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HAZARDS SUMMARY FOR THE ACCELERATOR
PULSED FAST ASSEMBLY

by

K. L. Crosbie and J. L. Russell, Jr.

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

February 25, 1965

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I. INTRODUCTION

1.1. PURPOSE

General Atomic has tested a complete accelerator pulsed fast assembly (APFA) to verify the methods and theory to be used in designing an APFA Facility. The assembly unit and fuel were provided by Oak Ridge National Laboratory and the system was tested in the Critical Cell of the High-temperature Gas-cooled Reactor. The General Atomic Linear Accelerator (Linac) and Critical Facility are described in the Hazards Summary Report for the metal assembly (GA-4488⁽¹⁾).

The success of the APFA prototype program led to requests by both the Defense Atomic Support Agency and the Atomic Energy Commission for General Atomic to conduct further investigations. To conduct these investigations, it will be necessary to operate the reactor in the experimental area of the Linac.

The reactor will be located in the C-D experimental area of the Linac about 50 ft from the accelerator. The reactor control room containing the console and control system is located in a building above the experimental area. The reactor will be operated with a steady state neutron source or with a pulsed neutron source provided by the Linac.

The purpose of this document is to provide information necessary to obtain authorization to operate the APFA in the C-D experimental area and to show that such operation will create no undue risk to the health and safety of personnel or of damage to the facility.

1.2. EXPERIMENTAL PROGRAM

Experiments with the APFA in the C-D experimental area will consist primarily of measurement of the leakage neutron spectra from 15 MeV to 10 keV and of irradiation, for defense contractors, of small electronic components and instrumentation in close proximity to the reactor. In addition, some of the measurements made during the initial program will be repeated. These include pulse shape, absolute neutron yield, and mechanical shock measurements.

Much of the experimental program will consist of low level experiments in which the reactor is pulsed with a high repetition rate (360 pps) and an

average power of less than 10 watts. This mode of operation will be used for measuring the leakage neutron spectra and absolute yield of the sub-critical reactor. The mechanical shock, pulse shape, and electronic component irradiations, however, will require a maximum pulse from the reactor. This is accomplished by putting the reactor on a 10-sec period (minimum positive period corresponding to an excess reactivity of $\sim 39\%$ and operating the Linac with its largest pulse strength (0.7 amp, 30 MeV, 5 μ sec pulse). The resultant peak power is $\sim 3 \times 10^{19}$ fissions per second for 5 μ sec, or a total of $\sim 1.5 \times 10^{14}$ fissions per burst. The resulting maximum temperature rise is $\sim 2^\circ\text{C}$ from fission heating and $\sim 3^\circ\text{C}$ from electron heating in the vicinity of the impinging electron beam.

As in the previous operations, the maximum power will be 500 watts and the reactor will be operated such that 100 watt-hr will not be exceeded during any 24-hr period. Also, as before, the highest over-power trip will be set at less than 500 watts, and all manipulations to obtain period information will be conducted below this level. This power level will be exceeded only when the reactor is pulsed with an intense Linac burst, and then the over-power trips and fast scram circuit will initiate a scram.

II. DESCRIPTION OF GENERAL ATOMIC LINEAR ACCELERATOR FACILITY

2.1. EXPERIMENTAL FACILITY

The proposed experiments with the APFA will be conducted within the C-D experimental area of the Linac building. This area is approximately 50 ft from the accelerator and is separated from the A-B experimental area by a 3-ft-thick lead and heavy concrete wall lined with borated polyethylene. A diagram of the accelerator building is shown in Fig. 1. The accelerator building is constructed of steel reinforced concrete and has an earth cover ranging from 9 to 25 ft. The walls are 1 ft thick, with 15 ft of earth on the canyon side and 25 ft of earth on the control room side; the ceiling is 12 in. thick and has an earth cover of 9 ft.

As shown in Fig. 1, the C-D area is approximately 30 ft by 40 ft and has two primary entrance doors (Nos. 1 and 2) plus one secondary entrance door (No. 3) to the A-B area. The doors shown in Fig. 1 are as follows:

Door No. 1--18 in. of poured paraffin with 1/2 in. lead lining on both sides encased in steel.

Door No. 2--4-ft-thick concrete block on poured concrete base.

Door No. 3--18-in.-thick concrete block on poured base. This door covers a 4 by 4 ft crawl hole connecting the A-B and C-D areas.

Door No. 4--Metal security door.

Door No. 5--3-ft-thick concrete block on poured concrete base.

Door No. 6--6-ft-thick poured concrete.

For spectral measurements, the APFA will be located in the middle of the C-D area in line with one of the drift tubes and will be housed in an aluminum enclosure. This enclosure will be aluminum sheet supported by a framework of aluminum angle. The enclosure will surround the APFA and will extend from floor to ceiling to prevent the possibility of a stream of water contacting the fuel assembly in the unlikely event that one of the water lines in the C-D area should fracture.

For all other experiments, the assembly will be located in the APFA vault, a 10-ft-square room in the corner opposite to the rear entrance.

Fig. 1--Diagram of accelerator building

The function of this room is to provide a personnel exclusion area around the reactor and serve as a storage vault for the APFA when it is not in use. The room is of fireproof construction and has a metal door which can be locked for security.

For the few weeks' period of the spectral measurements, during which time the APFA will be set up in the C-D area, but outside its vault, no other Linac experiments will be performed in the C-D area, and access to the C-D area will be only by permission of the Physicist-in-charge of the APFA.

2.2. STORAGE FACILITIES

When not in the Linac area, the fuel pieces will be stored in their Oak Ridge "bird cage" shipping containers within a vault as described in AEC license SNM-69 and in our application for renewal and extension of license SNM-69, dated March 29, 1963, Docket No. 70-72. The shipping containers will be arranged in a manner approved by the General Atomic Criticality Safeguard Committee. When the fuel is stored in the Linac area, it will be either in the assembly machine or in the Oak Ridge "bird cage" shipping containers in the APFA vault. The APFA vault is a fireproof room with a metal door, and is in the C-D area of the Linac, as shown in Fig. 1. A criticality alarm system meeting the requirements of Title 10, Chapter 1, Code of Federal Regulations, Part 20, "Standards for Protection Against Radiation," will be in operation whenever any fuel is in the C-D area. No more than one kilogram of special nuclear material other than the reactor fuel will be in the APFA storage vault. This will include fission counters, foils, and other experimental gear. Flooding considerations are discussed in Sections 6.2.1 and 6.2.6 of this report.

The fuel in the vault is decoupled neutronically from the rest of the C-D area by distance. When the fuel is in the "bird cages" in the vault, the distance from the vault wall is greater than the module size of the "bird cage." When the fuel is in the assembly machine, it is more than 2 ft from the vault wall.

III. DESCRIPTION OF ACCELERATOR PULSED FAST ASSEMBLY (APFA)

3.1. FUEL ASSEMBLY

The reactor core consists of a fully enriched uranium sphere. The fuel was machined from uranium metal by Oak Ridge National Laboratory and consists of five major pieces and 32 mass adjust buttons (16 buttons of 22 grams each and 16 buttons of 44 grams each) which can be attached to the sphere. The fuel assembly is shown in Fig. 2. The assembled sphere is approximately 17.8 cm in diameter and has a horizontal hole, 1-in. diameter and ~3 in. deep, to permit the electron beam to impinge near the center of the fuel. The five pieces of fuel are arranged so that there are three separate sections to the fuel when it is assembled (see Fig. 2). The total mass of the bare fuel is 54,558 grams, and the mass adjust buttons provide an additional 1056 grams in increments of 22 or 44 grams.

An 8-in. -high, 8-in. -diameter, 60-mil-thick, perforated aluminum protective screen surrounds the fuel assembly. This screen is rigidly attached to the four central section support pins and defines the distance of closest experimental approach. It also serves the function of protecting the fuel assembly from damage from experimental equipment and of preventing personnel contact with the fuel.

3.2. ASSEMBLY MACHINE

The assembly machine to be used for these experiments is the Planet assembly unit formerly used at Los Alamos Scientific Laboratory, with a few modifications. A schematic diagram of the unit is shown in Fig. 3. Basically, the assembly machine consists of three parts: (1) the main support, which supports (2) the upper frame and houses (3) the lift assembly and associated hydraulic-pneumatic system. The main support, a 50-in. -square, 4-post structure, is adjustable in height by means of a manual hydraulic jack system. The lift assembly, which supports the lower fuel section, consists of a magnet table attached to a vertically driven piston. The release of the magnet causes the table to drop 1.0 in. under gravity. With the magnet energized, the table will follow the motion of the piston through its 8 in. of travel at a maximum rate of 10 in./min. The rate is governed by an orifice in the hydraulic line. At a preset position a switch diverts the flow through another orifice so that the rate of movement through the last inch of travel is 0.2 in./min.

Fig. 2--Cross section view of the spherical fuel assembly

Fig. 3--Schematic diagram of the modified Planet assembly machine and the upper support spider

The normal lowering rate for controlled shutdown is 20 in./min., and when a scram condition occurs the magnet table allows the lower fuel assembly to drop 1 in. under gravity. The piston is then driven under its own weight in the downward direction by means of an oil bypass valve in the hydraulic system through the remaining 6 in. of its stroke. This requires approximately 6 sec. A schematic diagram of the hydraulic system is shown in Fig. 4.

In terms of reactivity rates (see Section 5.4.3), the hydraulic piston movement can insert a maximum of \$2.7/sec over the first 6 in. of travel and 8.2¢/sec over the last 1 in. of travel. Under a scram condition, the 1-in. magnet drop will cause a decrease in reactivity at the rate of \$167/sec over the first 1/4 in. of travel, \$333/sec over the next 1/4 in., and \$415/sec over the remaining 1/2 in. This is an average of \$275/sec over the first inch and a total of approximately \$20 of reactivity. The piston will then continue to fall at the rate of 1 in./sec with a reactivity decrease at the rate of \$12.25/sec over the first inch, \$5.5/sec over the next 3 in., and \$2.0/sec over the remainder of its travel.

The upper support structure for the upper fuel assembly consists of a steel cross frame attached to four support legs which connect to the main support structure. Centrally located on the cross frame is a pneumatic cylinder which raises and lowers the upper fuel piece. The piston is driven up and down with 40 psig air pressure and is driven upward with 100 psig air pressure when a scram signal is received. The cylinder has a solenoid release catch in the upper position, and it can only be released when the system has scram pressure.

The central fuel section is supported by four stainless steel rods extending from the upper support. These rods attach to the support pins on the central fuel section and fix the position of this element. Each rod is made of stainless steel tubing (1/2-in. outside diameter, 25-mil wall thickness) and will be under tension inclined 30° with the horizontal. The rods are attached to the center section by means of pins through four stainless steel threaded inserts, 3/8 in. in diameter by 3/4 in. long. This support system will withstand a load of 5000 lb.

3.3. CONTROL ROD

A control rod consisting of a small quantity of neutron reflecting material will be positioned horizontally near the midplane of the assembly and exterior to the assembly to provide fine control of reactivity. This

Fig. 4--Schematic diagram of hydraulic system

rod will be electrically driven and will have a position readout in the control room. It will not be possible to scram the control rod. The rod will be interlocked in such a way that it must be in its fully removed position to permit assembly of either the top or bottom fuel sections. The rod travel speed will be limited to give less than $2\phi/\text{sec}$ reactivity change at its most reactive position. Its travel will be limited so that the total reactivity it can add after the sections of the sphere are assembled is less than $\$1$.

3. 4. NEUTRON SOURCE

A steady state neutron source is used in the assembly and start-up of the core. This will be a Po-Be or Pu-Be source with a strength of approximately 10^7 neutrons/sec. It will be remotely positionable, and an interlock will be installed which requires that the source be present for start-up. This interlock takes the form of a low level trip on the log-micro-microammeter, which will be set at a level corresponding to at least 10^6 neutrons/sec in the assembly. Any time the neutron level drops below this value, a scram occurs. At its closest approach to the assembly, the source will be 2 in. or more from the assembly. The reactivity effect of the source (as a reflector of core neutrons from the source housing) will be measured. The source may be retracted to a shielded position when the assembly is critical or when it is being pulsed by the electron beam of the Linac.

IV. INSTRUMENTATION AND CONTROLS

4.1. NUCLEAR INSTRUMENTATION

The APFA control room is located above the experimental area over the rear entrance and will house the control console and monitoring equipment necessary for all operations.

Figure 5 is a block diagram of the instrumentation and control system for the APFA. This system incorporates four independent neutron measuring channels, one of which provides a signal for a period scram. Three of the four channels and a manual control at the console are capable of scrambling the assembly by releasing the magnet and driving the assembly apart.

Two ion chambers, individually supplied from separate voltage sources, give neutron level information on linear micro-microammeters with meter relay scrams. A compensated ion chamber, separately supplied, feeds a logarithmic micro-microammeter and a period circuit with a meter relay scram on the period circuit. This micro-microammeter has a low level meter relay trip which will interrupt the magnet current if there are insufficient neutrons present. Any of the outputs from these instruments can be fed to recording instruments.

There is also a BF_3 counter neutron channel, which will provide visual and aural indication of the neutron level, and a plastic fluor gamma sensor to provide fast scram capability.

The equipment described above constitutes the minimum instrumentation required for start-up of the APFA. Normally, extra channels will be used during most operations.

The fuel assembly temperature will be monitored with thermistors or thermocouples feeding a suitable readout device.

4.2. CONTROLS

4.2.1. Administrative

This section covers the organization, operating rules, safety regulations, and emergency procedures for the operation of the APFA.

Fig. 5--Block diagram of instrumentation and safety circuits

4.2.1.1. Personnel

All of the personnel who are permanently assigned to operate the APFA will be referred to as operating personnel. These will include the Physicist-in-charge, the Deputy Physicists-in-charge, operators, and technicians. The Physicist-in-charge and the Deputy Physicists-in-charge must possess senior reactor operator's licenses. Operators must possess a reactor operator's license. Health physicists, accountability representatives, and electronics and shop personnel who are provided on a service basis by the Laboratory will be referred to as non-operating personnel.

Operating Personnel

The duties of the operating personnel will be as follows:

Physicist-in-charge of the APFA. The Physicist-in-charge of the APFA is responsible to the Physicist-in-charge of the Linac and is directly responsible for staffing, scheduling, and operating procedures and for techniques used in the experiments. He will assist in interpreting experimental data and in developing modifications to the experimental program. He is responsible for conducting operations in accordance with established regulations, and he will enforce rules for the protection of personnel against radiation, including the regulations contained in Title 10, Chapter 1, Code of Federal Regulations, Part 20, "Standards for Protection Against Radiation." He is responsible for the maintenance of the assembly and the associated instrumentation and for all special nuclear material and fuel used in the APFA.

The Physicist-in-charge of the APFA is also responsible for periodically reviewing the hazards report and technical specifications and will initiate whatever changes may be required to keep these documents up to date. He will also consult with the Office of the Division Counsel in determining that experiments performed at the facility meet the conditions established by the Operating Authorization granted by the Atomic Energy Commission.

The Physicist-in-charge of the APFA, with the concurrence of the General Atomic Criticality Safeguard Committee, will establish a checkout procedure which will be used routinely before operating the assembly to check proper operation of the instruments. This procedure will be kept up to date to reflect the instrumentation in use. He will also establish proper scram levels to be applied during routine operations. He will maintain a complete log of APFA operations.

When the Physicist-in-charge is to be absent during the operation of the assembly, he will designate a Deputy Physicist-in-charge to assume

his responsibilities. Any action relating to the assumption of responsibility by a Deputy Physicist-in-charge will be entered in the assembly log. Assembly operations will always be directly supervised by the Physicist-in-charge or the Deputy Physicist-in-charge.

APFA Staff. The APFA staff, which constitutes the balance of the operating personnel, includes the Deputy Physicists-in-charge, operators, and technicians. They will assist in the transportation of nuclear materials to the assembly and will load the assembly according to specifications established by the Physicist-in-charge. They will assist in performing the experiments, in maintaining the facility, and in keeping the required log books. The reactivity of the core may be changed from the control console only by the Physicist-in-charge, a Deputy Physicist-in-charge, or designated operators under the supervision of the Physicist-in-charge or a Deputy Physicist-in-charge, provided that a description of the program has the necessary approvals as detailed in Section 4.2.1.2.

Non-operating Personnel

The duties of the non-operating personnel that are directly related to the safe operation of the facility are as follows:

Accountability Representative. The accountability representative is responsible for the storage, issuance, and inventory of all nuclear materials to be used in the experiments. He will issue materials to authorized personnel as necessary.

Health Physicist. The health physicist assigned to the APFA will advise the Physicist-in-charge regarding radiological safety and will evaluate compliance with the Atomic Energy Commission's standards for protection against radiation. The health physicist will inspect the radiation protection practices at the facility and periodically will report the condition of the facility to the Director of the Laboratory. A radiological safety orientation lecture will be presented to the operating staff to explain the use of personnel radiation survey instruments, the principles of controlling radiation exposure, and the limits of exposure permissible. Instruments for the measurement of radiation exposure and the detection of radioactive contamination will be supplied and periodically tested by the health physicist.

Administrative services will provide protective clothing and other safety devices as required to personnel working at the facility. The health physicist will recommend contamination control measures. Air and wipe samples will be evaluated by the health physics laboratory to determine the confinement of contamination.

Security Officer. The security officer is responsible for the security of the APFA. He will assign guards, prescribe their routine, and supervise the security of the control console area and the fuel storage vault.

The security officer will direct the conduct of the guards at the facility; in the event of an emergency, however, the guards will be under the supervision of the Physicist-in-charge of the APFA.

Criticality Safeguard Committee. The Criticality Safeguard Committee has been appointed by the Director of the Laboratory to review all reactor operations and other work involving possible criticality hazards. In connection with the APFA, the committee has the following responsibilities:

1. To review the safety of facility operating practices, experimental procedures, and equipment.
2. To approve or disapprove proposed programs and changes in routine operation or in the technical specifications from the standpoint of the criticality hazards involved.

Nuclear Facility Inspector. A General Atomic nuclear facility inspector has been designated with the responsibility of making routine periodic inspections of all facilities at General Atomic using nuclear materials, for the purpose of making an independent safety evaluation of facility operations and of the procedures being used during operation. Reports of such inspections are forwarded to the Physicist-in-charge of the facility, the General Atomic Criticality Safeguard Committee, the Isotopes Committee, and the Director of the Laboratory.

4.2.1.2. Review Procedure

The APFA program, significant changes in instrumentation, and all experiments must be authorized by the approval-review method in advance of assembly operation. The steps in this review procedure are described below.

A complete written description of the proposed action will be made by the Physicist-in-charge of the APFA and submitted (1) to the Physicist-in-charge of the Linac, (2) to the Criticality Safeguard Committee for approval from the standpoint of safety, (3) to the Office of the Division Counsel for determination that the proposed action is within the terms of the Operating Authorization granted by the Atomic Energy Commission, and (4) to the Assistant Director of the Laboratory. After the proposed action has received these approvals, it must then be approved by the Director of the Laboratory.

If in the opinion of the Physicist-in-charge of the APFA, the Physicist-in-charge of the Linac, the Criticality Safeguard Committee, the Assistant Director of the Laboratory, and the Director of the Laboratory the proposed action does not present an operational hazard that is larger than or significantly different from those that are evaluated in this Hazards Summary, and if any changes are within the limitations of the Technical Specifications, the proposed changes or experiments may then be performed without further approval. If the operational hazard is judged to be larger than or significantly different from those outlined in this Hazards Summary and the pertinent Technical Specifications, General Atomic will submit supplemental information for review and approval by the Atomic Energy Commission. The operator of the APFA may not proceed with the experiment or the change in instrumentation unless he has in his possession the necessary authorization approvals.

A flow sheet for the review procedure is shown in Fig. 6, followed by a sample of the scheduling sheet. The following information will be included on the scheduling sheet.

1. Purpose of the experiment or of the change in the assembly.
2. Description of the experiment. This will involve a description of the core configuration, an estimate of core reactivity, and a description of any instrumentation not mentioned in this document.
3. Time needed for the experiment.

4.2.2. Interlocks

The magnet power supplies, the piston drive power supplies, and the control rod power supply are controlled through a locking key switch on the console. The key to this lock, which also fits the lock on the entry doors to the assembly area, is called the interlock key. Entrance to the assembly room requires that the interlock key be removed from the console. When this key is removed, the assembly will be scrammed, if not already in a scrammed condition.

The entry doors (Nos. 1, 2, 4, 5, and 6 of Fig. 1) are interlocked with the operation of the reactor in such a way that the opening of any of these doors causes a scram. These doors are also interlocked with the operation of the Linac in such a way that if the beam stoppers in the beam tube leading to the C-D area are not closed, the opening of any of these doors will shut down the Linac. With the beam stoppers closed, entry may be gained into the C-D area through the rear door without shutting down the accelerator. Furthermore, a switch in the A-B area is used to disable the opening mechanisms of doors Nos. 5 and 6. This switch also is in the safety chain

Fig. 6--Flow sheet for obtaining approvals and scheduling of APFA experiment

SCHEDULING SHEET
ACCELERATOR PULSED FAST ASSEMBLY

Experiment _____

Equipment will be ready on _____

Approved by
Physicist-in-charge of
APFA _____

Approved by
Physicist-in-charge of
Linear Accelerator Facility _____

Approved by
Criticality Safeguard
Committee _____

Approved by
Assistant Director
of the Laboratory _____

May be done under
Operating Authorization:
Office of the Division Counsel _____

Approved by
Director of the Laboratory _____

Scheduled for _____

First performed on _____ by _____

and must be thrown to operate the reactor. The interlock key will override this switch from a lock outside door No. 6. Door No. 3 is simply pad-locked during reactor operations.

A low level interlock on the log micro-microammeter will drop the magnet table if the neutron level falls below some predetermined value. This value will be set below the level indicated on the log micro-microammeter when the neutron source is in the start-up position and will ensure the presence of a minimum number of neutrons for all operations.

The manual overhead chain hoist is interlocked in such a way that start-up is not possible unless the chain hoist is at the far end of the room (toward the accelerator).

In addition to the door interlock, at the main entrance and at the rear entrance there is a plug panel interlock. Any person entering the area removes a plug. Neither the reactor nor the accelerator can be operated while a plug is removed with the exception that if the beam stopper between the A-B and C-D areas is closed, the Linac may be operated even if the "back entrance" to the C-D area is open and the back entrance plugs are out.

Interlocks will not be overridden except on approval of the Criticality Safeguard Committee.

4. 2. 3. Systems

The APFA assembly machine was designed to ensure that a given set of procedures must be followed in order to assemble the fuel, and that bypassing any of the steps of the procedure would disable or scram the assembly machine.

Once the interlock chain is complete, and this includes having the source in the system, the assembly machine cannot be operated until the scram system has been pressurized. Pressurizing the scram system allows the magnets and the hydraulic and pneumatic systems to be energized and permits release of the solenoid catch on the upper fuel section piston. The fuel assembly drive switches are inoperable unless the control rod is in the "out" position.

The upper fuel section may then be lowered into position. Once the upper section is in the "down" position, a switch is actuated, allowing the lower section to be raised at a fast rate (10 in./min) until it is within 1 in. of the fully up position. At this point, a switch actuates a solenoid valve on the hydraulic system, which diverts the hydraulic fluid through another orifice, reducing the speed of the lower section to its "slow" rate (0.2 in./min).

Once the fuel is fully assembled and the lower section is in the "up" position, the control rod can be moved toward the assembly.

During all operations, the assembly room is continuously monitored visually and aurally by means of a closed circuit TV system and a voice communications circuit between the assembly room and the APFA control room and the Linac control room. During operations requiring the APFA to be repetitively pulsed with the Linac, it will be necessary to override (bypass) the period scrams. When the period scrams are bypassed, the motion of the control rod and fuel assembly drives is limited to the direction of decreasing reactivity. This is the only operation which routinely bypasses any of the scram circuits.

4.2.4. Functions

The functions performed by the various interlocks and controls are as follows:

1. Deactivate magnet only
Low level interlock
2. Scram system and deactivate magnet
Door interlock
Beam stopper interlock
Plug panel interlock
Console interlock key
Console power key
Manual scram interlocks
Chain hoist interlock
Over-power scrams
Fast scram
Period scrams
Scram pressure loss
Earthquake scram
3. Permissive
All of the above
Scram pressure switch
Magnet contact
Upper fuel assembly "down" light
Lower fuel assembly "up" light
Control rod "out" light
4. Preventive
Period scram override switch

V. OPERATION

5.1. GENERAL PROCEDURES

The formal operating procedures for the APFA may be summarized as follows:

1. A log book is to be maintained for all operations concerning the APFA. Each section of the log is to be signed by the person responsible for the assembly at the time.
2. The cause of any assembly scram will be determined and entered into the log.
3. Whenever the assembly is being operated, at least two members of the operations staff must be present in the area of the control console, one of whom must be the Physicist-in-charge or the Deputy Physicist-in-charge.
4. During any operation of the assembly and during any core changes, at least one member of the operating staff will be at the console.
5. At least two level and one period scram channels must be operating properly during any operation except pulsing. During pulsing operations, at least two level scram channels must be functioning properly. The period scram will not be set for less than a 3-sec period.
6. A signal of neutron multiplication will be audible at all times in the vicinity of the assembly and at the control console.
7. Operation of the assembly will be limited to an excess reactivity of less than 0.5% $\Delta k/k$ available to the operator.
8. The assembly will never be taken critical with a gap worth more than 0.35% $\Delta k/k$.
9. The power level will be kept below 500 watts average.
10. The interlock key is used for the locks on the experimental room entry doors and the power supply to the magnet and pistons. For strict control, there will be only two such keys. One of these will be kept in a locked box in the control room and will be available to the Physicist-in-charge or Deputy Physicist-in-charge, and one will be kept in the office of the Director of the Laboratory.

11. Interlocks will not be overridden except on approval of the Criticality Safeguard Committee.
12. The beam stoppers are to be moved only by Linac operators specified by the Physicist-in-charge of the APFA. Each movement of the stoppers is to be logged and signed on a chart located at the beam stoppers. In addition, after each movement of the stoppers, a seal will be attached.
13. At the two entrances to the Linac experimental areas, interlock plug panels are installed, and each person will remove a plug to be carried with him while he is in the experimental rooms. While a plug is out, neither the APFA nor the Linac can be operated. The exception is that if the beam stopper between the A-B and C-D areas is closed, the Linac may be operated even if the "back entrance" is open and the back entrance plugs are out.
14. Only one of the three parts of the uranium sphere may be detached from the assembly machine and not be in storage.
15. Before anyone may use the General Atomic APFA, he must submit an experimental plan describing in detail the experiments he wishes to perform, the components he intends to irradiate, his method of mounting components, and the size and mass of all components and materials he plans to use. This plan must be approved by the Physicist-in-charge of the APFA and the Criticality Safeguard Committee before the experiments can be performed.
16. The Physicist-in-charge of the APFA is in charge of experiments performed thereon.

5.2. FUEL LOADING PROCEDURE

5.2.1. Personnel Protection

All personnel within the loading area will be required to wear shoe covers, and all personnel handling the fuel will be required to wear protective clothing and gloves. There will be a neutron counter in the assembly room with an audible indication of the count rate.

During the fuel loading procedure, there will be an operator at the control console and a senior operator supervising the loading of the fuel. All instrumentation connected with the assembly will be operative.

5.2.2. Fuel Loading and Alignment

All "bird cages" will be transferred to the C-D experimental area and placed in the APFA vault. Each piece of the fuel will remain in its "bird cage" until it is to be loaded on the assembly machine. The pieces will be loaded one at a time in the following order:

1. Central section (lower) with mass of 12,502 grams.
2. Bottom section (lower) with mass of 10,106 grams.
3. Bottom section (upper) with mass of 11,083 grams. (Alignment check—interlock violation procedure is described below.)
4. Central section (upper) with mass of 8371 grams.
5. Top section with mass of 12,496 grams. (Alignment check—interlock violation procedure is described below.)

After the first three pieces are loaded, the alignment of the assembly machine must be checked by mating the bottom section with the central section (lower). This will be accomplished as follows:

1. The regular reactor start-up procedure will be followed in detail up to and including raising the bottom section to closure. The condition of the reactor will be noted.
2. The top section and the central section (upper) will not be in the assembly machine.
3. The "back entrance" interlocks will be jumpered at the jumper panel and tagged.
4. Three people will enter the experimental area, the Physicist-in-charge or Deputy Physicist-in-charge and two other qualified persons.
5. An operator will be at the control console during the entire loading operation.
6. The three people mentioned in step 4 will put on protective clothing at the loading area.
7. The system will be aligned by adjustment of the central section supporting turnbuckles.
8. The bottom section will be lowered and raised to closure under direct observation to confirm alignment.
9. The operator will scram the reactor.
10. A safety spacer will be placed between the bottom and central sections.

11. Another safety spacer will be placed so as to prevent lowering of the top support shaft.
12. The central section (upper) will be loaded with thermocouples in place.
13. The top section will be loaded.
14. The safety spacer will be removed from the top section, but the safety spacer will be left on the bottom section.
15. The assembly room will be evacuated, and regular reactor start-up procedure through lowering of the top section will be followed.
16. The three people mentioned in step 6 will re-enter through the still-jumpered front doors.
17. They will put on protective clothing at the loading area.
18. The alignment of the top section will be checked and adjusted as necessary.
19. The upper section will be raised and lowered under observation to confirm alignment.
20. If further adjustments are necessary at this point, the top section-center section closure will be checked, but with the bottom safety spacer in place, and the bottom section-center section closure will be checked, but with the top section safety spacer in place.
21. After alignment is satisfactory, the safety spacers will be removed, the assembly room evacuated, and the door jumper removed.
22. Regular reactor start-up procedure will be followed to check the reactivity of the bare core.

This will conclude the loading of the major fuel pieces into the core.

The mass adjustment buttons will be loaded for a particular experiment at the discretion of the senior operator in charge. No more than 50¢ in reactivity will be added to the core in any one operation. No more than 0.5% excess reactivity will be made available to the operator. The core will not be loaded so as to reach criticality with a gap allowing more than 0.35% reactivity addition on closure.

5.3. CHECKOUT PROCEDURES

Initial checkout prior to a series of operations will be performed as follows:

1. The upper and lower safety spacers will be inserted and the fuel and assembly will be checked visually for signs of mechanical failure.
2. All electrical connections and microswitches and differential transformer readout will be checked.
3. The control rod (shim rod) drive will be checked.
4. System air pressure will be checked and recorded on a check list.
5. The source drive mechanism will be checked.
6. The fast scram system will be checked with a Co⁶⁰ source.
7. The chain hoist position will be checked.
8. Operation of the intercom and television will be checked.
9. The area will be cleared of all personnel, the safety spacers will be removed, and all doors will be locked.
10. The jumper panel will be checked.
11. The response of neutron sensitive detectors will be checked by moving the source in; in and out readings will be logged.
12. All scram circuits will be checked to ensure that they are functioning properly.
13. With all scrams and instruments reset, the bottom section will be raised 100 mils and one of the scram systems will be actuated (the scram system will be rotated daily).
14. All scrams and instruments will be reset.
15. The source will be put in the in position and the low level scram will be set.
16. All keys will be checked to ensure that they are in place and that the interlock chain is complete.
17. The scram surge tank will be charged. (This supplies the high pressure air to the scram system and energizes the scram circuit).

5. 4. APPROACH TO CRITICALITY

5. 4. 1. Initial Approach to Criticality

The initial approach to criticality will be performed as follows:

1. The top section will be lowered slowly, with the source multiplication, if any, being observed on the count rate meter (visual and audible), until the top piece engages the central section.
2. With the top and central sections in contact, the bottom section will be raised with coarse drive (10 in./min rate), step-wise, with any source multiplication being observed until slow drive takes over--about 1 in. from closure.
3. The bottom section will continue to be raised (speed now reduced to 0.2 in./min), step-wise, with the source multiplication being observed. Each time the source multiplication increases two-fold, travel will be stopped to allow the instruments to stabilize. Then a 1-min count will be taken from the BF_3 neutron monitor and recorded in the log book. The reciprocal count versus separation will be plotted and the critical mass estimated.
4. The reactivity will be increased (separation decreased) in steps one-half that amount necessary to give a critical mass as estimated from the plot.
5. If necessary, the shim control will be inserted, step-wise (1/2-in. steps), to obtain the necessary reactivity to reach criticality.

5. 4. 2. Subsequent Approaches to Criticality

All core changes will be made with the pistons fully retracted, safety instrumentation channels functioning properly, and an audible monitor of neutron level. Approach to criticality after a core change which is estimated to alter the reactivity by more than 20¢ will proceed as an initial approach to criticality. For subsequent approaches to criticality on known cores, the operator will monitor start-up visually from charts and instruments.

During any core change, a member of the operating staff will be at the control console and a senior operator, the Physicist or Deputy Physicist-in-charge, will be present in the assembly room along with at least one other person.

5.4.3. Reactivity Rates on Closing and Separating

The reactivity change per mil of separation as a function of separation is shown in Fig. 6. This curve was obtained by normalizing the data from Ref. 3 (for a rectangular assembly) to the reactivity at closure, which was measured for the APFA spherical assembly during the feasibility studies conducted at General Atomic.

The integrated reactivity as a function of separation was obtained by graphical integration of Fig. 7. This is shown in Fig. 8.

The reactivity rate (in $\$/\text{sec}$ and ϕ/sec) obtained on closing is shown in Fig. 9. These curves were obtained from Fig. 8 and the closing rates of 10.0 in./min at separations greater than 1 in./min and 0.2 in./min for separations less than 1 in.

Calculated scram reactivity versus time is shown in Fig. 10. This assumes that the magnet support drops the table 30 msec after a fast scram signal from the gamma sensor and the hydraulic motion starts 30 msec later. After 102 msec, the table has dropped and the hydraulic motion governs the time dependence of the reactivity.

5.5. EXPERIMENTS

5.5.1. Calibration

After loading to critical, the first part of the experimental program will be devoted to checking certain reactivity calibrations. These include:

1. Gap worth.
2. Button worth.
3. Shim rod worth.

5.5.2. Low Level Experiments

Measurements of the properties of an APFA will begin with low intensity pulsed experiments. Beam intensities will be quite low (~ 1 ma, 30 MeV, 20 ns, 360 pps), because the detector systems utilized will be neutron counters and multichannel analyzers. The experiments to be performed are measurements of the reactor die-away by conventional PNS methods using the Linac as the pulsed source; measurements of the total burst width utilizing the same technique and equipment as for measuring neutron die-away but operating so as to measure the buildup as well as decay of the burst; and measurement of the neutron yield per incident electron by using a long counter and a current integrator to measure the

Fig. 7 -- Reactivity per mil versus gap width

Fig. 8. Reactivity versus gap width

Fig. 9--Reactivity rate on closing

Fig. 10--Scram reactivity versus time

charge collected on the reactor. * These measurements will be made (1) as near to critical as is feasible for the neutron die-away measurement, (2) for the bare reactor (no buttons), (3) for \$1.0 subcritical with the gap, and (4) for the fuel removed from the upper shaft.

The energy spectrum of neutrons leaking from the surface of the core will be measured by time-of-flight techniques. For spectrum measurements, the reactor is placed in front of an evacuated flight path and is adjusted to be several dollars subcritical. The electron beam is injected at 360 pps (pulses of 2×10^{-8} sec, a few ma, 30 MeV) to produce an average reactor power of less than 10 watts.

5.5.3. High Level Experiments

The high level experiments will be conducted with the APFA in the 10-ft-square room opposite the rear entrance to the experimental room. The experiments to be performed are (1) measurement of the high intensity burst shapes with solid state ionization and photomultiplier-type burst sensors and (2) measurement of the rate of expansion due to rapid heating of the metallic core by the neutron burst. Tune-up of the Linac will be done with the reactor in a scrambled position and an aluminum beam stopper between the end of the beam tube and center section of the reactor. After the Linac is tuned to the desired parameters, the Linac will be switched to "gated" (single pulsed operation controlled by a push button in the APFA control room). The aluminum beam stopper will be removed and the reactor started up according to the regular start-up procedure. When all instruments are ready, the Linac will be single pulsed, whereupon all scrams should trip and shut down the reactor. The high intensity experimental instrumentation will consist of several detectors at several locations around the outside of the reactor and a shock probe, the latter being a 1/4-in. quartz rod, the end of which is in contact with the surface of the reactor. † Measurements will be made for the subcritical reactivity conditions described in Section 5.5.2, with the reactor just critical, and with the reactor in supercritical conditions (up to $\sim 40\%$).

5.5.4. Component Irradiation Experiments

An unreflected fast critical assembly is strongly influenced by its environment; therefore, great care must be exercised in placing and securing materials of any sort in close proximity to the fuel. In view of this, any component to be irradiated must be:

1. Mounted rigidly.

* The current is actually measured by a secondary emission monitor located a few inches upstream from the beam exit window.

† The anticipated reactivity increase of a few cents from the neutron reflection by the shock probe will be compensated for by removal of mass adjustment buttons.

2. Mounted at or below the fuel centerline in such a way that it will fall away from the fuel and therefore decrease reactivity.
3. Mounted no closer than the protective screen,
4. Mounted so that it will not interfere with any part of the reactor control or monitoring system.

Since any material placed near the reactor will add to the reactivity of the system, it is necessary to determine the worth of each series of experiments and adjust the mass of the fuel with the mass adjust buttons so that there is less than 0.35% $\Delta k/k$ at closure excluding the shim rod or 0.50% $\Delta k/k$ available to the operator. With the component(s) in place, the reactor will be brought to critical following the procedure described in Section 5.4.1. Subsequent approaches to criticality will be in accordance with the procedure described in Section 5.4.2.

If there is an increase in component size or mass, or if the component is repositioned nearer the fuel, the system excess reactivity must be redetermined and adjusted accordingly.

VI. HAZARDS ANALYSIS

6.1. NORMAL CONDITIONS

The APFA was designed with built-in safety features and instrumentation to provide protection to personnel and to the assembly. Also, a set of operating procedures has been established and approved for conducting experiments in a safe manner. To minimize the possibility of an accident, the assembly will always be operated with less than \$1.00 excess reactivity available to the operator.

The main danger during normal operations is the overexposure of personnel to ionizing radiation. The interlock system associated with the Linac and the APFA prevents anyone from entering the assembly area while either is in operation.

Assembly and assembly room radiation levels will be monitored when personnel enter the room after any operation to ensure that radiation doses received are within accepted levels.

The Physicist-in-charge, working in cooperation with health physics personnel, will be responsible for assuring that all radiation doses received by personnel are within the limits imposed by Title 10, Chapter 1, Code of Federal Regulations, "Standards for Protection Against Radiation" (10 CFR 20).

6.2. ACCIDENT CONSIDERATIONS

The types of accidents considered here are those resulting from events which may cause a change in the reactivity of the assembly, rapid enough or large enough to cause a hazardous condition, that are not under control of the operating personnel or safety circuits and controls. Thus, these accidents must be a result of simultaneous failure of several of the interlocks and controls. The probability of these accidents is kept small by duplications in the protective design.

6.2.1. Flooding

Since the assembly is about 5-1/2 ft above the assembly area floor, the possibility of flooding is extremely slight. Approximately 65,000 gallons of water would be required to fill the room to core level. Also, since the assembly is above ground level, the water would have to come from an

internal supply which is limited in flow rate; the supply is from a 3/4-in. - diameter city line and the room has a 4-in. -diameter sanitary sewer drain. The flooding of the assembly is not considered a credible accident.

The rapid addition of water to the assembly owing to a fractured water line is not considered credible because of the enclosure.

The slow addition of water to the core, e. g., by condensation, would result in a slow addition of reactivity. However, if this caused the reactor to exceed critical, the reactor power would rise, the water would evaporate, and the reactor would return to subcritical.

6. 2. 2. Power Failure

All controls and equipment are designed so that a power failure will cause the assembly to shut down safely. Upon restoration of power, a complete start-up procedure must be followed.

6. 2. 3. Manual Assembly

The manual assembly of the three core sections with a resultant rapid increase in reactivity above critical is not considered credible for the following reasons:

1. Normal operating procedure requires all three core sections to be mechanically attached to the remote assembly machine. The core is in the separated position whenever there are personnel in the assembly room. To assemble the core manually, a person would have to disconnect the core sections from the assembly machine.
2. Manual assembly of any two of the three core sections would not cause an accident because they would constitute only two-thirds of a critical mass. The only fuel at the Linac site in a form suitable for use in the assembly machine will be the three core sections, which constitute a critical mass.
3. By procedure, only one of the three core sections can be in the C-D area while disconnected from the assembly machine or out of its "bird cage."

6. 2. 4. Falling Objects

Rapid increases in reactivity due to objects falling on the assembly are not considered credible for the following reasons:

1. A falling object could add reactivity above prompt critical only if the core were assembled and at or near critical.

2. The assembly is under continual observation during all operations by means of a closed circuit TV system.
3. The only non-fixed overhead equipment in the experimental area is the chain hoist, and the reactor cannot be assembled unless the hoist is in position at the far end of the room.
4. All experiments will be mounted so that they fall away from the fuel.

6.2.5. "Fat-Man" Hazard

The so-called "Fat-Man" accident is an accident resulting from the moderation and resultant excursion of a fast reactor by a person. The critical mass of a sphere immersed in an infinite water reflector is 24.7 kg of oralloy. The largest single piece of core is less than 22 kg. Therefore, a single core piece will not create a "Fat-Man" accident.

Only one piece of the core is allowed (by procedure) to be out of the storage vault or "bird cages" and unattached to the assembly machine. Therefore, the maximum assembled mass of material in the assembly machine, with personnel present, is less than 42 kg (half of which is attached to the machine, the other half handled by a person). The construction of the assembly machine is such that it is very awkward to place the trunk of the body closer than ~18 in. from the assembly; to do so would require climbing over the cross braces.

Calculations (multigroup Sn) indicate that a 40-kg oralloy sphere reflected by 1 cm of water (approximately the mass of a pair of hands) is subcritical by \$3. During the critical experiment program at ORNL on this assembly, the subcriticality of the potential "Fat-Man" conditions were verified before shipment to General Atomic.

All core changes are supervised by either the Physicist-in-charge, the Deputy Physicist-in-charge, or the Physicist-in-charge of the Linac. The purpose of this supervision is to ensure that no procedures are violated, and that a "Fat-Man" condition is not developed which is more reactive than the conditions established as safe by the ORNL experiments.

6.2.6. Moderation

The control system of the metal assembly can prevent its going critical even if completely submerged in a hydrogenous moderator such as water or oil. A 15-cm separation of reactors immersed in water effectively isolates them. The separation of lower and upper fuel pieces of the APFA assembly from the central fuel piece is 20 cm. Each isolated piece is less than 22 kg, and therefore subcritical when fully immersed. When the fuel is stored in the "bird cages," the largest single package is less than 19 kg and the minimum separation is 30 cm. Therefore the "bird cages" are also subcritical when immersed.

The potential hazards from moderation stem from more complex considerations. The "Fat-Man" accident is discussed in Section 6.2.5. Inadvertent addition of reactivity (by moderation or other reflector) prior to start-up, so that criticality is achieved at the maximum assembly rate, is considered in the discussion of the maximum credible accident (Section 6.3).

6.2.7. Release of Radioactive Material

The consequences of fission-product release depend directly on how much contaminant is released to the atmosphere. The C-D area, although not airtight, is relatively well isolated (the A-B area is between the C-D area and the unshielded areas. A 12-ft access tunnel is to the rear with a metal door on one end and a 6-ft shield door on the other end). In addition, the exhaust system is filtered. Significant fission product release requires an accident large enough to breach the containment,

Even though there is no credible mechanism for producing such large bursts, a 1×10^{18} fissions accident and a 3×10^{18} fissions (100 Mw-sec) accident are considered to illustrate fission product release. A 10^{18} fissions accident has a kinetic energy equivalent to about 1.4 lb of high explosive. This would breach the containment by rupturing the diaphragms on the end of the evacuated flight paths, which protrude into the C-D area. Ten percent of the core would be vaporized, and the remainder would be molten. To attain this accident would require a prompt insertion of $\sim \$1.45$, or a ramp of \$200 to \$2000 per second (depending upon statistics). The diaphragms on both ends of the 50-ft flight paths would be breached by the shock wave, and the air in the reactor cell would immediately begin to exhaust out the flight paths into the buildings housing the flight path electronics. These corrugated iron buildings are not airtight and fission products will diffuse out of these buildings. If all of the fission heat were transferred to the air in the cell, it would raise the air temperature by 40°C . This would increase the volume of the air in the cell by about 10%, which would in turn leak into the flight paths. Therefore, the fission products would not be immediately released to the atmosphere. If a 10-min hold-up time is assumed, and that 5% of the fission products are released to a diffusion cloud (half of the volatile fission products), then the dose produced can be calculated. At 150 meters from the point of release, the dose due to inhalation will be 25 rem; the cloud dose will be 0.02 rem from gammas and 0.15 rem from betas. The nearest General Atomic property line is 250 meters from the Linac.

An accident of 100 Mw-sec (3×10^{18} fissions) would vaporize between one-half and three-quarters of the core. The blast effect would be comparable to 9 lb of high explosive. Containment would be breached, and a large fraction of the fission products would be quickly dispersed to the

atmosphere. If 100% release of fission products from a 100 Mw-sec burst is assumed to be contained in a diffusion cloud, the inhalation dose is 10^4 rem at 250 meters and 25 rem at 5000 meters. There is no credible mechanism for producing these large bursts.

6.2.8. Fire

The nature of the construction of the assembly room (concrete structure, underground) is such that chemical fires would be contained. Hazards resulting from fire concern possible personnel exposure. Emergency procedures to be followed in the case of fire are described in "Technical Specifications for the Accelerator Pulsed Fast Assembly" (GA-6093). (2)

1. If the assembly is in operation when a fire within the Linac facility is discovered, the assembly will be scrambled and the accelerator will be turned off. The ventilation fans for the experimental room are turned off by the scram.
2. The Security Office will be notified and all further notifications will be handled by that office.
3. When the firemen arrive, they will not be admitted into the assembly cell except by the Physicist-in-charge of the Linac, by the Physicist-in-charge or Deputy Physicist-in-charge of the APFA, or by the Emergency Director of the Laboratory. The firemen must consult one of these to ensure that methods taken to combat the fire do not lead to additional hazards. Liaison has been established with the fire department to ensure that its personnel are familiar with the geography of the area and the procedures to be followed.
4. Before arrival of the firemen, the staff under the supervision of the Physicist-in-charge of the Linac, Physicist-in-charge or Deputy Physicist-in-charge of the APFA, or the Emergency Director of the Laboratory may attempt to keep the fire from reaching the assembly core.

6.2.9. Earthquake Considerations on Building Construction

The building in which the APFA experiments will be performed has been constructed to meet the requirements of the Uniform Building Code⁽⁴⁾ for Zone 3. The geologic region of a large part of Southern California, including San Diego County, is classified Zone 3 in TID-7024.⁽⁵⁾

The building construction is approved under the City of San Diego Code and by the Nuclear Energy Property Insurance Association (NEPIA).

The assembly is protected by an earthquake scram set at V on the modified Mercalli scale.

Earthquake hazards are discussed more fully in Appendix B.

6. 2. 10. Tuning Accident

In the event that the Linac is not turned off after a single pulse, or is adjusted to higher powers than anticipated for the high-repetition-rate experiments, it is possible to produce more fission power than planned. For the reactor in the scrambled condition (as it is while the Linac is being tuned), the consequence of allowing the maximum beam intensity at the maximum Linac repetition rate to impinge on the reactor for an indefinite period is the gradual burning of a hole in the uranium. A few tens of seconds elapse before the melting starts. This accident would be completely contained in the C-D area.

If the reactor is critical, the first pulse scrams the reactor, and the rest of the accident history is as above.

However, this accident is not very probable, since tuning the Linac for maximum output at maximum repetition rate takes approximately 45 min (depending upon the skill of the operator) and is not the operating condition used for any of the APFA experiments.

6. 3. MAXIMUM CREDIBLE ACCIDENT

The maximum credible accident is assumed to occur if the reactor is assembled at the maximum closure rate (10 in. /min) after a reflector has added reactivity so that the reactivity can exceed prompt critical, and if the improbable time has been chosen for the assembly operation so that the start of the power rise is delayed by the weak source statistical effect.

The sequence of events leading to this accident is difficult to visualize because of the several preventative procedures and interlocks which would have to be violated. However, the size of the accident can be calculated from the given assumptions.

The rate of addition of reactivity at closure can be estimated from data given in Section 5. 4. 3. The reactivity effect of a small gap in this fast assembly was measured to be 2. 44¢/mil. For a closure rate of 10 in. /min, this is \$4. 1/sec. Assume that this ramp can continue through prompt critical. The work of G. Hansen⁽⁶⁾ has shown that in rare instances, a ramp of this type can continue for a surprisingly long time before the

neutron chain reaction begins. His work shows that in 99 accidents out of 100, less than 10¢ over prompt critical will be added by the postulated ramp before a chain reaction starts (our start-up source strength is $\sim 10^6$ neutrons/sec). The resulting power excursion is equivalent to a 10¢ prompt reactivity step. This results in a prompt burst of 1.5×10^{16} fissions. (7) The consequences of this excursion are an average temperature rise of 70°C , which does not damage the core, a burst of fast neutrons, and an inventory of delayed neutron precursors which are a source of approximately 10^{10} neutrons/sec, which makes statistical effects unimportant for the remainder of the accident history. The heating can continue until the uranium metal phase transition to β (665°C), and then γ (770°C) phase volume expansion provides the ultimate shutdown after approximately 2×10^{17} fissions. The total shutdown available from temperature rise and phase expansion is \$5.00. There will be no blast effects because, after the burst, the temperature will follow the reactivity addition and prevent rapid power surges.

The heating of the air in the room from the ~ 7 Mw-sec excursion would cause a negligible pressure increase, and therefore no physical damage or fission product release.

The point of maximum radiation exposure to personnel for this accident would be directly atop the experimental building. The distance from the reactor is ~ 17 ft and there is a minimum of shielding (1 ft of concrete and 9 ft of earth). Based upon gamma dose measurements made on Godiva I, the total gamma dose would be less than 0.2 mrem. In addition, the fast neutron dose would be less than 2.0 mrem, giving a total dose of less than 2.2 mrem.

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Appendix A

SITE DESCRIPTION AND EVALUATION

GENERAL LOCATION

The General Atomic APFA will be located on Torrey Pines Mesa in the City and County of San Diego, California, where General Dynamics owns a tract of approximately 290 acres of ground. This tract is the site of the John Jay Hopkins Laboratory for Pure and Applied Science of the General Atomic Division.

The center of the tract lies 1-1/2 miles from the Pacific Ocean shore lines. Its southern boundary is about 2600 ft north of Miramar Road in San Diego. Its western boundary is adjacent to U. S. Highway 101, but by agreement with the City of San Diego the buildings are set back at least 400 ft from the highway. The Laboratory extends eastward 500 ft to Soledad Valley (commonly known as Sorrento Valley), where the Santa Fe Railroad line through the valley forms the eastern boundary.

Roughly 130 acres of the ground is level, the remainder being in side slopes and ravines as deep as 250 ft below the mesa tops. The level mesa tops are 300 to 350 ft above sea level.

The building housing the APFA and the General Atomic linear accelerator is located 1800 ft from the nearest point on U. S. Highway 101, 700 ft from the nearest point on the public road which connects U. S. 101 to Sorrento Valley Road, about 450 ft from Science Building B (see Fig. A.1) and about 1200 ft from a small sewage plant just north of the Laboratory site. This plant is used for the treatment of sewage from the General Atomic site and from a nearby municipal golf course.

The General Atomic Linac facility is adjacent to the HTGR Critical Facility. Concrete and earth shielding are provided between these buildings. About 150 ft to the northeast is the EBOR Critical Facility and 440 ft to the northeast is the building housing TRIGA, the General Atomic isotope-production reactor, and the TRIGA Mark F, the General Atomic pulsed reactor and associated laboratories and office space. All other buildings on the site are at least 450 ft from the Linac facility.

The accelerator building is surrounded on two sides by earth embankments of a height greater than that of the building. The third side, which faces away from the General Atomic site and toward a steep canyon, is

Fig. A. 1-- Aerial view of General Atomic

shielded with a 1-ft-thick conventional concrete wall and a minimum of 15 ft of earth. On the fourth side, between the accelerator room and the control room and offices, there is also a 1-ft-thick conventional concrete shield wall and a minimum of 25 ft of earth.

A detailed discussion of the geology and hydrology and seismology of the site may be found in Appendix B.

A. 2. POPULATION DENSITY

The population distribution for 1960 for the San Diego area is shown in Fig. A. 2. The critical facility is 1,900 feet from Highway 101, and 7,000 feet from the nearest place of business (a service station and restaurant).

At present, the population around Torrey Pines Mesa is concentrated to the south and southwest of the site (Table A. 1). The General Atomic on-site population is given in Table A. 2.

Table A. 1
POPULATION OF COMMUNITIES NEIGHBORING
GENERAL ATOMIC SITE

	<u>La Jolla</u>	<u>San Diego</u>
1950.	5,451*	334,387*
1952.	6,289*	---
1957.	14,889*	---
1964.	<u>20,210*</u>	<u>638,675*</u>
1970 (Estimated)	34,000**	760,000*

*Obtained from the Planning Department of the City of San Diego.

**Obtained from the San Diego Gas and Electric Company.

The new Scripps General Hospital is almost one mile south of the site. It has 250 beds and a staff of approximately 500. The present San Diego campus of the University of California lies 1-1/2 miles southwest of the site. The expected student population is 1,500 for the near future. About six miles to the East lies the Miramar Naval Air Station of approximately 5,000 personnel. Also to the east, at approximately six miles is located the Miramar Water Treatment Plant. It has a rated capacity of 48 million gallons per day. The dam capacity is 1,594 acre-feet.

To the northeast is the General Atomic Sorrento Valley Fuel Fabrication Facility and a small industrial park which includes Sharp Laboratories, Sorrento Square and a warehouse. (See Table A. 3) Beyond

Fig. A. 2 -- Population map

this lie sparsely populated farm and grazing areas for a distance of 25 miles. To the north for about 25 miles along the coast is a series of small towns. The populations and distances of these towns are given in Table A. 4.

Table A. 2

GENERAL ATOMIC ON-SITE POPULATION

<u>Facility</u>	<u>Distance from Linac</u>	<u>No. of Employees</u>
NUROC Critical Facility	150	9
TRIGA	440	15
Hot Cell	600	17
Laboratory	600 - 1100	398
Library-Document Center	850	38
Administration Building	900	230
Technical Office Building	1250	404
Experimental Building	1050 - 1250	112
Maintenance Building	1350	49
Fusion Building	1500	12
Tower Facility	1600	6
Waste Yard	1600	3
Service Building	1800	79
Sorrento Valley Complex	3000 - 3400	285

Table A. 3
NEARBY FACILITIES

	<u>Facility</u>	<u>Distance</u>	<u>Direction</u>
1.	Salk Institute	3, 000 ft.	West
2.	University of California	8, 000 ft.	Southwest
3.	Scripps Hospital	6, 000 ft.	Southeast
4.	Control Data Systems	7, 000 ft.	Southeast
5.	Union Brick Company	7, 000 ft.	East
6.	Sharp Laboratories and Oceanographic Engineering	6, 000 ft.	Northeast
7.	Sorrento Square (a group of six small business offices)	7, 000 ft.	Northeast
8.	Warehouse (to house a box manufacturing concern)	7, 000 ft.	Northeast

Table A. 4
POPULATION AND DISTANCES OF COASTAL TOWNS
(1960)

<u>Community</u>	<u>Population</u>	<u>Distance (Air Miles)</u>
Del Mar	3, 124	5
Solana Beach	4, 513	7.5
Cardiff	3, 960	9.8
Encinitas	6, 345	11.5
Rancho Santa Fe	<u>1, 960</u>	9.8
Total Population	19, 902	

Twenty-five miles north on the coast is the City of Oceanside (which had a population of 24, 971 in 1960) and 25 miles northeast lies Escondido (which had a population of 16, 373 in 1960).

A population distribution as a function of radius from the critical assembly facility has been constructed. Table A. 5 shows the daytime population within specified radii up to five miles from the critical facility. The previously mentioned industries in the vicinity of General Atomic have been included in the totals.

Table A. 5

ESTIMATED DAYTIME POPULATION WITHIN FIVE MILES
OF LINAC CRITICAL FACILITY

<u>Miles From Facility</u>	<u>Population Within Circular Annulus</u>	<u>Cumulative Population</u>
1/4	1, 276	1, 276
1/2	149	1, 425
3/4	285	1, 710
1	200*	1, 910
2	4, 266*	6, 176
3	4, 228*	10, 404
4	7, 743*	18, 147
5	36, 614*	54, 761

*Estimated by Planning Department, City of San Diego,
February 1965.

A. 3. METEOROLOGY

The meteorology of an area plays a large part in evaluating airborne hazards from an accident. The lapse rate (change of temperature with altitude) of the atmosphere and occurrence of temperature inversions are significant in determining the size and height of an airborne cloud. Wind velocity and direction are important in determining the areas affected by an accident and the degree to which they are affected. Precipitation of various kinds also affect the concentration of radioactivity which may be expected near the scene of an accident. These effects will be considered in the evaluation of the consequences of the maximum accident.

Wind Velocities and Directions. Winds over San Diego County are generally from westerly directions, more so in the summer months than in the winter, when easterly winds are almost as probable. Average wind velocities range from 6.5 to 9 mph westerly, and from 1 to 7.2 mph easterly. Light, variable winds are typical of the area, with on-shore (westerly) winds generally prevailing late in the day, and with weaker

off-shore (easterly) winds normally occurring in the early morning hours. Strong winds are very infrequent; the strongest wind recorded in San Diego was 53 mph (from the southeast) in February, 1938. A typical wind rose, based on observations at the San Diego Weather Station, is shown in Fig. A. 3. Table A.6 lists average and maximum velocities.

Table 2.6
AVERAGE AND MAXIMUM WIND VELOCITIES
FOR 20-YEAR PERIOD

Period	Mean Hourly Speed (mph)	Prevailing Direction	Maximum Speed (mph)	Strongest Wind Direction	Year
January	5.5	NE	39	SW	1955
February	6.1	NE	35	SW	1958
March	6.8	WNW	46	SW	1945
April	7.3	WNW	37	S	1958
May	7.5	WSW	27	SW	1947
June	7.2	SSW	26	S	1948
July	6.7	WNW	18	SW	1959
August	6.6	WNW	23	SW	1945
September	6.2	NW	25	W	1955
October	5.9	WNW	31	W	1961
November	5.3	NE	51	SE	1944
December	5.2	NE	34	S	1951
YEAR	6.4	WNW	51	SE	Nov., 1944

Temperature. The City of San Diego enjoys very mild temperatures. The difference between the average highest and lowest daily temperatures is only 10°F in summer and 16°F in winter. Table A.7 shows temperature values for the year 1963.

Fig. A.3--Typical wind rose for San Diego

Table A. 7
TEMPERATURE (°F)

Month	Daily Mean		Extremes	
	Maximum	Minimum	High	Low
January	63.8	46.3	88	25
February	69.8	52.6	89	34
March	65.9	49.0	99	36
April	66.5	50.9	96	39
May	69.4	50.8	98	45
June	70.5	58.9	97	50
July	74.3	62.1	100	54
August	78.7	65.4	98	54
September	82.3	66.2	111	50
October	75.6	60.7	107	44
November	70.3	52.0	96	36
December	70.9	46.1	88	32

Temperature-inversion Phenomena. A most significant feature of the meteorology of the San Diego area is the frequent occurrence of temperature inversions which produce a region of low diffusibility starting at a height called the inversion base (the lower altitude limit of the inversion) and extending upward. The occurrence of inversions is important, since the inversion base is an upper boundary beyond which cloud rise is retarded.

Records of inversion layer base heights for San Diego have been maintained for the past eight years by the local Air Pollution Control District. These records are summarized in Table A. 8, which shows the number of days per year that a temperature inversion exists and the height of the inversion base.

Table A. 8

NUMBER OF DAYS IN WHICH INVERSION BASE
IS AT LEVEL INDICATED

<u>At 0330 (Morning)</u>	<u>Surface</u>	<u>Below 1500'</u>	<u>Below 2500'</u>
1956	128	184	245
1957	157	198	256
1958	184	218	291
1959	149	186	244
1960	185	224	296
1961	151	214	276
1962	137	210	283
1963	163	212	269
1964	170	218	286

<u>At 1530 (Afternoon)</u>	<u>Surface</u>	<u>Below 1500'</u>	<u>Below 2500'</u>
1956	91	192	239
1957	40	152	224
1958	8	127	223
1959	6	117	217
1960	2	149	251
1961	2	136	232
1962	2	161	241
1963	2	124	218
1964	1	127	227

Ref.: San Diego County, Bureau of Industrial Hygiene,
Air Pollution Control District

Appendix B

REPORT ON EARTHQUAKE HAZARD AT
THE TORREY PINES MESA SITE*

B. 1. SUMMARY OF CONCLUSIONS

1. The region is one of moderate earthquakes. Construction should be such as to resist an earthquake of intensity VIII on the modified Mercalli Scale.† This corresponds to an acceleration of about a quarter of gravity and to accompanying periods of 0.1 to 0.3 sec repeated several times.

2. As to epicenters of small shocks in the period 1934 to 1958, the maps show three such within 5 miles of the site, probably on the Rose Canyon fault.

3. No faults pass through the site. The geologic foundation is satisfactory.

B. 2. EARTHQUAKE HISTORY

Southern San Diego County has been reasonably free from severe earthquakes. The zone of earthquake centers (the San Andreas Fault System) which follows the coast to the north lies in the Imperial Valley in the latitude of San Diego County. It is the fringe effects of large shocks centering to the south in Lower California, to the east in Imperial Valley, and to the north, perhaps near San Juan Capistrano, that would appear to be the hazard. Table B.1 gives the historical record of the larger shocks reported from the San Diego region. The letters after the magnitude of recent earthquakes indicate how accurate the locations of the epicenters are considered to be: a, excellent; b, good; and c, fair. The information comes from references listed at the end of this appendix. Figure B.1 gives the epicenters of these shocks, where they are known.

* Written by Drs. Perry Byerly and William Quaide, University of California, Berkeley.

† See K. E. Bullen, Introduction to the Theory of Seismology, Cambridge University Press, 1947, or other texts on seismology for a description of the scale.

Table B.1

SHOCKS WHICH HAVE GIVEN RISE TO INTENSITY OF V OR MORE AT SAN DIEGO

No.	Mag.	Date	Epicenter	Intensity and Location	Remarks
1		Nov. 22, 1800		VIII (?), San Diego	Damaged walls of adobe barracks in San Diego and cracked walls of new church in San Juan Capistrano
2		Dec. (?), 1856(?)		VII, So. Calif.	"Very severe" at San Diego (verbal account)
3		May 27, 1862		VI, So. Calif.	Severe shock at San Diego
4		Oct. 21, 1862		VI, San Diego	Violent shock, seventh since May 28
5		Jan. 25, 1863		VI, San Diego	Severe shock
6		Apr. 15, 1865		VI, San Diego	Severe shock
7		Oct. 12, 1873		V, San Diego	
8		Jan. 13, 1877		VI	About 45 miles SE of San Diego. "Heavy earthquake"
9		Dec. 21, 1880		V, San Diego and Campo	
10		Oct. 8, 1882		V, San Diego	Heavy shock; felt at Los Angeles
11		Feb. 23, 1892		VII, San Diego	Plaster cracked, general fright, Court House walls cracked
12		Feb. 24, 1892		VI, San Diego	Many were frightened and ran outdoors
13		Oct. 23, 1894		VII-VIII, San Diego	Walls cracked, people ran outdoors, rocks shaken from hillsides, booming noises heard
14		July 22, 1899	Cajon Pass	IV-V, San Diego	Felt all over Southern California
15	7.1	Nov. 20, 1915	32°N, 115°W, near Volcano Lake in Baja Calif.	VI, San Diego	A rocking motion, lasted 50 sec
16		Sept. 29, 1916		V, San Diego County	Located in mountains about 40 miles NE of San Diego

Table B.1 (continued)

No.	Mag.	Date	Epicenter	Intensity and Location	Remarks
17	6.8	Apr. 21, 1918	33-3/4°N, 117°W at San Jacinto	V to VI, San Diego	Most severe shock in California between Apr. 18, 1906, and Jan. 31, 1922
18	6.5	Dec. 30, 1934	32.2°N, 115.5°W, Baja Calif.	V, San Diego IV, La Jolla	Strongly felt throughout the Imperial Valley region. Stopped clocks in San Diego
19	7.0	Dec. 31, 1934	31.8°N, 115.1°W, Colo. R. Delta	VI, San Diego III, La Jolla	Plaster fell, windows broke, cracks in City Hall widened in San Diego
20	6.0	Mar. 25, 1937	33° 28'N, 116° 35'W, Terwilliger Valley	V, San Diego III, La Jolla	Clocks stopped, small objects moved at San Diego
21	5.5b	May 31, 1938	33° 41'N, 117° 32'W, Santa Ana Mts.	V, San Diego IV, La Jolla	Large number awakened, slow motion
22	5.5b	May 17, 1940	34° 03'N, 116° 17'W, Little San Bernardino Mts.	V, San Diego	Trees and bushes shaken, hanging objects swayed. About 50 aftershocks during next 8 hr
23	6.7	May 18, 1940	32° 44'N, 115° 17'W	V, San Diego IV, La Jolla	The Imperial Valley earthquake. Hanging objects, trees and bushes disturbed, some clocks stopped at San Diego
24	5.0b	June 4, 1940	33° 07'N, 116° 25'W, near Verruga	V, San Diego	Hanging objects swung
25	3.0c	Sept. 13, 1941	32° 53'N, 117° 24'W, near La Jolla	V, Point Loma	Hanging objects swung, subterranean sounds heard. Intensity not given at San Diego or La Jolla
26	6.5b	Oct. 21, 1942	32° 58'N, 116° W, Borrego Valley	VI, San Diego IV, La Jolla	Generally felt, plaster and windows cracked, and canned goods fell in San Diego
27	5.7b	Aug. 15, 1945	33° 13'N, 116° 08'W,	V, San Diego	San Jacinto Fault zone, near Borrego Valley
28	3.3b	Jan. 1, 1946	32° 43'N, 117° 25'W, (offshore)	V, San Diego	Pictures and mirrors fell from walls, buildings swayed, residents ran outdoors
29	6.8a	Apr. 10, 1947	34° 58'N, 116° 32'W, Manix Fault	V, San Diego III, La Jolla	Felt over 75,000 square miles

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Table B.1 (continued)

No.	Mag.	Date	Epicenter	Intensity and Location	Remarks
30	5.5a	July 24, 1947	34°01'N, 116°30'W, Morongo Valley	V, San Diego	Dishes rattled and chandeliers swayed throughout San Diego
31	6.7b	Dec. 4, 1948	33°53'N, 116°20'W, near Desert Hot Springs in Little San Bernardino Mts.	VI, San Diego IV, La Jolla	Concrete cornice broke loose, water main burst, pendulum clocks stopped, hanging objects swung, canned goods fell in San Diego
32	5.7c	Nov. 4, 1949	32°12'N, 116°33'W, Baja Calif.	VI, San Diego	Plaster walls cracked, people ran outside, tall structures swayed in San Diego
33	5.1	Nov. 4, 1949	32°12'N, 116°33'W (aftershock)	VI, La Jolla VI, San Diego	Inner wall cracked at La Jolla; rumbling, walls cracked at San Diego
34	5.9b	Dec. 25, 1951	32°49'N, 118°21'W, SE point of San Clemente Island	VI, San Diego	Buildings rocked, chandeliers swung, Christmas trees fell over, plaster cracked
35	3.3c	June 5, 1952	33°17'N, 116°42'W, near Warner Springs	V, San Diego III, La Jolla	Many awakened, few frightened at San Diego
36	7.7a	July 21, 1952	35°N, 119°02'W, 26 miles south of Bakersfield	V, San Diego V, La Jolla	Main shock of the Kern County series and largest in the U.S. since 1906. Felt over 160,000 square miles
37	6.2b	Mar. 19, 1954	33°17'N, 116°11'W, Santa Rosa Mts.	V, San Diego

Fig. B.1--Epicenters of shocks which have produced intensities of V or more at San Diego

Since the written record began, only two shocks have been rated as intensity VIII. Nevertheless, we feel that it would be well for those constructing sensitive installations to anticipate intensity VIII. Intensity VIII, according to Hershberger (see references at the end of this appendix), is to be associated with an acceleration of 0.25 of gravity. It would accompany waves of period 0.1 to 0.3 sec and be repeated several times.

The San Diego region is the least seismic region in coastal California.

B. 3. THE DISTRIBUTION OF EPICENTERS

Figure B. 2 gives the epicenters of earthquakes in the vicinity of La Jolla. These epicenters were located by the Pasadena Seismological Laboratory. The period covered is 1934 through 1958; earlier, there were no seismographic stations. The epicenters are plotted according to magnitude. The magnitude is determined from the amplitudes and periods of waves recorded on seismographs. An earthquake has only one magnitude. It has different intensities in different localities depending on distance from the source, the size of the shock, and the nature of the geologic foundation. The magnitude is related to the energy released. A formula connecting them is

$$\log E = 11 + 1.6 M ,$$

where E is measured in ergs.

Table B. 2 lists the epicenters shown in Fig. B. 2. Note the earthquake of January 1, 1946, magnitude 3.3. In Table B. 1 we note intensity V in San Diego. The shock centered at sea.

B. 4. GEOLOGY AND FAULTING

The General Atomic property, shown generally in Fig. B. 3 and specifically in Fig. B. 4, lies on Torrey Pines Mesa in San Diego in the northwest part of the city, approximately 1 mile north of the intersection of U. S. Highway 101 and Miramar Road and immediately east of U. S. Highway 101. Location of the site within the property limits is shown in Fig. B. 4.

B. 4. 1. Faults

The relation of the Torrey Pines site to faults is shown in Fig. B. 3 (adapted from the State of California Division of Mines Bulletin 170, 1954).

Fig. B.2--Epicenters of earthquakes in the vicinity of La Jolla

Table B. 2
EPICENTERS NEAR LA JOLLA

Mag.	Date	Epicenter		Pacific Standard Time
		Latitude North	Longitude West	
2.5c	Aug. 12, 1934	32°53'	117°30'	1657
2.5c	June 4, 1936	32°50'	116°50'	2138
3.5c	Sep. 10, 1936	32°50'	117°30'	0245
3.0c	Sep. 10, 1936	32°50'	117°30'	0247
2.5c	Sep. 10, 1936	32°50'	117°30'	0618
2.5c	June 5, 1937	32°58'	116°53'	1714
3.5b	Aug. 10, 1937	33°01'	116°51'	1439
3.5b	Aug. 10, 1937	33°01'	116°51'	1440
3.0c	Aug. 14, 1937	33°01'	116°51'	1510
3.0b	Oct. 10, 1937	33°55'	116°55'	2055
3.0c	Oct. 25, 1937	33°00'	116°50'	0228
2.5c	Sep. 27, 1938	32°42'	117°24'	0918
3.0c	Jan. 12, 1939	33°00'	116°55'	0800
3.0c	Sep. 14, 1941	32°53'	117°24'	0550:53
4.0c	Feb. 23, 1943	32°51'	117°29'	0121:12
3.3b	Jan. 1, 1946	33°43'	117°25'	1556:32
2.5c	July 9, 1948	32°48'	117°12'	1530:40
2.9c	Feb. 11, 1949	32°53'	116°56'	1634:11
3.0b	June 20, 1949	32°55'	117°18'	1035:29
2.9c	June 20, 1949	32°48'	117°20'	1139:34
2.8c	June 20, 1949	32°33'	117°16'	1953:40
3.1b	June 24, 1949	32°52'	117°20'	1813:18
2.5b	Aug. 3, 1949	32°43'	117°21'	1724:29
2.3b	Aug. 12, 1949	32°51'	117°00'	1657:31
2.4b	Sep. 29, 1949	32°52'	117°15'	1808:01
2.4b	Sep. 29, 1949	32°52'	117°15'	1808:24
2.3c	Oct. 4, 1949	32°59'	117°16'	1852:08
2.9b	May 13, 1950	32°50'	117°28'	0411:35
3.2c	Apr. 20, 1952	32°38'	117°17'	1801:43
3.2c	Apr. 20, 1952	32°38'	117°17'	2112:28
3.0c	June 11, 1952	32°45'	117°20'	0801:57
3.4c	June 12, 1952	32°34'	117°16'	1245:42
2.6c	June 12, 1952	32°34'	117°16'	1254:38
3.0d	Jan. 1, 1953	32°36'	117°06'	1736:54
3.5c	June 14, 1953	33°03'	117°18'	1728:29
3.5c	Dec. 21, 1954	32°38'	117°07'	0711:12
3.7b	Jan. 14, 1958	32°34'	117°09'	1405:40
3.4b	Nov. 23, 1958	32°44'	117°23'	2104:02

Fig. B.3--Fault map of San Diego County with generalized geology of the southwestern part

Fig. B. 4--Geology of the General Atomic property

No mappable faults exist within the property limits. The fault nearest the property is the Rose Canyon fault, which is 5 miles distant at its closest approach. This fault trends northwesterly from Mission Bay on the south through a curving course up Rose Canyon, east of Mount Soledad, and thence seaward between La Jolla and the Scripps Institution of Oceanography. Geological evidence indicates that there has been no surface displacement on the fault since early Pleistocene times, before deposition of the terrace deposits which cover much of Torrey Pines Mesa. Epicenters have been located along the fault trace, however, and the fault cannot therefore be ruled inactive.

The next nearest faults, on land, are a series of northwesterly trending systems in the mountainous, northeast portion of the county and in Imperial County (see Fig. B. 3). Many of these faults are active and are the source of earthquakes felt in San Diego. The nearest fault of this system, the Elsinore fault, lies 40 miles from the site.

There are a number of epicenters offshore on the Continental Shelf. Faults cannot be mapped there, but bottom topography indicates their presence.

Many earthquakes originating to the southeast have their epicenters in northeastern Baja California, a particularly active area. This region is considerably more distant from the site than the other two areas just discussed.

A few epicenters of recent earthquakes have been located in areas of the county where faults have not been mapped. The epicenters probably lie along faults which have not been recognized.

B. 4. 2. Geology of the Site

The rocks which crop out along the coast of southern San Diego County are part of a prism of sedimentary rocks of Cretaceous and Tertiary age which thin eastward and are seldom found more than 10 miles inland. They lie upon crystalline rocks which make up the Peninsular Range in central and eastern San Diego County. In the Torrey Pines Mesa site, the sedimentary rocks are not more than 1,000 ft thick. They consist of extremely well cemented sandstones and shales of Cretaceous age below (not exposed in the site area) and firmly indurated siltstones, shales, and sandstones of Eocene age above.

1. Eocene Rocks. The oldest rocks exposed in the Torrey Pines Mesa area are Eocene in age. These are flat-lying beds which everywhere underlie the area and crop out over most of it (see Fig. B. 4). These rocks, called the La Jolla formation by Hanna, are made up of siltstone,

shale, and sandstone in order of abundance. They are firmly indurated and hard beneath the thin zone of weathering. The mesa area where the formation is exposed is well dissected by deep canyons, effectively removing surface waters. Outcrops of the flat-lying sandstone beds on canyon walls ensure good subsurface drainage. Water saturation of the rocks is always low. It should be noted that test bores beneath structure sites in the area failed to find ground water.

Geologic sections show the character of the rocks beneath the reactor site for a thickness of 200 ft. These rocks consist of the siltstone, shale, and sandstone described above. The lithology shown is idealized to indicate the general nature of the sequence. The type of sedimentation which gave rise to these deposits precludes the possibility of projecting the position of the plotted horizons beneath the General Atomic site with any degree of precision.

2. Pleistocene Rocks. Pleistocene terrace deposits overlie the Eocene rocks in parts of the area and consist of two general rock types, sandy beach deposits and terrace-capping sandy conglomerates. The sandy beach deposits occur in a beach ridge which trends northwesterly along Torrey Pines Mesa, with U. S. 101 running along the axis of the feature (see Fig. B. 4). The ridge is made of well-rounded and well-sorted beach sands which reach a maximum thickness of 100 ft along the axial trend. The deposit thins rapidly to a feather edge both to the east and to the west. The General Atomic Division Office Building, Library, and Science Buildings are situated on the eastern margin of this deposit where the sands are only a few feet thick. The sands of the beach ridge are variably cemented, but most are soft and porous. Saturation of the deposits in wet years would further increase the earthquake hazard to structures constructed on this type of rock unless the foundations were set in the harder, underlying Eocene rocks.

Farther to the east, Pleistocene deposits consist of thin layers of sandy conglomerate with a maximum thickness of 25 ft in the local area. These deposits are well cemented and hard and would make good foundation rocks for structures located on them.

B. 4. 3. Geologic Conclusions

1. No faults were found in the General Atomic Division property.
2. The nearest fault, the Rose Canyon Fault, lies 5 miles from the site. There is no geologic evidence for recent movements of the fault, but location of epicenters on its trace indicates that the fault is still active.
3. Other active faults lie at considerable distances from the site. The closest, on land, lies 40 miles to the northeast in the northeastern

part of San Diego County, a seismically active area. Active faults in Baja California are still farther from the site. Areas offshore are seismically active, and although faults cannot be mapped, submarine topography indicates their presence.

4. The ground beneath the reactor site is made up of flat-lying beds of firmly indurated siltstone, shale, and sandstone of Eocene age. These beds are well drained of surface and subsurface waters and make a good foundation rock.

5. Pleistocene beach ridge deposits to the west would make relatively poor foundation rock for any future structures, whereas Pleistocene terrace gravels to the east would make good foundations.

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Appendix C

TECHNICAL QUALIFICATIONS OF RESPONSIBLE PERSONNEL

Dr. John L. Russell, Jr., Physicist-in-charge of APFA Assembly

B. S. (Electrical Engineering), University of Texas, 1951

M. A. (Physics), Rice Institute, 1954

Ph. D. (Physics), Rice Institute, 1956

From 1956 to 1957 Dr. Russell was a member of the General Electric Atomic Power Equipment Department, where he worked on reactor core physics problems. In 1957 he joined the theoretical physics group at Vallecitos and in 1960 became manager of all experimental reactor physics at Vallecitos. In this capacity Dr. Russell supervised the experimental portions of the AEC Control Rod Materials Program, the Pulsed Neutron Source Development Project, and the critical experiments for Dresden and the Mixed Spectrum Superheat Reactor Concept. At General Atomic Dr. Russell is the principal investigator for the development of an accelerator pulsed fast assembly for the Defense Atomic Support Agency. In this capacity he is investigating means of increasing neutron yields from electron targets and output from electron linear accelerators.

Mr. K. L. Crosbie

Bachelor of Chemical Engineering, Pratt Institute, 1959

Master of Nuclear Engineering, University of Virginia, 1961

Mr. Crosbie attended the University of Virginia under an AEC fellowship program and conducted research and development work on a nuclear powered plasma thermocouple. From 1961 to 1963 he was with the Sandia Corporation as a reactor supervisor at the pulsed reactor facility. His primary responsibilities included the supervision of pulsed reactor operations where the primary concern was the safety of the reactor and personnel conducting experiments. While at Sandia, his main research was on the penetration and activation of shielding materials by neutrons from the reactor pulse.

Since joining General Atomic in 1963, Mr. Crosbie has been with the linear accelerator group, where he has been engaged in fast neutron physics and fast neutron detection systems employing time-of-flight techniques.

Dr. J. R. Beyster, Physicist-in-charge of Linear Accelerator

B. S. (Physics), University of Michigan, 1945

M. S. (Physics), University of Michigan, 1947

Ph. D. (Physics), University of Michigan, 1950

Dr. Beyster was a member of the physics division at the Los Alamos Scientific Laboratory for six years before joining General Atomic. While at Los Alamos he worked on elastic and nonelastic neutron cross-section measurements using the water-boiler reactor and the large Van de Graaff accelerator and conducted analysis of these data using the diffuse-edge optical model. During 1950 and 1951, he worked on critical experiments in connection with the submarine reactor program at the Westinghouse Atomic Power Division.

Dr. Beyster's work at General Atomic includes supervising the operation of the linear accelerator facility and participating in neutron thermalization studies being conducted with this machine under AEC Contract AT(04-3)-167.