a result of uninterrupted withdrawal of the poison sleeve. Both mechanisms for initiating a startup accident are considered incredible. The analysis is presented in the following paragraphs.

The first case, that is, reactivity addition by increasing water level, can only occur as a result of multiple component failure and operator error. The control system contains a seat-switch interlock which prevents water addition unless the sleeve is seated, i.e., in the scrammed position. In this manner, uninterrupted addition of water to the calorimeter does not result in criticality of the reactor. However, if seat-switch interlock failure is postulated, it is conceivable that the sleeve could be in the withdrawn position during water addition. If the operator then disregards sleeve position indication, startup instrumentation, and seat-switch indication, and if supervisory cognizance is

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assumed to fail, he could then add water to the calorimeter vessel through the two inch fill line at a rate of 0.6 inches per minute. Assuming that the reference probe interlock failed, he could then continue to fill the calorimeter with this system beyond the bottom edge of the reactor. By simultaneous operation of the burette fill system, reactivity addition rates of approximately 4 cents per second could be obtained. Ramp inputs of this amount were used to compute power and energy as a function of time by means of the IREKIN code 10. As is common practice in carrying out a safety analysis, conservative assumptions were employed, that is, no feedback mechanisms were used and the period trip was assumed to fail, with scram occurring after the 2 kw high-power level trip was actuated. The power was then allowed to rise for an additional 350 milliseconds, which is the time required for the magnet to release and the sleeve to fall to the fully scrammed position. The resultant energy release is calculated to be less than 0.02 Mw-second which is negligible with respect to reactor damage or hazards to personnel.

The second case, reactivity addition by uninterrupted sleeve withdrawal, can occur only as the result of control system component failure and operator error. If it is assumed that the calorimeter is filled with water prior to actuation of the sleeve, uninterrupted withdrawal of the sleeve due to operator error and failure of supervisory cognizance could result in reactivity addition rates of approximately 12 cents per second. Ramp input calculations were also conducted for this case assuming again no feedback mechanisms and failure of the period scram trip circuit. The resultant energy release was calculated to be approximately 0.13 Mw-second.

In either case, the energy generated within the core is not sufficient to damage the reactor system or to result in release of fission products to the atmosphere. A startup accident is not considered credible since simultaneous miltiple failures in the control system, the failure of administrative procedures and supervisory cognizance, and operator error are required. In any event this accident does not represent a potential hazard to operating personnel or the general public.

3. Reactor Shut Down

During reactor shutdown, certain operations are necessary in the test cell which require that some functions of the control console remain operable. These functions include the movement of the slow drive mechanism before the power calibration and the maintenance of the environmental tank water level following the power calibration.

In order to facilitate administrative control in the test cell during these periods, two additional keyswitches are provided in the control system. The main-bus-drive keyswitch maintains the scram circuit in the de-energized condition. It also prevents the sleeve magnet from being energized and water from being in the tank. The drive-lockout keyswitch ensures the presence of water shielding around the reactor and sleeve immobilization after the power calibration by locking out the sleeve drive circuits and by activating circuits which will trip alarms if any of the following conditions are not met: (1) calorimeter and environmental tank water level at high reference level, (2) drive at lower limit, (3) sleeve seated, and (4) magnet in contact.

The facility is provided with a warning horn which is audible throughout the test area. The horn operates for 20 seconds each time the sleeve seat switch indicates that the sleeve is being withdrawn from the seat position or the water level probe indicates water at the bottom of the reactor vessel. Thus, any personnel which may be in the test cell area are warned of reactor operation well in advance of significant neutron multiplication. In this event, administrative controls require that personnel evacuate the area and operate the nearest scram button upon exit. These scram buttons are of the manual reset type. The operator at the console is required to determine the cause for scram and obtain permission from the Nuclear Test Section Chief before he can reset the scram circuit and continue operation.

C. System Failure

1. Control System Component Failure

One type of failure that must be considered in the safety evaluation of a reactor system is failure of the mechanical or electrical components of the control system. Several types of failure during periods of shutdown and operation have been considered and those aspects of the control system and operating procedures which reduce the probability of such failures are discussed below.

a. Failure During Operation

Mechanical failure of the sleeve drive, such as a broken gear, sheared key, or jammed ball screw could prevent changing the sleeve position except by dropping it from the magnet. To ensure that magnet release, by interruption of magnet current, can always be accomplished, the magnet current is controlled directly from the console by manual switches, that is, the console power keyswitches, the scram buttons, or the magnet release button. Also, if sleeve drive failure should result in excessive power level or too short a period, safety instrumentation will automatically drop the sleeve by de-energizing the scram circuit. Once dropped, the sleeve cannot be raised until the drive is inserted to the lower limit and the magnet and armature are in contact.

Redundancy in manual and automatic scram mechanisms provides protection against failure of water level controls during water level criticality studies.

Failure of electrical components, such as relays, switches, or wiring could cause false indications, failure of the drive to operate, or failure of valves to operate. Most of these failures result in an inability to increase reactivity, but it is conceivable that broken insulation on a wire or a switch malfunction could cause power to be applied to the drive motor inadvertently. If such an improbable event were to occur, power could be interrupted by turning off a console power keyswitch. All motor circuits are controlled on the console by manual switches to avoid the hazards of remote relays becoming stuck closed.

False indications of water level and sleeve position could result in improper action by the reactor operator and the possible attainment of high power levels. Redundancy in water level and sleeve position indicators plus automatic scrams are provided to preclude this possibility.

b. Failures When Reactor is Shut Down

The reactor will be considered shut down when the sleeve is held in the seated position by the electromechanical drive. Indications of this condition are provided by the seat light, magnet contact light, and drive lower limit light on the console.

The reactor will be secured in the shut down condition by opening the two series console power keyswitches, removing the keys and placing one in the custody of Health Physics supervision and the other in the custody of Nuclear Test supervision. De-energizing the control system opens the tank-dump solenoid valves and allows all water to drain from the system.

2. NaK System Failure

Although the possibility of a NaK leak during nuclear operation is considered highly unlikely, the potential hazard associated with such an occurrence has been investigated.

If such a leak were to occur directly below the reactor vessel, the NaK in the vessel and expansion line could potentially react with the water in the calorimeter vessel. For the purpose of this analysis, it has been postulated that all the NaK in the vessel is immediately exposed to the water even though such an event is highly improbable since a large opening in the reactor vessel is required. Tests conducted by ANL on NaK-filled capsules containing small defects indicate the chemical reaction rate is relatively slow and non-explosive. Tests conducted by Sandia Corporation[11] with a NaK-filled SNAP reactor vessel containing relatively large openings indicates the reaction time to be of the order of 15 msec, however, the reactor vessel and dummy fuel was not appreciably distorted or damaged.

Using the assumption that a large rupture might occur, the NaK could react violently with the water and could conceivably split, deform, or otherwise remove the poison sleeve. The loss of the poison sleeve does not in itself necessarily constitute a severe hazard as the calorimeter vessel would in all probability also be ruptured, thereby causing a rapid expulsion of water to the environmental tank. Operating procedures for the predestructive tests do not require water in the environmental tank above the bottom of the reactor vessel, therefore, no set of circumstances appear conceivable which would not result in a loss of water reflector from around the reactor. The water expulsion would therefore result in a loss of reflector from the system. The reaction could be of such severity, however, that the vessel becomes dislodged from the support pedestal, falling into the environmental tank water. An uncontrolled nuclear excursion would result which would eventually be terminated by destructive disassembly of the reactor. The maximum energy release that could be expected under such conditions has been estimated to be approximately 50 Mw-sec. The consequences of this accident, if occurring under strong inversion conditions, are of a magnitude sufficient to classify the accident as the maximum expected accident.

3. Operational Instrument Failure

Protection against instrument failure will be effected by frequent performance checks on neutron startup channels, power level channels, and safety circuits, sleeve position indicators, water temperature indicators, and water level indicators. In addition, redundancy is provided for all these measurements, i.e., there will be two independent startup channels, at least one linear power channel with indicator and recorder, one log power channel with indicator and recorder, and two independent safety channels each having period and level indication and trip circuits. Sleeve position is indicated by a digital synchro system on the sleeve drive and by seat and contact switches. Water level is monitored by differential-pressure systems continuously referenced to fixed-position conductance probes.

4. Electrical Failures

The reactor control system, including the sleeve drive and the water valves, is designed to operate from failure-free 26-volt battery power. Instrumentation power is provided by a gasoline powered 60-cycle alternator with automatic transfer to commercial power in case of failure, and manual transfer provided in case of impending trouble.

Loss of commercial power interrupts control room lighting, battery charging, and camera light and power. Emergency control room lighting is provided automatically by battery operated floodlights mounted in appropriate locations. Since failures of the engine driven alternator or commercial power can in no way increase the reactivity of the system, an electrical power failure during operation does not present a hazard.

5. Pyrotechnic Actuator Failure

The pyrotechnic actuator cannot fail in a manner hazardous to personnel or to the reactor during any test prior to the destructive test since the propellant will be loaded only as part of the destructive test procedure. Circuits for inserting the charge into the actuator, as well as for firing the squibs to accomplish the test, will be kept inactive and separate from the remainder of the control system until the appropriate time for their use. In addition, after connecting these circuits, the control system prevents actuation of the loading mechanism until the destruct mode keyswitch and arming switch have been closed. Firing of the actuator can take place only through the sequence timer which may be operated after all control system and administrative interlocks have been satisfied.

Should the pyrotechnic actuator fail to remove the sleeve sufficiently far to initiate the nuclear excursion, the water surrounding the reactor will be drained by a remotely operated valve and the sleeve drive operated to assure the sleeve is positioned around the reactor.

Should the pyrotechnic actuator fail in a manner creating only a partial removal of the sleeve sufficient to initiate a nuclear excursion, the event will be treated as a destructive test. Draining of the water, however, will be initiated as rapidly as possible. A remotely retractable high resolution television system will be brought up above the environmental tank permitting a determination of the state of the system.

Personnel are not permitted in the test area, except in the control room, during the final arming and test initiation. The above procedures therefore minimize hazards to personnel following an aborted test.

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D. Radiological Safety Analysis

The radiation levels considered in the following sections are those resulting from: (1) nuclear operation during the power calibration and long-period power excursion tests, and (2) fission product decay following these tests.

1. Nuclear Operation

The power calibration will involve operation of the reactor at a steady power of 1 kilowatt for two to four hours. During the entire operation, the water level in the environmental tank will be even with the bottom of the reactor core. The dose rate, neutron plus gamma, above the reactor under these conditions is calculated to be approximately 80 rem/hr. At the outer wall of the environmental tank the dose is calculated to be less than 1 rem/hr. During the power calibration, personnel will not be allowed within the boundaries of the IET obstruction fence, which is a minimum of 5000 ft from the reactor, with the exception of those in the control room. The dose rate at the obstruction fence is calculated to be less than 0.1 mrem/hr. In the control room, the dose rate during the power calibration will be less than 0.01 mrem/hr. On the basis of these dose rates, the power calibration test will not contribute an excessive radiation dose to site or operating personnel.

The fast neutron dose rate (D_n) at the water surface was calculated using the following point source equation[12]:

$$D_n \left(\frac{\text{mrem}}{\text{hr}}\right) = \frac{S}{4\pi r^2} f(r)$$

where:

$$f(r) = 0.0316 \times 10^{-2} e^{-0.098\ pt} + 0.221\ e^{-0.16\ pt} - 0.1275\ e^{-0.283\ pt}$$

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where:

$$S\left(\frac{\text{neutrons}}{\text{sec}}\right) = (3.1 \times 10^{10})\ P\ Y$$

r = distance from center of core, cm

t = thickness of water, cm

p = specific gravity of water

P = reactor power (1×10^3 watts)

Y = neutron yield (2.47 neutrons/fission)

The gamma dose rate at the water surface was calculated using the following equation[13] for a cylinder on end:

$$D\left(\frac{\text{rem}}{\text{hr}}\right) = \frac{K_e B S_v}{2\mu_s}\left[E_2\ (b_1) - \frac{E_2\ (b_1 \sec \theta_1)}{\sec \theta_1}\right]$$

where:

$$E_2(b_1) = b_1 \int_{b_1}^{\infty} \frac{e^{-t}}{t^2}\ dt$$

b_1 = $\mu_1 t_1$

μ_1 = macroscopic cross section (linear absorption) of the water shield, cm^{-1}

t_1 = thickness of water, cm

μ_s = macroscopic cross section (energy absorption) of the core material, cm^{-1}

B = dose buildup factor, based on external shield (water) only

S_v = source density, $\frac{\gamma's}{cm^3\ sec}$

θ_1 = $\tan^{-1} \frac{R_o}{t_1}$

R_o = radius of the core

K_e = conversion from gamma flux to dose rate[13] as a function of energy.

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Three effective gamma energies were considered: 0.8, 2, and 4 Mev[14]. The calculated total dose rate is the sum of the contribution from each energy group.

In order to obtain a performance check of the instrumentation and to determine some of the self-shutdown characteristics of the reactor, a few long period power tests will be performed. The periods will not be shorter than 10 seconds and the energy release will be maintained below 10 megawatt-seconds for a single test by means of a programmed scram of the reactor. Since the total energy release from any transient is of the same order of magnitdue as that for the power calibration, the integrated dose from the transient can be expected to be approximately the same as for the power calibration test. Since it was shown in the above section that the radiation hazard to personnel during the power calibration is negligible, it can also be assumed negligible in the case of the long period power excursion tests.

2. Reactor Shut Down

No one will be allowed in the test cell or the immediately surrounding area after the power calibration or kinetics tests until it has been determined by the health physicist that the dose rates are within safe limits. Following these tests, however, it will be necessary for personnel to enter the test cell so that the reactor system can be prepared for the destructive test. The only major operation involved in this preparation is the removal of the calorimeter.

The initial activity following a run at one kilowatt for four hours is estimated to be 3000 curies. The dose rates as a function of distance from the edge of the reactor vessel, one hour after shutdown, for the case in which the tank is drained is shown in Figure VI-2. Figure VI-3 presents the corresponding dose rates for the case in which water is left in the environmental tank. Dose rates for times other than one hour after shutdown, may be obtained by multiplying the dose rate at one hour by the relative dose rates given in Figure VI-4.

The gamma dose rates from fission product decay after shutdown were calculated by considering the reactor to be a point source, except for distances less than 10 ft from the side of the core, in which case a cylindrical source geometry was used.

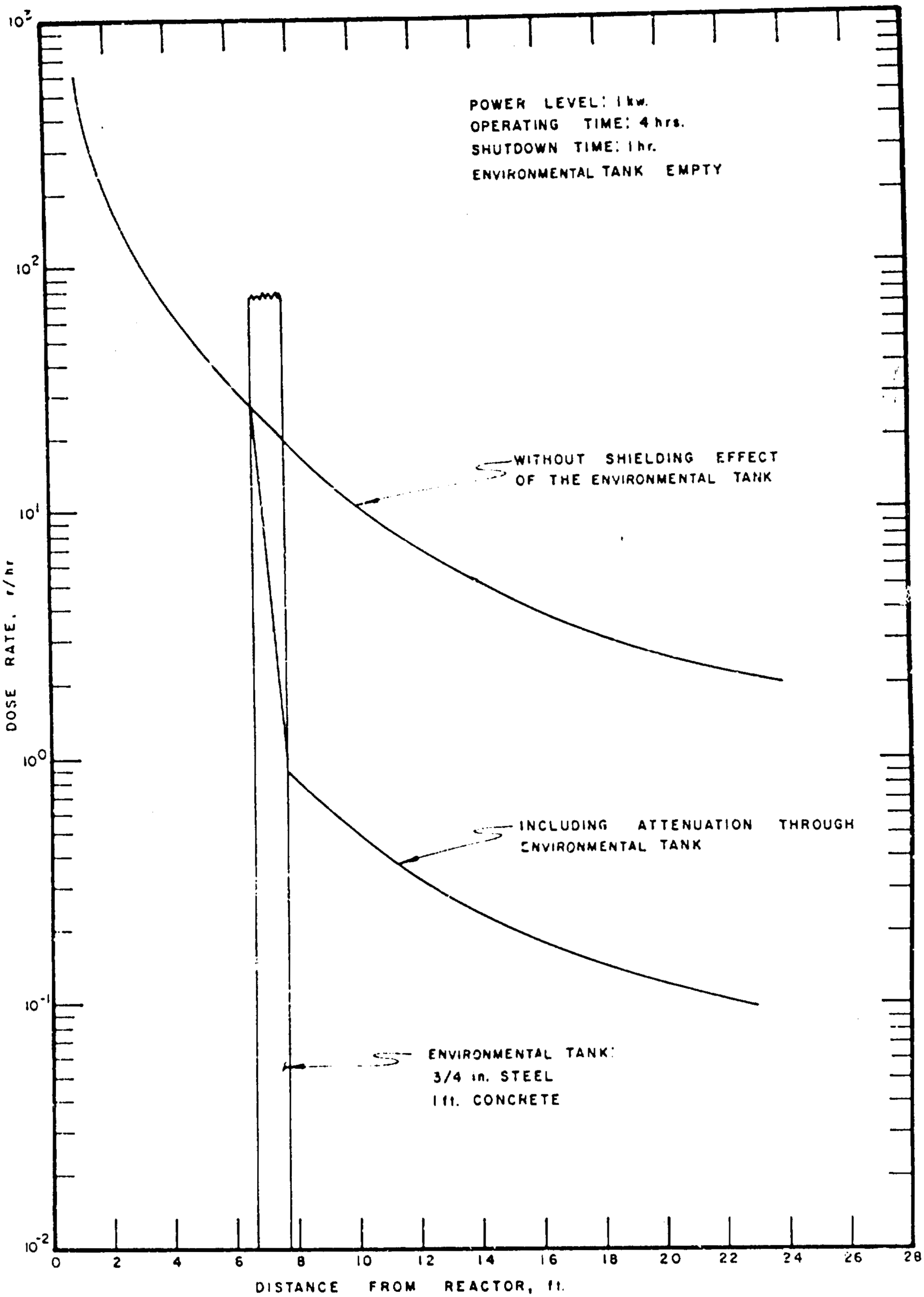

Figure VI-2 - Gamma Dose Rate from Fission Product Decay After Power Calibration: Environmental Tank Empty

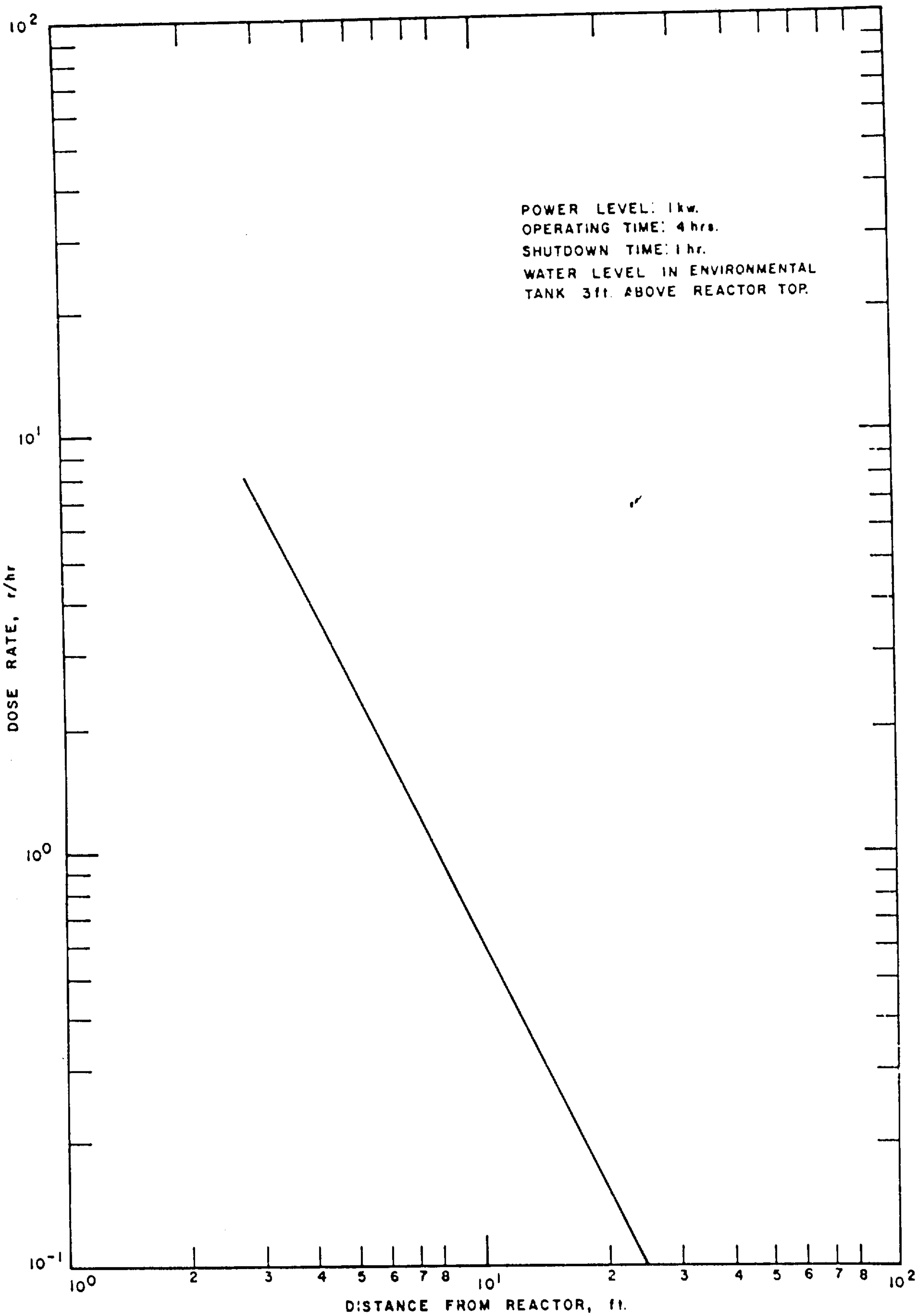

Figure VI-3 - Gamma Dose Rate from Fission Product Decay After Power Calibration: Water Remaining in Environmental Tank

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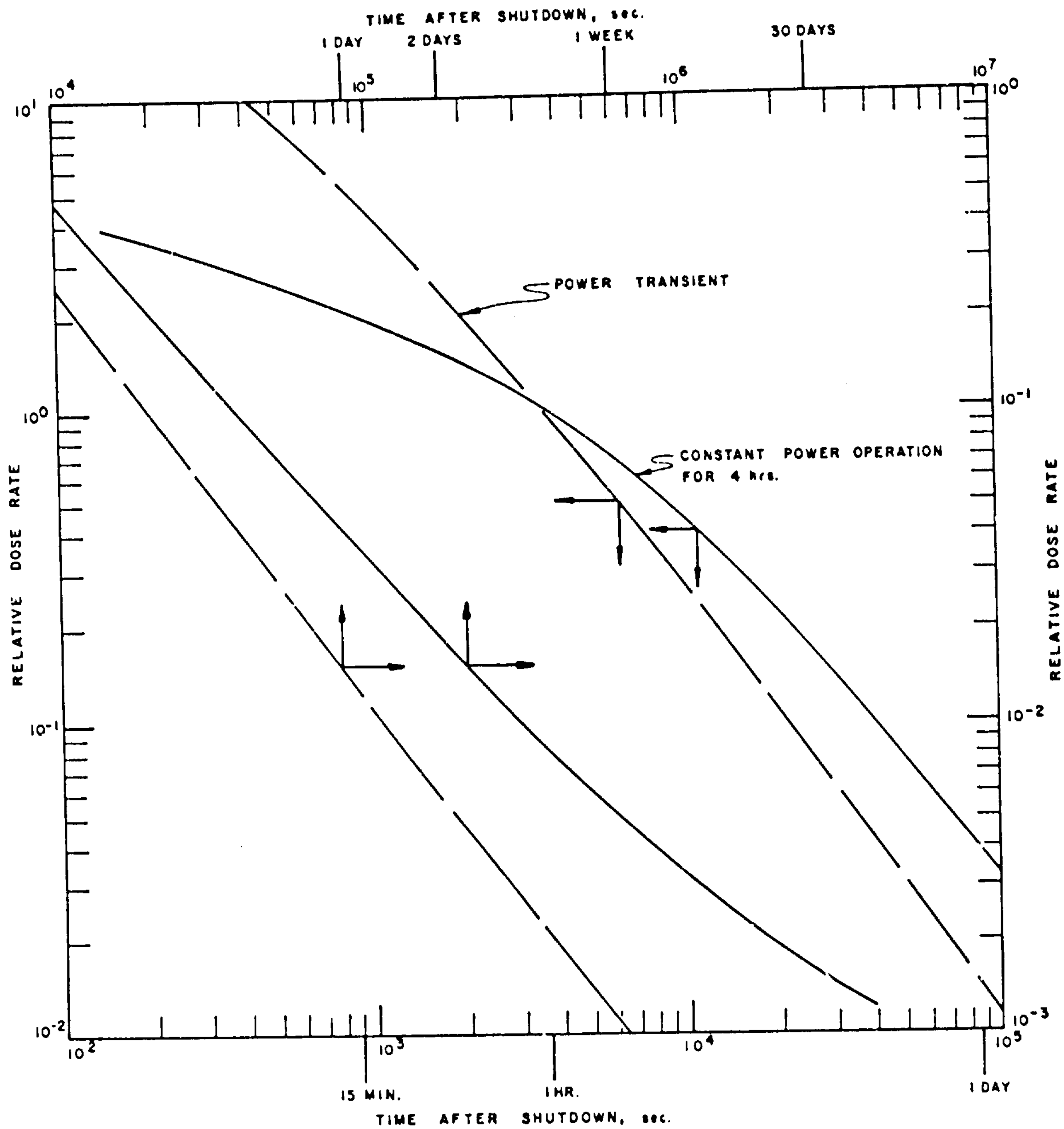

Figure VI-4 - Dose Rate as a Function of Time After Shutdown Relative to the Dose Rate One Hour After Shutdown

The calculations for the point source and cylindrical source geometries are based on the following equations:

Point Source[13]:

$$D_\gamma \left(\frac{\text{rem}}{\text{hr}}\right) = K_e B \frac{S_o e^{-b_1}}{4\pi a^2}$$

where:

D_γ = gamma dose rate

B = gamma dose buildup factor, based on external shield only

S_o = source strength, $\frac{\gamma\text{'s}}{\text{sec}}$ of energy $E = 3.1 \times 10^{10} \, P \, G(t_o, t_s) \, f_E$

P = operating power, watts

f_E = number of γ's of energy E per mev

a = distance from source to dose point, cm

$b_1 = \sum_{i=1}^{n} \mu_i t_i$ (includes an effective self-shielding from the core material)

μ_i = macroscopic cross section (linear absorption) of the i th external shield, cm^{-1}

t_i = shield thickness, cm

K_e = conversion from gamma flux to dose rate[13], $\frac{\text{rem}}{\text{hr}}$ per $\frac{\gamma}{\text{cm}^2 \text{ sec}}$, a function of gamma energy.

In calculating S_o, the gamma energy release per fission, $G(t_o, t_s)$, was obtained from[15]:

$$G(t_o, t_s) = G(\infty, t_s) - G(\infty, t_o + t_s)$$

where:

t_o = operating time

t_s = time after shutdown

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The gamma energy spectrum was obtained from reference (15) also. Three effective gamma energies, 0.9, 1.8, and 2.6 Mev, were used in calculating the dose rates.

Cylindrical Source[13]:

$$D_\gamma \left(\frac{\text{rem}}{\text{hr}}\right) = K_e B \frac{S_v R_o^2}{2\,(a+Z)} \; F\,(\theta,\, b_2)$$

where:

S_v = source density, $\frac{\gamma\text{'s}}{\text{cm}^3\text{-sec}}$

Z = effective self-absorption thickness of the core, cm

R_o = core radius, cm

$$F\,(\theta,\, b_2) = \int_0^{\theta} e^{-b_2 \sec\theta}\, d\theta$$

$$b_2 = \sum_{i=1}^{n} \mu_i\, t_i + \mu_s Z$$

$$\theta = \tan^{-1}\left(\frac{h/2}{a+Z}\right)$$

h = cylinder height, cm

The other quantities are as previously defined.

The relative dose rate as a function of shutdown time (Figure VI-4) was obtained from published curves[15].

VII. SAFETY ANALYSIS OF THE DESTRUCTIVE TEST

A. Introduction

The SNAPTRAN 2/10A-3 destructive test will be initiated after the reactor power calibration and a few long-period power excursion tests have been performed. It has been calculated by means of the CURIE computer code that the fission product inventory built up during the predestructive tests will not be significant compared to that produced during the destructive experiment.

As discussed in the SNAPTRAN 2/10A-1 Safety Analysis Report[1], the upper limit to the nuclear energy release from the SNAPTRAN 2/10A-1 destructive test has been computed to be 170 Mw-sec, which is the amount of energy necessary to raise the temperature of all the metal in the core to the melting point, to add the heat of fusion to this metal, and to also dissociate all the hydrogen from its bound state. The reasons why this represents an upper limit are discussed in some detail in the report, but to briefly recount that discussion it may be said that the "end-point" of such an energy release or, in other words, the condition of the core at that instant represents a situation which cannot be reconciled with basic physical laws. The pressure generated from the entrapped hydrogen within the reactor vessel would be in the order of several hundred thousand psi while the vessel will only withstand an internal pressure of approximately 750 psi. The core boundaries would therefore at this time be accelerating at several hundred thousand ft/sec^2, which would mean complete reactor shutdown within 50 microseconds, assuming no shutdown mechanisms whatsoever had acted prior to that time. Experimental data[16] indicate that the prompt temperature coefficient alone is sufficient to remove the total excess reactivity available by the time fuel melting temperatures are reached. In addition, the effect of non-uniform power distribution within the core was also neglected in the aforementioned analysis. The maximum/average power density, and hence temperature distribution, is approximately 1.8. Shutdown from hydrogen gas expansion would then commence long before the integrated energy reached 170 Mw-sec. It can therefore be stated that although theoretically the energy release could approach 170 Mw-sec, the actual release expected is lower by about a factor of three. These figures are considered to apply to the SNAPTRAN 2/10A-3 destructive test; also, for the following reasons: (1) the core is essentially the same in both tests, (2) the prompt neutron lifetime is about twice as long in the water immersion test as in the beryllium-reflected test due to the difference in reflector material, (3) the disassembly process is expected to be about the same in both tests, and (4) the excess reactivity addition will be about the same in both tests. Therefore, the biological radiation doses to be discussed in the following sections covering the on- and off-site radiological analysis are based on 170 Mw-sec to give the worst case. The SNAPTRAN 2/10A-1 Safety Analysis Report[1] also indicates that the maximum energy release which can reasonably be expected for complete and rapid immersion of the core is 40 to 50 Mw-sec. Further analysis[16] yields an expected maximum energy release of 46 Mw-sec. A plot of average fuel temperature and core power versus time after a \$3.60 step reactivity insertion is presented in Figure VII-1. It has been postulated[17] that the power burst may be turned over by the temperature coefficient before core disassembly begins. The results of all analytical studies indicate that the maximum expected energy release will not exceed 60 Mw-sec.

Some of the other assumptions that have been made in assessing the radiological consequences of the destructive test are also believed to give pessimistically high results. First, the calculations of doses downwind of the test cell, due to transport of radioactive material, are based on the assumption that 100% of the noble gas isotopes, 50% of the halogens, and 50% of the remaining (non-gaseous) fission products are released to the atmosphere. It is anticipated that considerably less than these percentages will actually be released. This estimate is based primarily on the fact that a considerable amount of water will be available to retain radioactive material. (This assumption is supported by the SPERT I destructive test in which less than 1% was released[18].) Thus, on the basis of the estimated lower fission product release, the radiological doses downwind would be roughly a factor of 50 lower than those to be discussed. Second, the effect of cloud depletion due to fallout of particulate matter was not considered in the calculations.

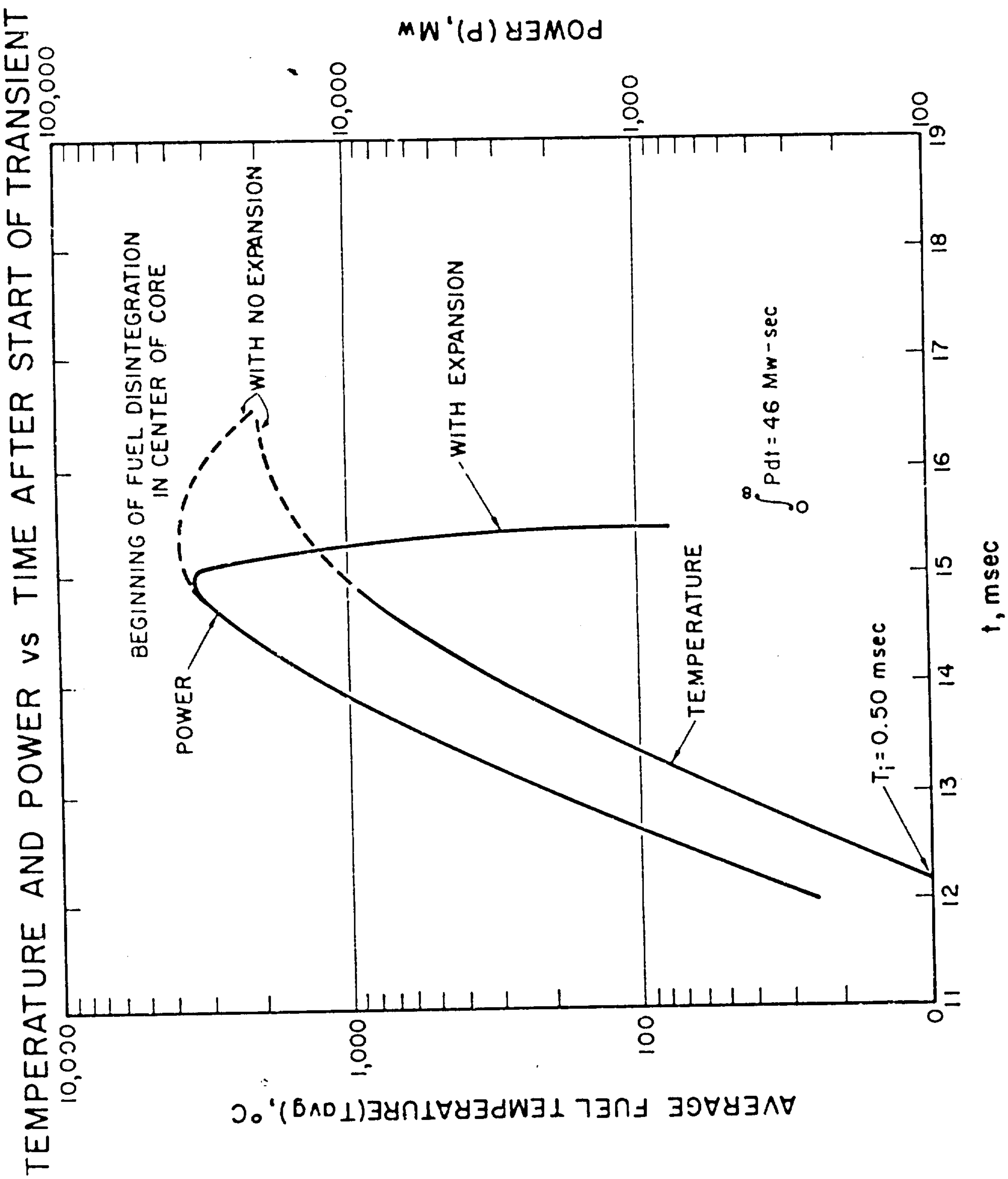

Figure VII-1 - Temperature and Power vs Time After Start of Transient

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B. On-Site Consequences of the Destructive Experiment

1. Radiological Doses

Several sources of on-site radiological hazards of the SNAPTRAN 2/10A-3 destructive test have been considered. These are: (a) direct radiation during the power burst, (b) doses from radioactive material transported downwind from the test cell under the planned meteorological conditions, and (c) consequences of a wind shift soon after the initiation of the destructive test. The downwind doses considered are: (1) gamma dose from a cloud of radioactive materials, (2) gamma dose from radioactive material that has fallen from the cloud and deposited on the ground, and (3) dose to the thyroid from the inhalation of radioactive iodine.

a. Radiation from the Power Burst

The radiation from the power burst will consist of radiation from the side of the environmental tank plus that from the top which is scattered by air to the ground. The actual doses will lie within the limits shown in Figure VII-2, based on a point-source geometry and a 170 Mw-sec nuclear energy release. The total integrated dose from the power burst 5000 ft from the test cell is calculated to be less than 1 mrem. Since no personnel will be within 5000 ft of the test cell, except those in the shielded control room, it is evident that no danger exists from direct radiation from the power burst.

b. Downwind Radiation Doses

In order to reduce the radiological dosages to personnel in the TAN area and to the off-site population, strict meteorological control will be exercised during the destructive experiment. These controls, agreed upon by Phillips Petroleum Company and AEC-ID are:

(1) Wind direction variance: 160° to 220° during second and third quarters of calendar year (grazing season), and 180° to 240° during first and fourth quarters[19].

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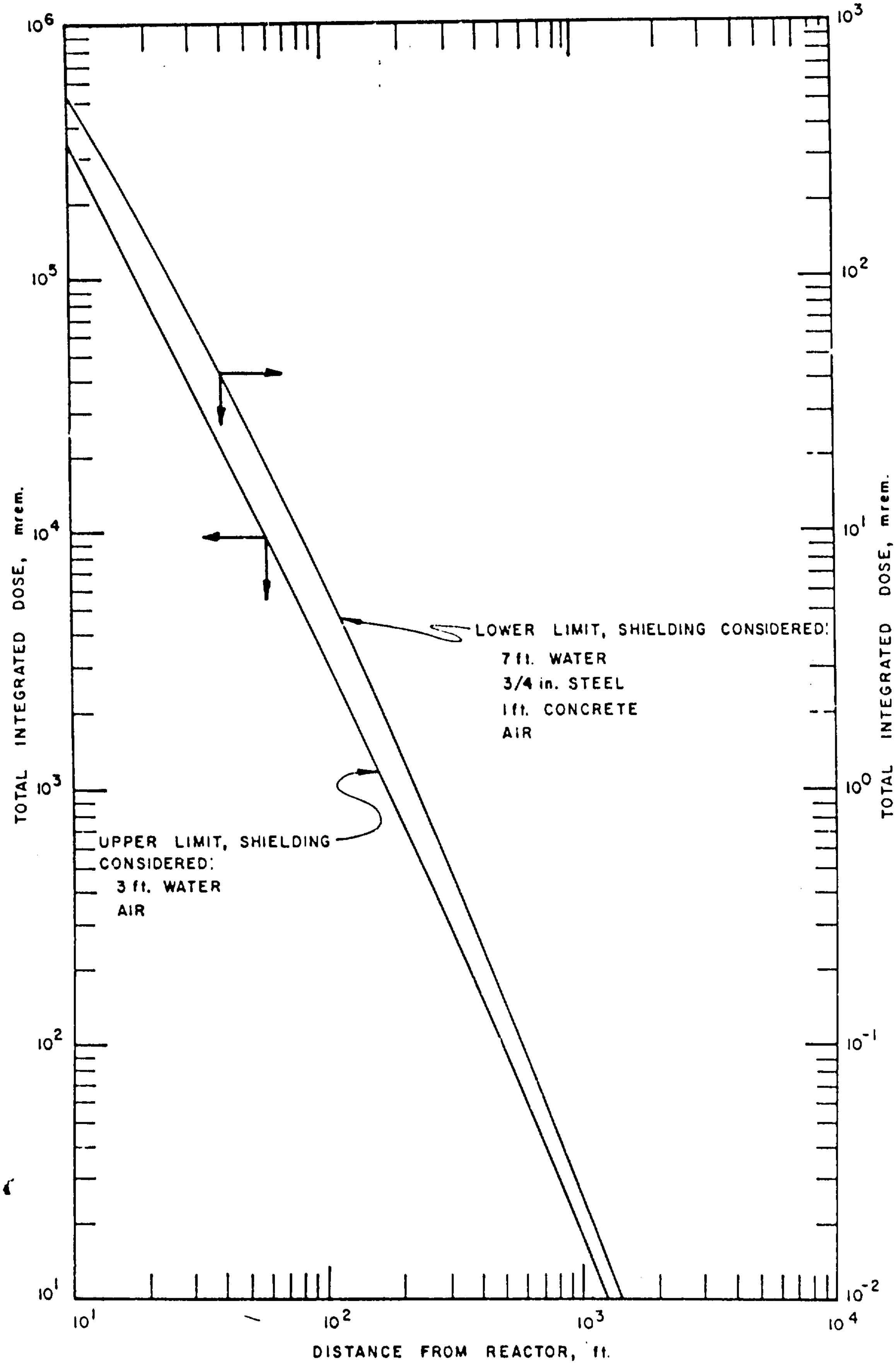

Figure VII-2 - Total Dose from Direct Radiation for a 170 Mw-sec Power Burst

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(2) Minimum wind speed of 10 mph.

(3) Lapse conditions.

(4) No precipitation.

These parameters shall be forecast to last for at least three hours following the destructive test. Forecast will be provided by the U. S. Weather Bureau at the NRTS through the ID Health and Safety Division. The 60° radiological surveillance grid[3] will be located in the sector given in (1) above.

Under these conditions, the passage of a cloud containing radioactive material will be over an uninhabited area for a distance of at least 6.5 miles. The gamma dose from deposited material will be significant for a period of time following the test. Thus, the area will be restricted until it has been determined by the Health Physicists that the dose rates are acceptably low. The integrated gamma dose from radioactive fallout as a function of distance from the reactor is presented in Figure VII-3.

c. <u>Consequences of a Wind Shift</u>

Although the SNAPTRAN 2/10A-3 destructive experiment will be initiated under controlled meteorological conditions, the effect of a shift in wind direction immediately following the power excursion has been investigated. In the event that a wind shift occurs and the radioactive cloud passes over one of the on-site work locations, an exposed person would receive a radiation dose. This would consist of an external dose directly from the cloud and radioactive deposition and an internal dose resulting from the inhalation of radioactive materials during the time the person remains in the area.

It has been postulated that TAN area personnel can be evacuated in less than ten minutes. It is assumed in the safety analysis, therefore, that if the wind shifts such that on-site personnel are exposed to a radioactive cloud they are not exposed to deposition from the cloud for more than ten minutes. Under these conditions, the maximum total dose received by a person in the TSF area during the passage of the cloud is

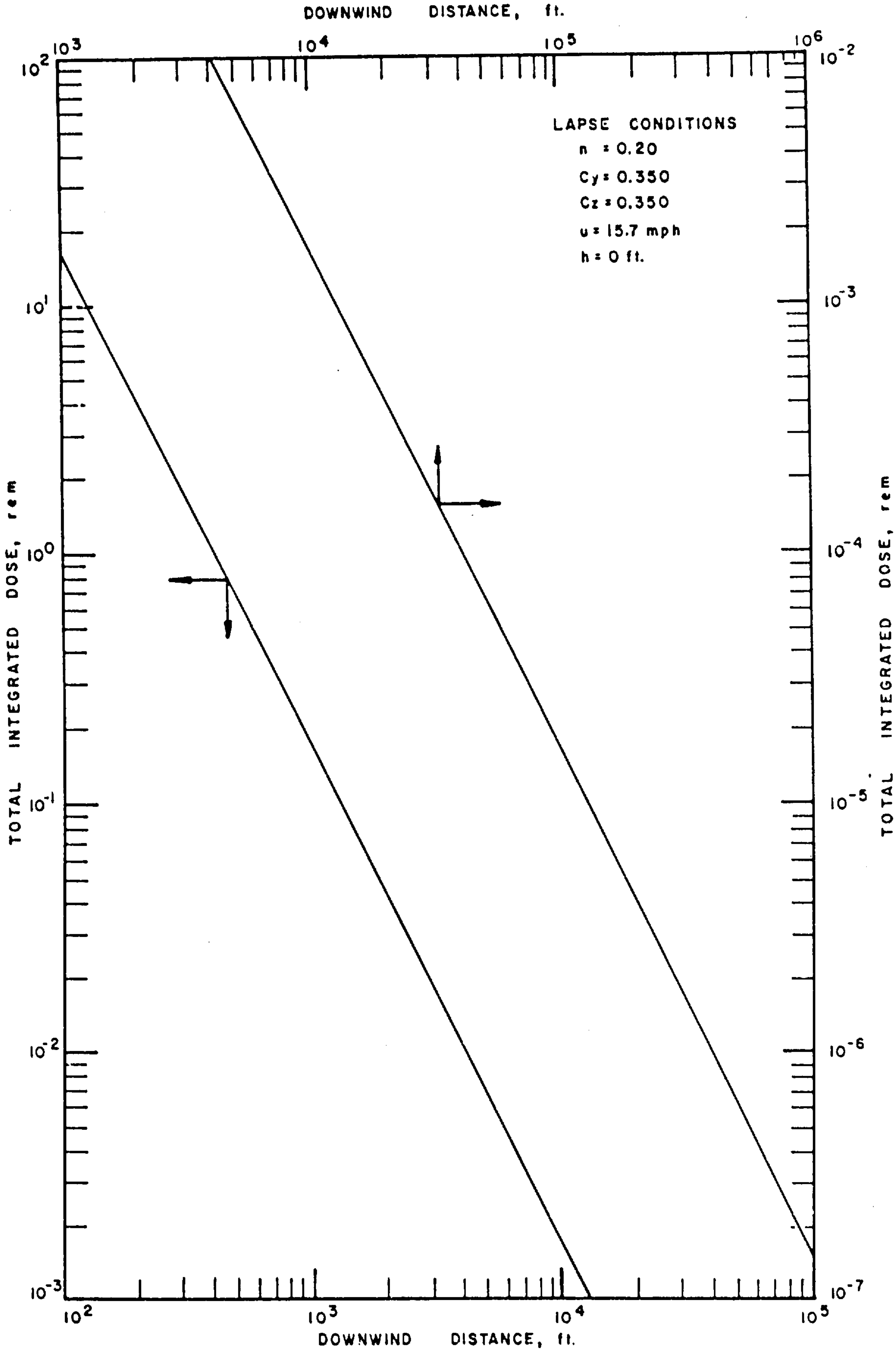

Figure VII-3 - Deposition Gamma Dose for 170 Mw-sec Power Excursion - Lapse Condition, 15.7 mph Wind

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calculated to be 32 mrem. This includes 24 mrem directly from the cloud, less than 1 mrem from the ten minutes exposure to the deposition, and 7 mrem to the thyroid from inhalation.

Figures VII-3, -4, and -5, from which the dose at the Technical Support Facilities (TSF) is obtained give the total integrated cloud, deposition, and thyroid inhalation doses as a function of distance. The deposition dose for a ten minute exposure is less than 20% of the total integrated dose shown in Figure VII-3, which is based on an infinite exposure time. The thyroid dose has been chosen to represent the inhalation dose, since it is the major contributor to the total inhalation dose.

The TSF area is the closest location to the reactor (1.3 miles) that any personnel, except those in the control room at IET, will be permitted. Doses at other locations, therefore, would be lower than those presented in the above figures. The closest on-site area to IET, outside the TAN complex, is the Naval Reactor Facility (NRF) about 22 miles to the southwest. If a radioactive cloud should pass NRF, the dose to an exposed person would be much less than 1 mrem.

The presence of a strong inversion in conjunction with a wind shift is not considered credible. However, the doses for this condition have been investigated. A maximum dose of 55 rem is calculated for a person exposed to the radiation from a passing radioactive cloud and subsequent deposited material for the ten minute evacuation time. This dose includes a 24 rem external cloud dose, a 30 rem thyroid inhalation dose, and a 1 rem dose from deposition. These doses were obtained from the curves in Figure VII-6, -7, and -8. Personnel in any work location other than TSF would receive a smaller dose than that stated above since the other locations are all farther from the test cell.

It is concluded that the destructive test will contribute no serious radiation doses to on-site personnel. In the event of some unforeseen circumstance requiring emergency procedures, such as a wind direction shift, the Phillips Petroleum Company Emergency Action Plan will be placed into effect.

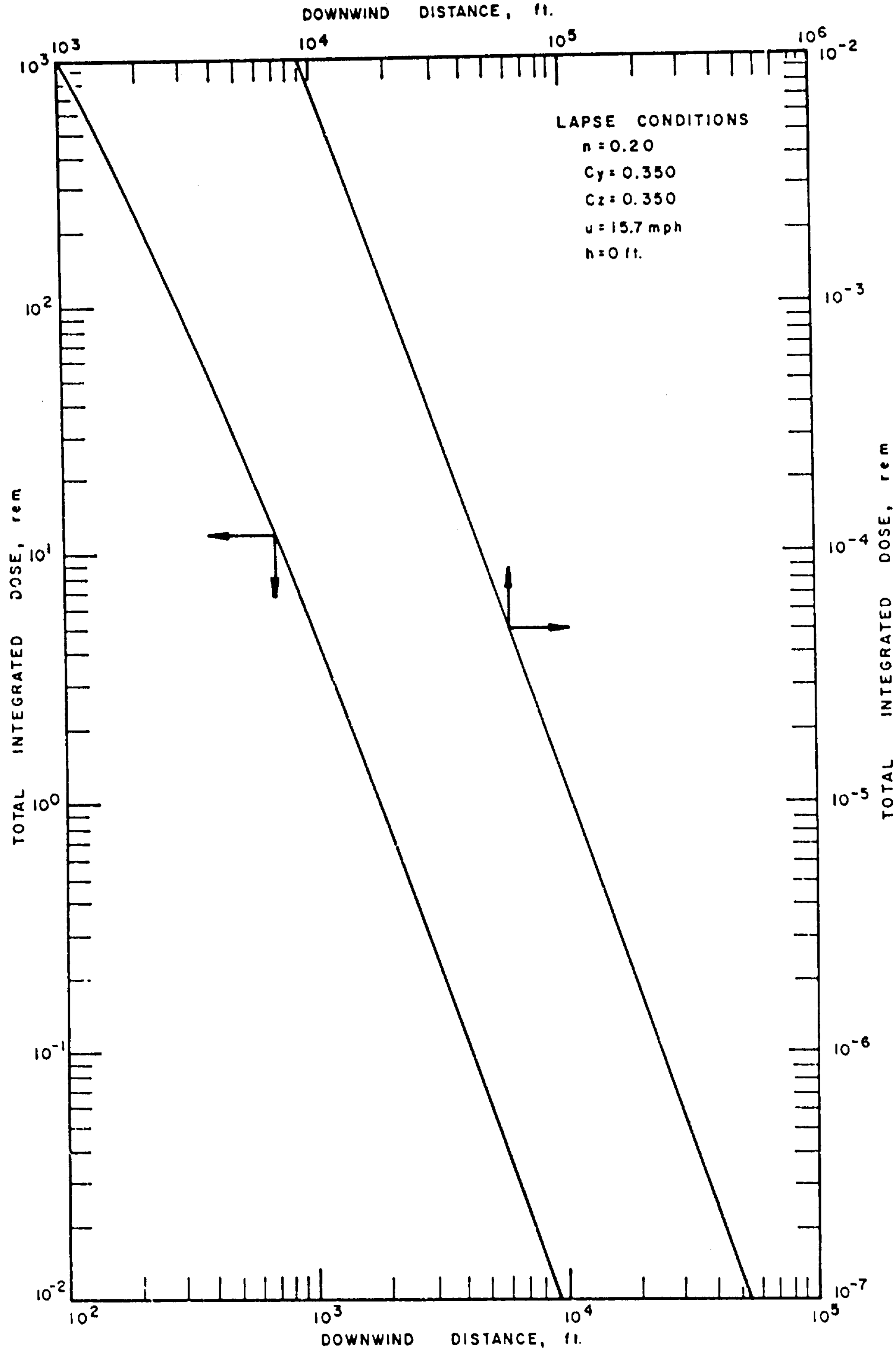

Figure VII-4 - Cloud Dose for 170 Mw-sec Power Excursion - Lapse Condition, 15.7 mph Wind

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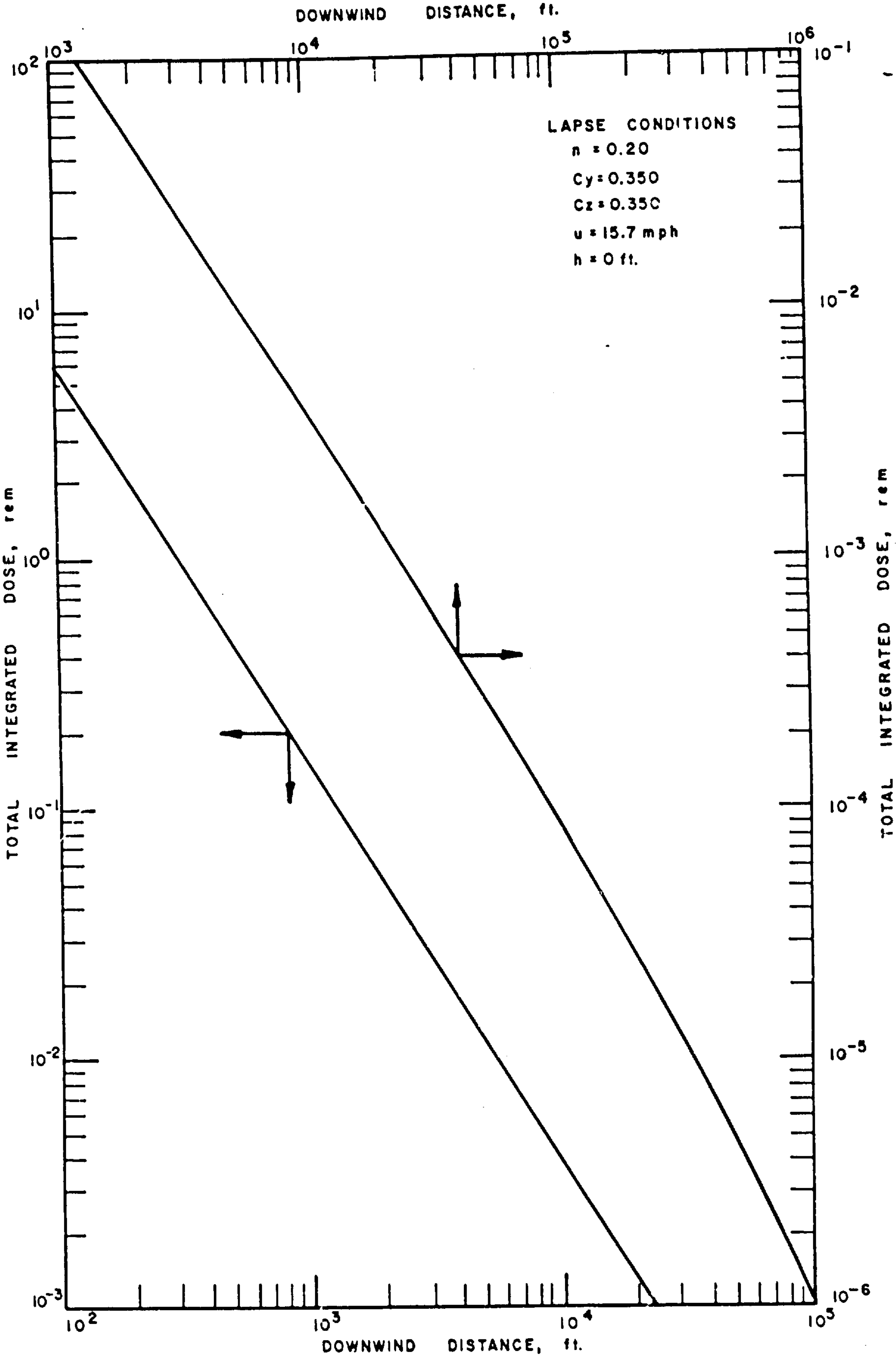

Figure VII-5 - Thyroid Dose for 170 Mw-sec Power Excursion - Lapse Condition, 15.7 mph Wind

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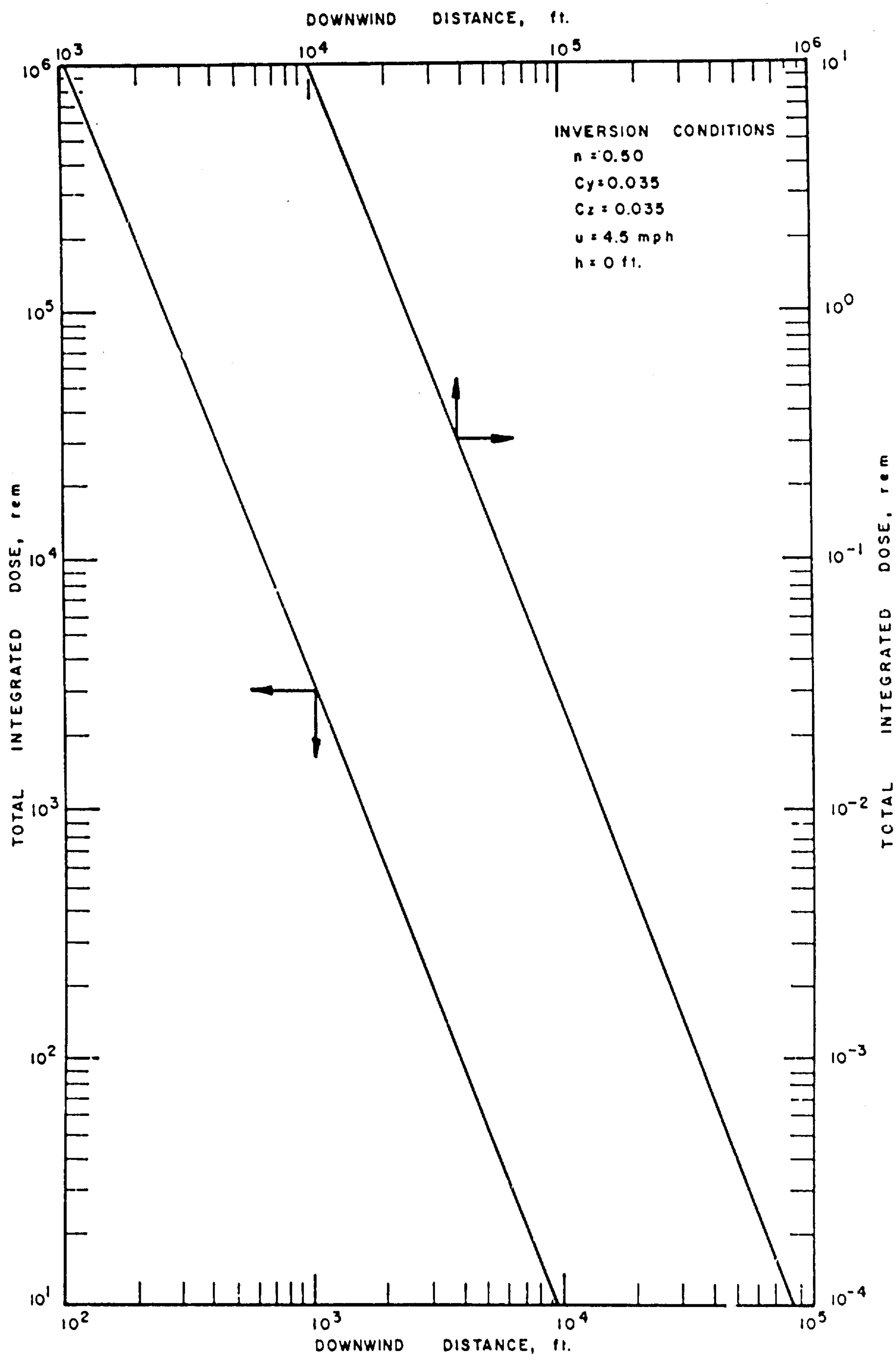

Figure VII-6 - Cloud Dose for 170 Mw-sec Power Excursion - Inversion Condition, 4.5 mph Wind

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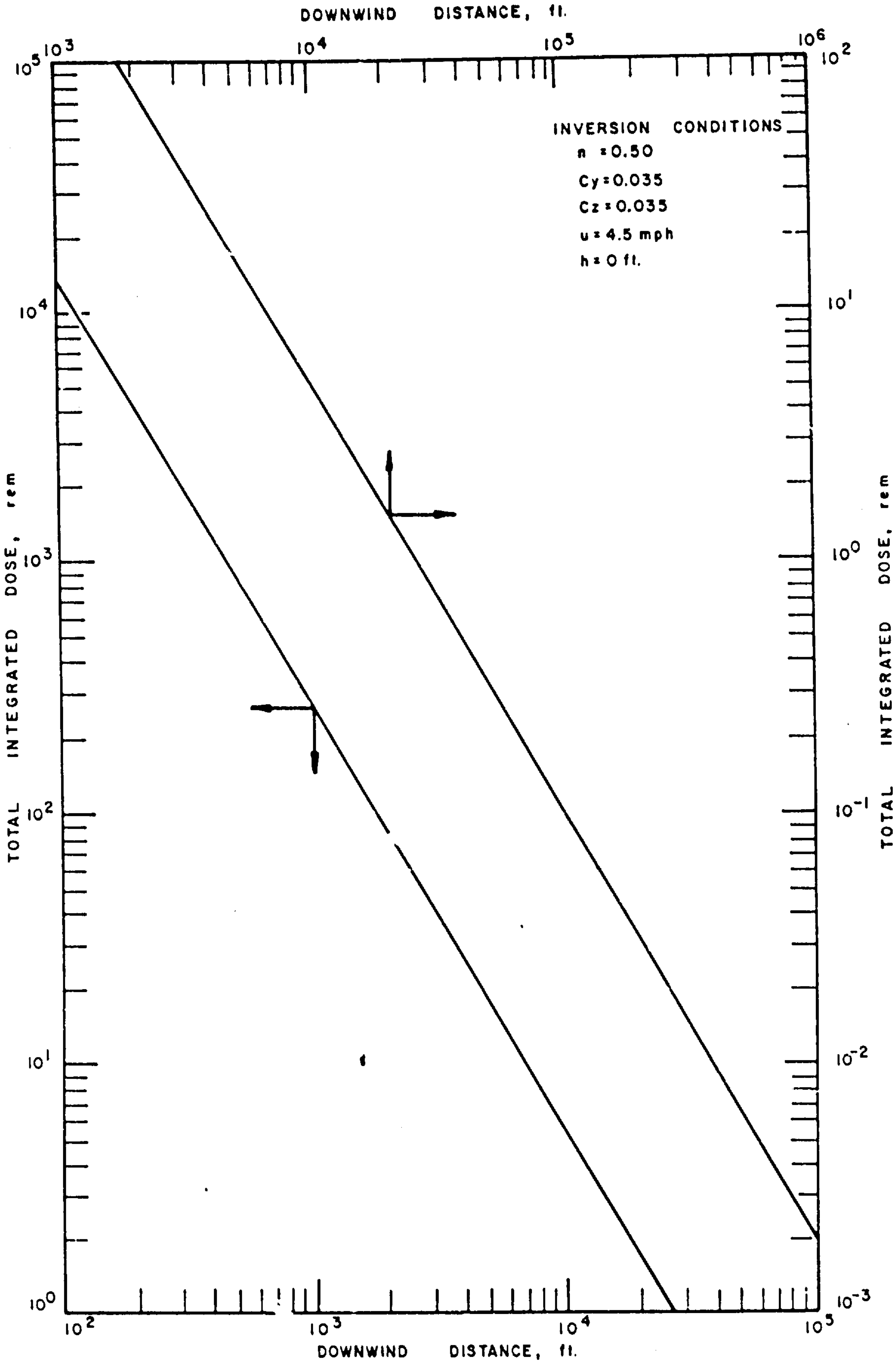

Figure VII-7 - Deposition Gamma Dose for 170 Mw-sec Power Excursion - Inversion Condition, 4.5 mph Wind

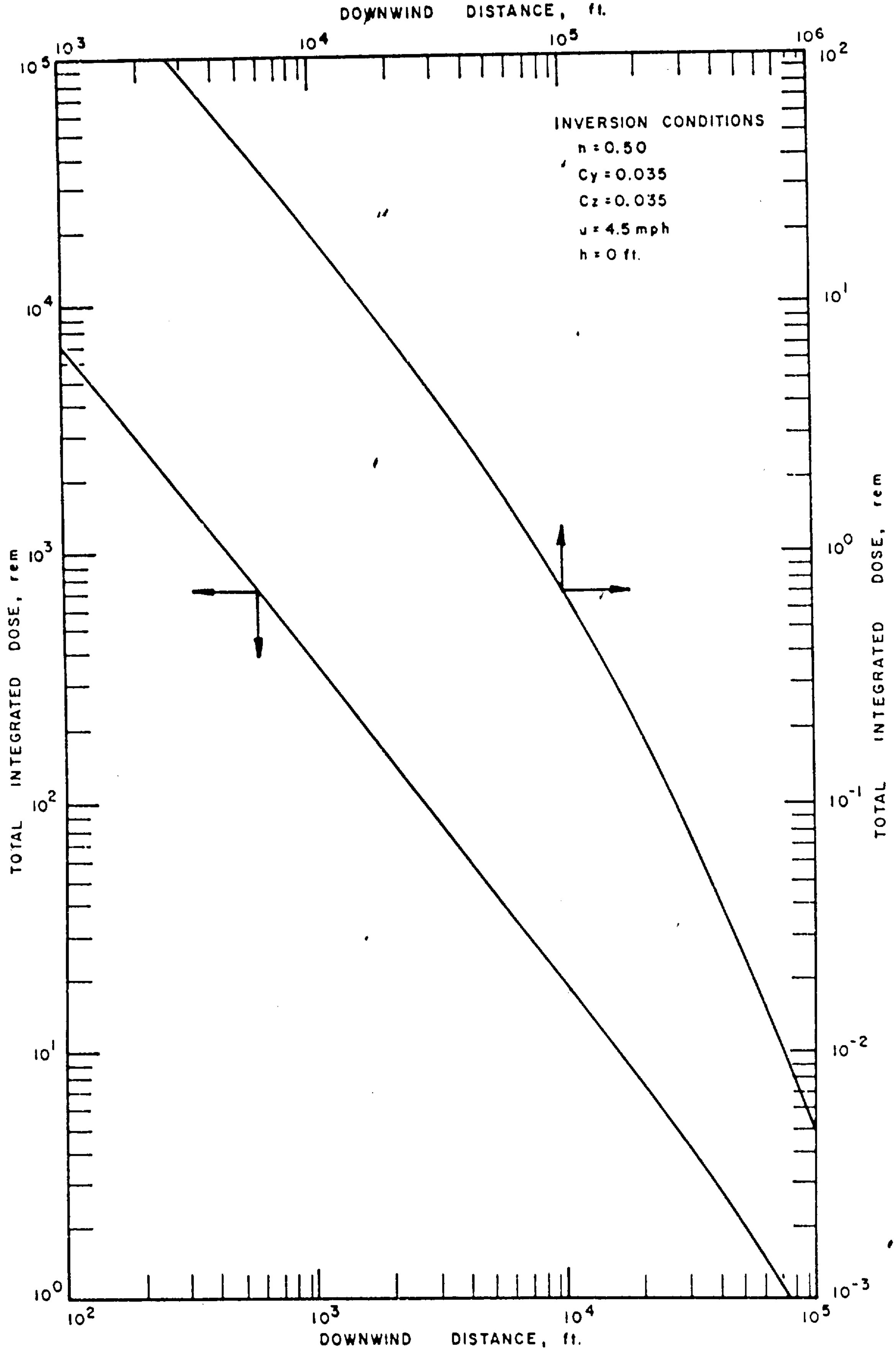

Figure VII-8 - Thyroid Dose for 170 Mw-sec Power Excursion - Inversion Condition, 4.5 mph Wind

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d. Radiological Calculation Techniques

The following methods were used in determining the radiological dosages to on- and off-site personnel due to the passage of a radioactive cloud.

The wind speeds used in computing the doses, 7 meters/sec for lapse conditions and 2 meters/sec for inversion conditions, are the speeds considered most probable at the NRTS by the U. S. Weather Bureau[20].

(1) Integrated External Cloud Gamma Dose

The integrated external cloud dose is the maximum amount of radiation to which a point at the ground may be exposed as a result of the passage of a cloud of diffusing substance.

The radioactive material released to the atmosphere as a result of the core destruction will probably not rise to any great distance above the ground because of the resistance of the water above the reactor. For this reason, and also because it gives the most pessimistic results, the assumption has been made that the cloud remains essentially at ground level. In this case, assuming an instantaneous release of the radioactive material to the atmosphere, the integrated external cloud dose is given by[21]:

$$D_c(\text{rem}) = \frac{2\,Q(t)\,F}{\pi c_y c_z u\, d^{2-n}}$$

where:

$Q(t)$	=	number of curies in the cloud at time t
c_z	=	Sutton's diffusion coefficient (0.350, vertical direction)
c_y	=	Sutton's diffusion coefficient (0.350, lateral direction)
u	=	mean wind speed (7 meters/sec)
d	=	downwind distance, meters, = ut
n	=	Sutton's stability parameter (0.20)
F	=	conversion factor[22], $\left(0.26\ \frac{\text{rem-m}^3}{\text{sec-curie}}\right)$

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(2) Integrated Deposition Gamma Dose

The integrated deposition dose is the maximum amount of radiation which a point at the ground will receive as a result of deposited radioactive materials.

Two groups of fission products, the halogens and all the non-gaseous isotopes, will be deposited from the radioactive cloud. The dose calculations have been made separately for these two classes, so the total deposition dose is the sum of the two contributions.

Nineteen isotopes of iodine and bromine were considered in computing the deposition dose from halogens. For zero cloud height, the equation used was[23]:

$$D_d = \frac{2 V_g C}{\pi c_y c_z u \, d^{2-n}} \sum_{i=1}^{19} Q_{o_i} \int_{\frac{d}{u}}^{\infty} e^{-\lambda_i t} \, dt$$

$$= \frac{2 V_g C}{\pi c_y c_z u \, d^{2-n}} \sum_{i=1}^{19} \frac{Q_{o_i}}{\lambda_i} e^{-\frac{\lambda_i d}{u}}$$

where:

Q_{o_i} = the initial number of curies of isotope i release to the atmosphere, as given by the CURIE code

V_g = deposition velocity, $\left(2 \frac{cm}{sec} \text{ for halogens}\right)$[20]

λ_i = decay constant of isotope i, sec^{-1}

C = conversion factor, $\left(2.78 \times 10^{-3} \frac{rem\text{-}m^2}{sec\text{-}curie}\right)$[23]

The other quantities are as previously defined.

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The deposition dose from non-gaseous fission products is given by[23]:

$$D_d = \frac{2\,V_g C\,Q_o}{\pi c_y c_z u\; d^{2-n}} \int_{\frac{d}{u}}^{\infty} \left(\frac{t}{t_1}\right)^{-1.21} dt$$

$$= \frac{2\,V_g C\,Q_o}{\pi c_y c_z u\; d^{2-n}} \; \frac{\left(\frac{d}{u}\right)^{-0.21}}{0.21} \; \left(t_1\right)^{1.21}$$

where:

Q_o = the initial number of curies of non-gaseous fission products released to the atmosphere

t_1 = 1 sec

V_g = deposition velocity, $1\,\frac{cm}{sec}$ for this group of isotopes[20].

The deposition dose for a ten minute exposure is obtained by merely substituting the time d/u + 600 seconds as the upper limit in the integrals of the two preceding dose equations.

(3) Integrated Thyroid Inhalation Dose

The integrated thyroid inhalation dose is the maximum dose a human would receive to the thyroid gland as a consequences of breathing the material from the radioactive cloud. The dose to the thyroid is the major contributor to the total inhalation dose received.

The thyroid inhalation dose is given by[24]:

$$D_t(\text{rem}) = \frac{2\,B_r}{\pi c_y c_z u\; d^{2-n}} \sum_{i=1}^{i=5} K_i\,Q_i\,(t)$$

where:

$Q_i\,(t)$ = curies of isotope i in the cloud at time t, as given by the CURIE code

B_r = breathing rate, $3.47 \times 10^{-4}\,\frac{m^3}{sec}$

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K_i = conversion factor[25], tabulated below

$$= 7.38 \times 10^7 \frac{f_a \bar{E} T_e}{m} \left(\frac{\text{rem}}{\text{curie}}\right)$$

f_a = fraction of inhaled material which reaches the thyroid

$\bar{E}$ = effective energy absorbed by the thyroid per disintegration, Mev/dis

T_e = effective half-life, days

m = mass of the thyroid, gm

Values for f_a, $\bar{E}$, T_e, and m were obtained from the literature[26].

i	Isotope	$K_i \left(\frac{\text{rem}}{\text{curie}}\right)$
1	I^{131}	1.49×10^6
2	I^{132}	5.36×10^4
3	I^{133}	3.99×10^5
4	I^{134}	2.51×10^4
5	I^{135}	1.24×10^5

In all the calculations of downwind doses, the following percentages of fission product inventory from a 170 Mw-sec nuclear power excursion were assumed released to the atmosphere: (1) noble gases--100%, (2) halogens--50%, and (3) remaining (non-gaseous)--50%.

2. Beryllium Contamination

It has been shown[1] that the beryllium concentrations resulting from the SNAPTRAN 2/10A-1 destructive test will not endanger the health of the on-site personnel. This same conclusion is considered valid for the SNAPTRAN 2/10A-3 destructive test. In fact, the water covering the reactor should tend to reduce the air concentration.

3. Fission Products Generated and Released

The activities of fission products of major radiological concern listed in Table VII-A are based upon a decay time of zero seconds.

TABLE VII-A

FISSION PRODUCT ACTIVITY GENERATED FROM A 170 Mw-sec POWER BURST

Isotope	Half-Life	Activity at Decay Time t = o (curies)
Bromine		
82-85		4.86×10^{2}
87	54.5 sec	1.00×10^{2}
88	16.3 sec	1.80×10^{5}
89	4.4 sec	1.00×10^{6}
90	1.6 sec	2.62×10^{6}
Total Bromine		4.15×10^{6}
Krypton		
83m	1.9 hr	1.87×10^{-2}
85m	4.4 hr	1.49×10^{-2}
85	10.4 yr	3.43×10^{-12}
87-95		2.39×10^{5}
Total Krypton		2.39×10^{5}
Strontium		
89	50.4 day	1.78×10^{-5}
90	28 yr	1.93×10^{-6}
91	9.7 hr	1.16×10^{1}
92-97		2.48×10^{6}
Total Strontium		2.48×10^{6}
Zirconium		
95	65 day	1.84×10^{-4}
Ruthenium		
103	40 day	4.35×10^{-3}
Tellurium		
127	9.3 hr	2.57×10^{-5}
131	25 min	8.81×10^{-1}
132	78 hr	3.74×10^{0}
Iodine		
131	8.05 day	5.37×10^{-1}
132	2.3 hr	1.57×10^{-4}
133	20.8 hr	3.50×10^{-2}
134	53 min	2.63×10^{2}
135	6.7 hr	1.60×10^{2}
136-139		1.56×10^{6}
Total Iodine		1.56×10^{6}

TABLE VII-A (Continued)

Isotope	Half-Life	Activity at Decay Time t = o (curies)
Cesium		
135	2.0×10^6 yr	1.64×10^{-9}
137	30 yr	1.66×10^{-4}
141	25 sec	1.46×10^5
Total fission product activity including above isotopes		2.75×10^7

C. Off-Site Consequences of the Destructive Experiment

1. Radiological Doses

Off-site radiological exposure can occur only from the fission products released to the atmosphere since the direct radiation effect has previously been shown to be negligible.

During controlled meteorological conditions the wind will blow in a northeasterly direction. The nearest inhabited area in this direction is approximately 6.5 miles, and the nearest town is Monteview, 12 miles away. Table VII-B give the maximum exposure to inhabitants of towns lying in the expected path of a radioactive cloud released as a result of the destructive test. The doses listed are the combined effect of external cloud dose, inhalation thyroid dose, and dose from deposition. These dosages were obtained from the dose versus distance curves in Figures VII-3, -4, and -5 and are based on a probable wind speed of 15.7 mph.

The effect of a wind change occurring during the destructive test has been presented in the safety analysis report(1) for the SNAPTRAN 2/10A-1 destructive series. It is very unlikely, however, that a complete reversal of wind direction will occur during or immediately following the destructive test since the test will be conducted only under controlled meteorological conditions.

TABLE VII-B

DOWNWIND DOSES FROM CLOUD (EXTERNAL AND INHALATION) AND DEPOSITION - WITH METEOROLOGICAL CONTROL

Town	Distance From IET (Miles)	Total Integrated Whole Body Dose (mrem)	Total Integrated Thyroid Dose (mrem)
Monteview	12	0.086	0.19
Winsper	21	0.023	0.074
Camas	26	0.014	0.05
Small	30	0.01	0.039
Dubois	33	0.008	0.033

Although the destructive test is to be run under strict meteorological control, the effect to the general population of no meteorological control has also been investigated. Table VII-C gives the total integrated doses for various towns surrounding the test site. The integrated doses for inversion conditions are shown in Figure VII-6, -7, and -8.

In some coses the postulated doses under adverse conditions are slightly greater than the maximum permissible exposures[27]. However, it is inconceivable that a release will occur during these conditions.

It is recognized that a potential radiation dose exists to humans from the consumption of food products which were produced in an area where fission products had deposited. Consumption of milk is the chief way in which radioactive material could be ingested. It has been calculated that the dose to a child's thyroid from continued daily consumption of one liter of milk would not exceed 25 mrem, assuming that the cow grazed every day following the destructive test on the nearest grazing land to IET (6.5 miles).

The thyroid ingestion dose per liter of milk per day was calculated by means of the following equation[28]:

$$D = \sum_j C_{m_j} \; K_j/20 \text{ and } C_{m_j} = \frac{2Q_j \; V_g F_i F_m M_d}{\pi c_y c_z u \; d^{2-n} F_w V_m} \int_0^\infty e^{-\lambda_j t} \, dt$$

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TABLE VII-C

DOWNWIND DOSES FROM CLOUD (EXTERNAL AND INHALATION) AND DEPOSITION - NO METEOROLOGICAL CONTROL

		Total Integrated Whole Body Dose (mrem)		Total Integrated Thyroid Dose (mrem)	
Town	Distance from IET (miles)	Lapse (u=15.7 mph)	Inversion (u=4.5 mph)	Lapse (u=15.7 mph)	Inversion (u=4.5 mph)
Monteview	12	0.085	300	0.19	1450
Mud Lake	13	0.07	255	0.165	1300
Terreton	15	0.06	195	0.13	1000
Howe	16	0.04	170	0.12	910
Winsper	21	0.025	105	0.075	600
Roberts	30	0.01	53.5	0.04	310
Small	30	0.01	53.5	0.04	310
Dubois	33	0.008	45	0.035	260
Atomic City	33	0.008	45	0.035	260
Arco	34	0.0075	42.5	0.03	240
Menan	37	0.006	36.5	0.027	205
Idaho Falls	39	0.0055	33	0.024	185

where:

C_{m_j} = total integrated milk concentration due to the j th isotope of iodine

K_j = conversion factor, $\frac{rem}{curie}$

Q_j = curies of isotope j at a time of two days after deposition on the grazing land. (Milk activity is found to be highest two days after grazing.)

F_i = animal intake factor, (4×10^4 gm/day)

F_m = fraction of daily intake converted to milk, (0.1)

M_d = milk density, $\left(1 \frac{gm}{cm^3}\right)$

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V_g = deposition velocity, $\left(2 \frac{cm}{sec} \text{ for halogens}\right)$ [20]

V_m = daily mass of milk, (2×10^4 gm/day)

F_w = vegetation weight/area factor, (50 gm/m^2)

λ_j = disintegration constant for isotope j, day^{-1}

The K_j values are listed below for the isotopes considered:

j	Isotope	$K_j \frac{rem}{curie}$
1	I^{131}	1.95×10^6
2	I^{132}	7.00×10^4
3	I^{133}	5.22×10^5
4	I^{134}	3.27×10^4
5	I^{135}	1.62×10^5

The factor of 20 in the equation is an empirical reduction factor[28]. All other factors in the equation are as previously defined.

VIII. SAFETY ANALYSIS OF THE POST-DESTRUCTIVE TEST OPERATIONS

The safety analysis of the post-destructive test operations presented here is taken largely from the SNAPTRAN 2/10A-1 safety analysis. Since the magnitude of both the SNAPTRAN 2/10A-1 and the SNAPTRAN 2/10A-3 nuclear excursions are expected to be about the same, and since some of the SNAPTRAN 2/10A-3 radioactive material may remain within the environmental tank, the actual radiation levels outside the tank should be less than those presented in this section.

Surface contamination, airborne contamination, and direct radiation in the IET and TSF areas are considered in the post-destructive analysis. Time limitations for personnel in the above areas are estimated. However, under no circumstances will a person be admitted to the area in question without proper Health Physics approval. Reentry procedures following the destructive test are discussed in Section V.

A. Radiological Safety Analysis

1. Initial Engineering Test (IET) Facility

a. Direct Radiation

The radiation doses resulting from fission product decay following the destructive test have been evaluated for the case in which all the fission products are retained on the test pad.

The gamma dose rate as a function of distance from the building for this condition is presented in Figure VIII-1. This analysis is based on the conservative assumption that the fission products constitute a line source just inside the building. The source is assumed to have no self-shielding or external shielding except air.

The predicted dose rates and access time limits for the various work areas at one hour and 24 hours after shutdown are presented in Table VIII-A. On the basis of this analysis, access to the area inside the security fence surrounding the IET, except inside the control and equipment building, cannot be permitted for at least 24 hours following the destructive test. After one week, access to the reactor building can be permitted for approximately 16 minutes before personnel receive 300 mrem.

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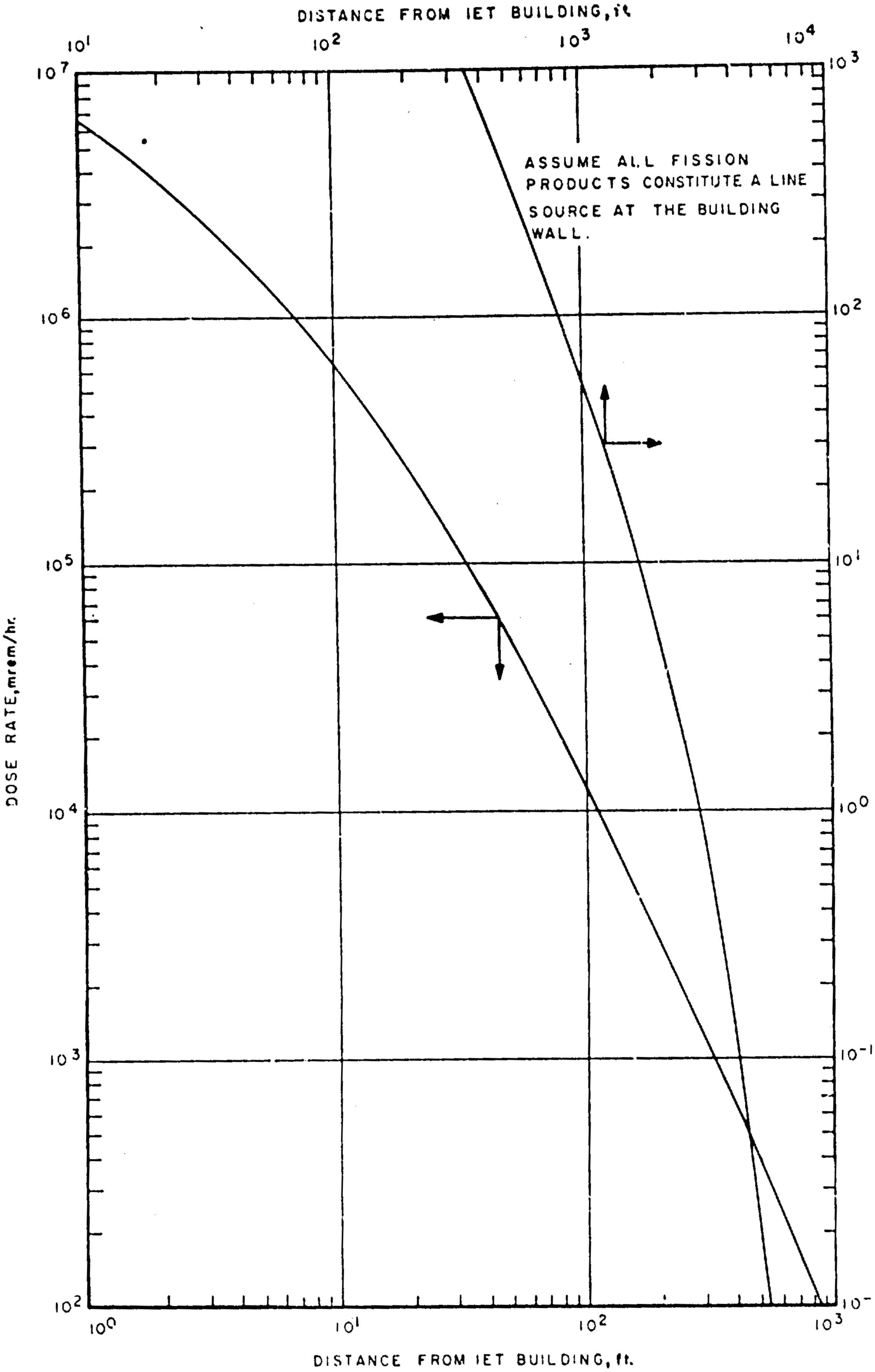

Figure VIII-1 - Gamma Dose Rate One Hour After Destructive Test

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TABLE VIII-A

RADIATION LEVELS FOLLOWING DESTRUCTIVE TEST

Location	Distance from IET Building (ft)	Dose Rate (mrem/hr) 1 Hour	Dose Rate (mrem/hr) 24 Hours	Access Time Limits 1 Hour	Access Time Limits 24 Hours
Fenced area around the TSF	> 4000	< 1	< 1	None	None
End of tunnel at IET	~ 1400	20	< 1	15 hrs/wk	None
Security fence around IET	~ 170	3.7×10^3	56	5 min/wk	5.3 hrs/wk
On the test pad*		9.0×10^5	1.3×10^4	No access	1.4 min/wk
IET control and equipment building		< 0.1	< 0.1	None	None
Coupling station		< 0.1	< 0.1	None	None

*An infinite plane source geometry was assumed on the test pad.

The reactor building will not be over the pad at the time of the destructive test. The activity could thus be scattered over a larger area than when enclosed in the building. The dose rate, if the activity is spread over a large area, will not exceed the predicted dose rate inside the test cell (9.0×10^2 rem/hr).

The total gamma energy (mev/sec) emitted by the fissiom products as a function of operating time (t_o) and shutdown time (t_s) when $t_o \ll t_s$, such as following a nuclear excursion is determined by the following equation(15):

$$Q\left(\frac{\text{mev}}{\text{sec}}\right) = 3.1 \times 10^{10}\, P\, t_o\, a\, G\,(t_o, t_s)/t_s$$

where:

a = 0.2919 for $1.5 \times 10^2 \leq t_s \leq 10^6$ sec

$(P)(t_o)$ = integrated power excursion (170 Mw-sec)

t_s = shutdown time (3.6×10^3 sec)

$G(t_o, t_s)$= gamma emission (mev/fission) as a function of operating and shutdown time.

The gamma energy spectrum as a function of t_s was also obtained from reference (15). The dose rates at other shutdown times, relative to that at one hour after shutdown, are given in Figure VI-4.

To determine the gamma dose rate from fission product decay, the source geometry was assumed to be a line source for distances less than 500 ft from the building and a point source for distances greater than 500 feet.

For a line source(13):

$$\Phi = B\,\frac{S_L}{2\,\pi\,a}\,F\,(\theta, b_1)$$

where:

$S_L = \frac{S_o}{L} = \gamma$'s/cm

S_o = gamma source strength of energy E (γ's/sec)

L = length of test pad (1.83×10^3 cm)

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B = dose buildup factor for water

$$F(\theta, b_1) = \int_0^{\theta} e^{-b_1 \sec \theta}\, d\theta$$

b_1 = μt for air

$$\theta = \tan^{-1} \frac{L}{2a}$$

a = distance from test pad to dose point.

The calculational technique for the point source is the same as that described in Section VI.

The radiation level inside the building was determined by assuming that the fission products were evenly distributed over the floor of the building. An infinite plane source geometry was used.

$$\theta = \frac{S_a}{2} E_1 (b_1)$$

where:

$$S_a = \frac{S_o}{A} \gamma\text{'s/cm}^2$$

A = area of test pad (2.52×10^6 cm^2)

$E_1 (b_1) \rightarrow 4$ as $b_1 \rightarrow 0$ where $b_1 = \mu t$ for the external shield.

2. Transportation to Examination Area

a. Contamination Spread

The spreading of radioactive materials along the railroad right-of-way is a possibility when the reactor debris is transported to the examination area. Therefore, a distance of 500 ft on each side of the tracks will be an exclusion area until it has been surveyed and decontaminated.

b. Radiation

The major radiation level associated with transporting the reactor to the examination area is the direct gamma radiation from the fission product decay. This has been evaluated for the maximum radiological conditions assuming all the fission products, following the destructive test, have been reassembled on the dolly with no shielding except air.

The gamma dose rate as a function of distance from the source (a point source) is presented in Figure VIII-2. The analysis is made for 24 hours after shutdown since it is felt that this is a reasonable time after shutdown at which personnel would be allowed access to the area for the purpose of preparing the reactor for movement. The analytical techniques are the same as those used to determine the gamma dose rate following the destructive test.

The gamma dose rates at various locations along the dolly track while the reactor is being transported to the examination area are presented in Table VIII-B.

When the reactor is being transported to the examination area, a distance of 500 ft on each side of the four rail dolly track, except behind the earth embankment, will be an exclusion area. In the event of high radiation levels, personnel inside the examination area (Bldg. 607) may be evacuated to a position behind the earth embankment until the reactor is inside the large hot cell room. Aside from the areas mentioned, all other areas will be considered as unlimited access areas.

3. Examination Area

a. Contamination

The hot shop in the examination area is designed to handle highly radioactive and contaminated materials. Thus, surface contamination of reactor components does not present an uncontrollable hazard.

b. Direct Radiation

The gamma radiation level outside the hot shop walls, with the radioactive core inside, is calculated to be less than 1 mrem/hr.

B. Secondary Criticality

Possible secondary criticality causes during or as a result of the cleanup operation are: (1) accumulation of dry critical mass, (2) accumulation of a critical solution in the drain system, and (3) accumulation of a critical mass on the trip to the examination area.

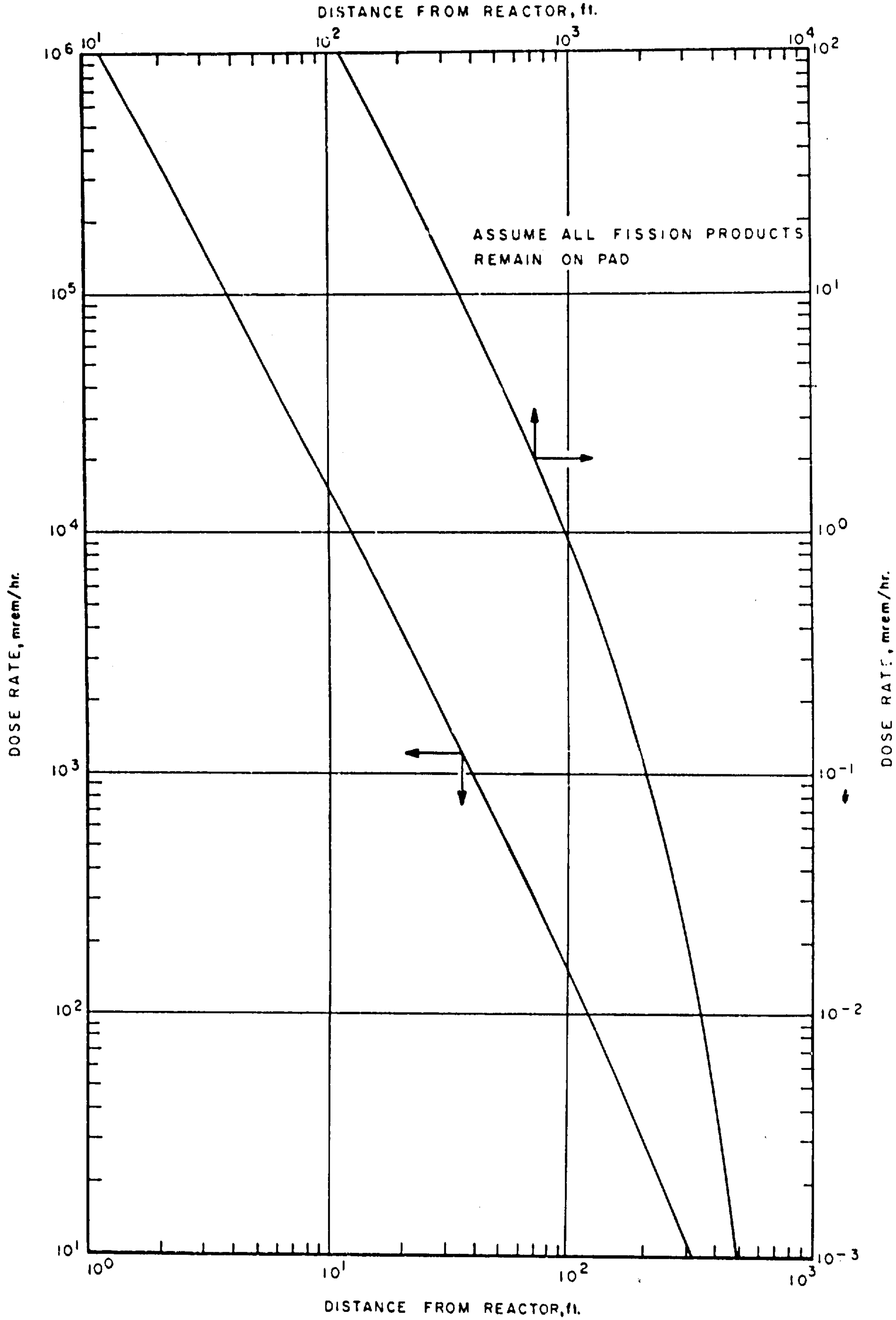

Figure VIII-2 - Gamma Dose Rate 24 Hours After Destructive Test

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TABLE VIII-B

RADIATION LEVELS WHILE TRANSPORTING REACTORS TO TSF FOLLOWING DESTRUCTIVE TEST

Location	Approx. Distance from Track (ft)	Dose Rate (mrem/hr)	Access Time Limits
Point on Taft road nearest the track	900	< 2	None
Administration Building	1000	< 1	None
Nearest point to security fence around Administration Bldg.--not shielded by the earth embankment	500	4.7	None
Shielded control room for hot cell (5 ft of concrete)	50	< 1	None
Unshielded part of Bldg. 607	60 (min.)	400 (max)	3/4 hr.
Shielded locomotive		< 1	None

It is expected that the explosive in the destructive test could dismantle the reactor and disperse debris over a large area. The proposed cleanup schedule will include the collection of debris outside the test pad, collection of coarse particulate debris on the pad, and then, after replacing the building, washing the remaining material into a drain system leading to a catch tank.

A possibility exists that a critical configuration could occur during the dry cleanup either by loading a critical mass into a waste container or vacuum cleaner or by pushing fuel debris into a critical configuration on the reactor dolly. These possibilities will be eliminated by securing debris to the dolly and by transporting the dolly during favorable weather conditions.

The wet cleanup of the test pad will be accomplished by washing fine debris into the drain system. The drain system is made up of a drain trench, a 10 in. pipe, a fine mesh particulate filter, and a 15,000 gallon catch tank. The 10 in. diameter drain pipe has not only been covered with cadmium but also has been sectioned into "critically safe" flow segments with cadmium strips. The particulate filter has been plated with cadmium and cadmium strips have been added to the drain trench to make this section of the system "safe" (see Figure VIII-3). Calculations on the IBM-650 using the DMM Code indicate that the drain system with this addition of poison, forms a critically safe configuration for the cleanup operation.

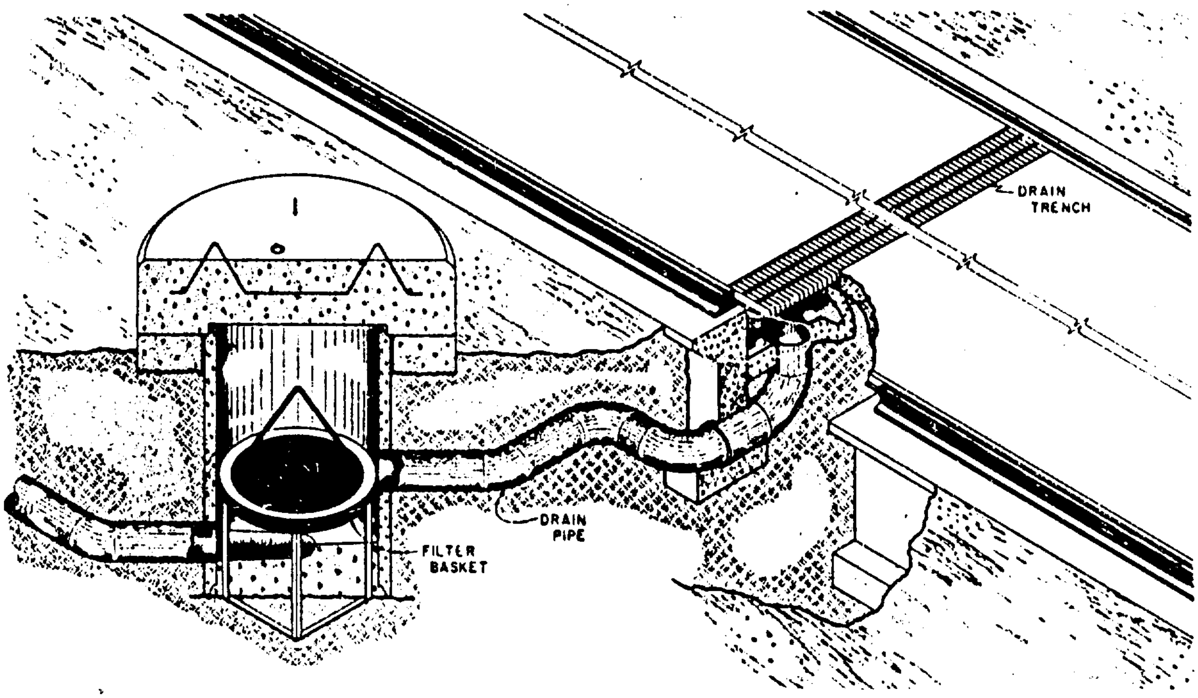

Fig. VIII-3 - Contaminated Waste Trench and Strainer

IX. CONCLUSIONS

The hazards associated with the conducting of the SNAPTRAN 2/10A-3 reactor safety test program have been considered in the previous sections. Some important points in the discussion are presented below:

(1) The core components to be used in the SNAPTRAN 2/10A-3 program have been used in extensive water-immersion critical experiments conducted by Atomics International. The static nuclear behavior of the test package has been established, including the determination that the poison sleeve will maintain the reactor extremely subcritical in the presence of water reflection.

(2) Mechanical controls and operating procedures have been established for the fuel loading and subsequent reactor preparation for the static physics measurements in order to ensure the safety of such operations.

(3) Mechanical controls and operating procedures have been established for the handling of all reflector-moderator materials, including removal of the calorimeter, in order to ensure the safety of such operations.

(4) System design, multiple channel instrumentation, operational interlocks, automatic period and level scrams, and failure indication monitors have been incorporated and operating procedures established in order to protect against operator error or system failure and to provide backup protection in the event of such error or failure.

(5) During nuclear operation of the reactor, personnel movement into and from the test area will be controlled. The test area is defined as that area enclosed by an obstruction fence surrounding the IET facility at a distance of at least one mile. Access to the area will be controlled at the fence gate adjacent to the Technical Support Facilities (TSF).

(6) Personnel remaining inside the test area during nuclear operation will be located in the underground, earth-shielded control and equipment building.

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