LA-4273



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# Safety Analysis for the Los Alamos Critical-Assembly Facility



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W. U. Geer, P. G. Koontz, J. D. Orndoff, and H. C. Paxton

## ABSTRACT

**The safety of Pajarito Site critical assembly operations depends upon protection built into the facility, upon knowledgeable personnel, and upon good practice as defined by operating procedures and experimental plans. Distance, supplemented by shielding in some cases, would protect personnel against an extreme accident generating $10^{19}$ fissions.**

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## Background

The Los Alamos Critical Assembly Facility now consists of three independent assembly buildings (called "Kivas") in which assemblies are operated remotely from three separate but grouped control rooms one-quarter mile from two Kivas (1 and 2) and somewhat less distant from the third. Kiva 1 was first used in 1947. Shortly thereafter, a universal machine called "Topsy" was constructed to investigate enriched uranium metal cores in a thick natural uranium reflector. This machine was later adapted to a nickel reflector and to other cores. As the weapon program expanded and weapon design became more sophisticated, the critical assemblies group, then Group W-2, was called upon to make measurements to (1) aid in the design of experimental nuclear explosive devices, (2) establish nuclearly safe procedures for handling, storing, and transporting weapons, and (3) provide neutron physics parameters necessary for the calculation of weapons systems. The work load soon became more than could be handled in one assembly building, and Kiva 2 was constructed in 1950 along with the present main laboratory building where the control rooms are located.

Although work directly related to weapon design continued to be of prime concern, activities gradually broadened. The nuclear safety program was expanded to include safety of active material processing and fabrication operations, both locally and AEC-wide. The reactor physics research program developed to include basic information on fissile and nonfissile materials of interest in reactor development as well as weapon design, particularly the derivation of consistent parameters for use in multigroup machine calculations.

In 1955 the Rover reactor category was added and has become a dominant field although weapon and nuclear safety responsibilities and other reactor interests are still active. At that time, the critical assemblies group was transferred from W Division (weapons) to N Division (Rover) and redesignated Group N-2. Demands of the Rover program led to construction of Kiva 3, in which preliminary assembly studies commenced during February 1961.

Critical assembly machines are frequently relocated to improve operating efficiency when program emphasis is changed.

## The Facility and Typical Assemblies

**Location.** The Los Alamos critical facility is located at Pajarito Site (TA-18), which is about two miles from the nearest residential area, and about one-quarter mile from the closest technical area (see Fig. 1). It is in a normally arid canyon, and some natural shielding is afforded by surrounding canyon walls (Figs. 2 and 3).

**General Features of Kivas.** The Kivas are of reinforced concrete and masonry block construction. Each has a traveling crane in the main assembly room. Gas-fired furnaces are used for heating, and forced-draft ventilation is provided. Each has provision for storage of active material in a separately locked area, with storage

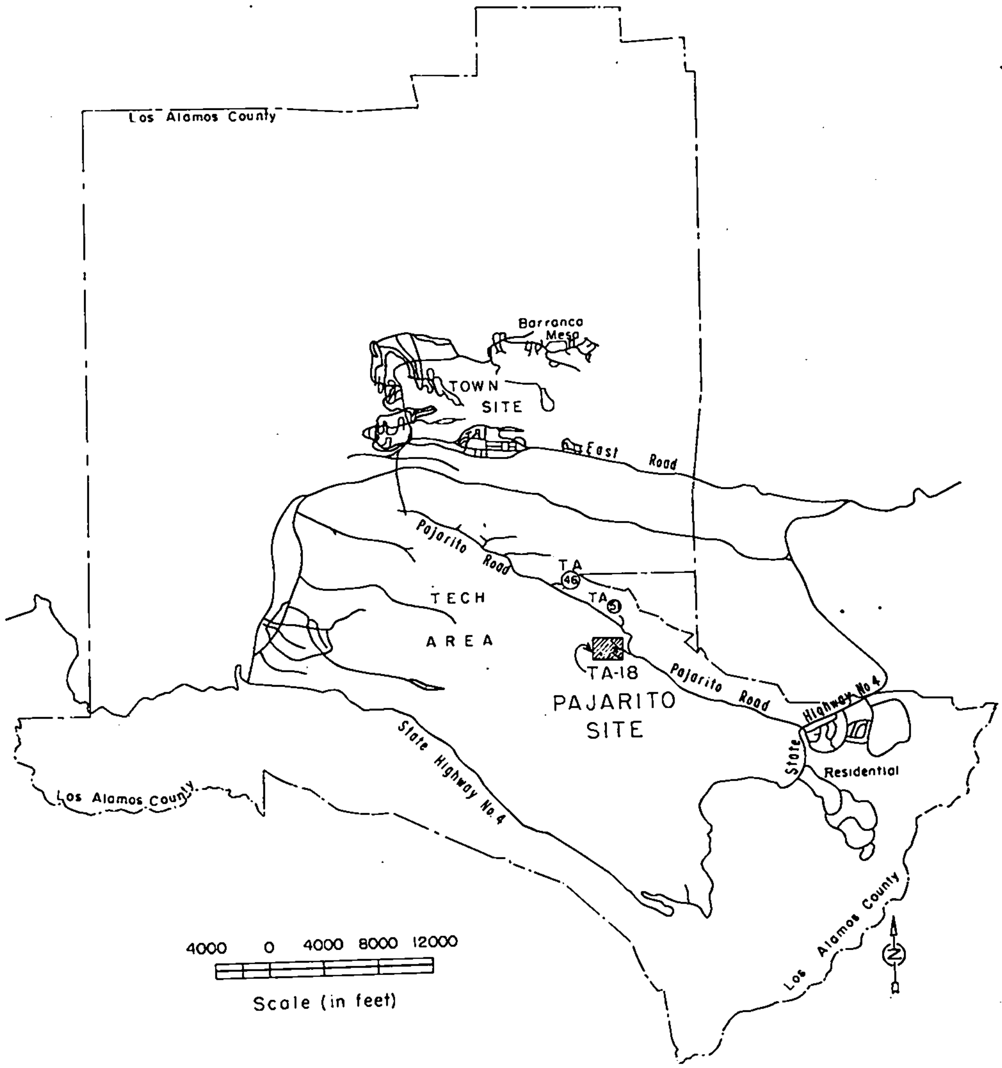


*Fig. 1.*
*Environs of Pajarito Site (TA-18).*

divisions for which load limits are posted. Keys for outside-door locks (except to isolated furnace rooms) have limited distribution.

In accordance with operating procedures, a system of five separate radiation level detectors is permanently installed in each Kiva and serves the roles of scram actuation and operational instrumentation. Compressed air is furnished from a common source. Hydraulic supplies are tailored to individual needs.

Each Kiva is surrounded by an exclusion area that is vacated before remote operation, and automatic signals forewarn anyone who might be overlooked. Operation with the gate to this area open is prevented by interlocks and by key-actuated switches that require the same (captive) key for supplying power to assemblies and for opening the gate.

**Typical Critical Assemblies**

**Kiva 1** (Fig. 4). Distance of about 1000 feet from Kiva 1 to the nearest occupied building is a primary safety feature, as the building itself affords only light shielding.

The following critical assemblies in Kiva 1 are subject to modification as required by changing demands of the Rover program.

1. Honeycomb Assembly (Fig. 5): Honeycomb is a versatile machine for mocking up relatively large critical systems and provides when assembled a 6-ft cubic matrix of 3-in. by 3-in. by 6-ft aluminum tubes for supporting reactor materials. It has been used since 1968 for a simple graphite-uranium assembly to

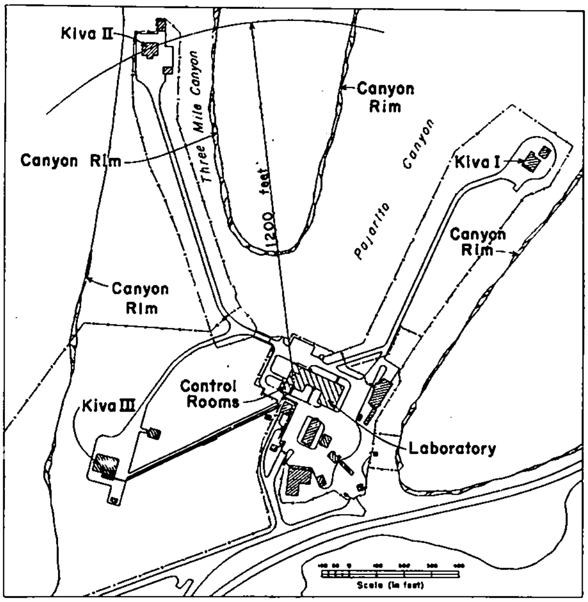


*Fig. 2.*
*Pajarito Site and terrain.*

give reactor-physics data pertinent to the Rover program. The assembly is an unreflected 4-ft cube of uniformly interleaved graphite plates and U(93) foil, with an overall $C/^{235}U$ atomic ratio of 180. It is expected that at least one similar assembly at another value of $C/^{235}U$ will be investigated. Scrams retract horizontally about one-half of the split assembly and withdraw fuel bundles (safety rods) worth about 1½\$. The effectiveness of controls is ∿0.8\$.

2. Pewee Zepo (Fig. 6): The Venus machine, on which the Pewee Zepo assembly is mounted, was designed originally for a neutronic mock-up of Kiwi-A, and was then adapted to mock-ups of Dumbo and an early member of the Kiwi-B series. The present assembly simulates the Pewee 2 reactor, designed as a test bed for Rover fuel elements. Except for zirconium hydride in support elements, and a consequent smaller diameter, Pewee core structure, reflector, and controls are like those of preceding Rover reactors. The core, predominately of Rover elements, is reflected laterally by beryllium within which typical control drums rotate. It is expected that this assembly will change to pace an extended series of Pewee reactors.

*Fig. 3.*
*Pajarito Site, 1969. Main building with control rooms is at right center, Kiva 1 right background, Kiva 2 left background, and Kiva 3 left foreground.*

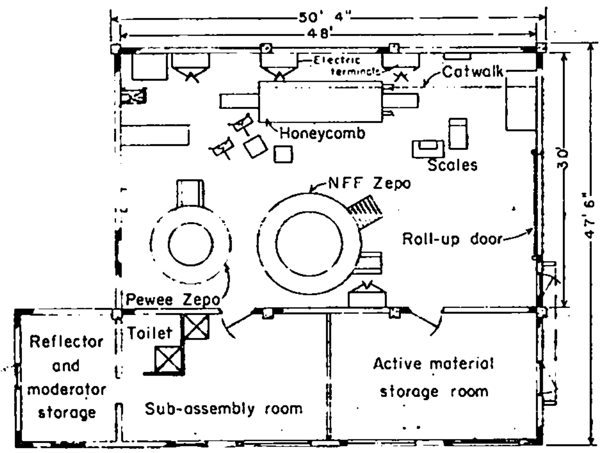


*Fig. 4.*
*Kiva 1 floor plan.*

The zero-power mock-up is arranged so that the core is removed from the reflector; it is thus far subcritical except during remote operation. A scram signal causes the core to drop out of the reflector as the principal means of disassembly. In addition, the control drums rotate to their positions of maximum effectiveness, contributing to shutdown about one-half of a 6 to 7$ total reactivity swing.

3. NFF Zepo (Figs. 7 and 8): The Mars machine, which had been used earlier for zero-power mock-ups of Kiwi-B, Phoebus 1, and Phoebus 2 reactors, now supports NFF Zepo. This assembly (more properly, series of assemblies) simulates concepts of the Nuclear Fuel Furnace, a proposed reactor for testing relatively small numbers of Rover fuel elements. The core of this reactor is a water-moderated lattice of fuel capsules, each of which contains a single Rover element. Again, there is a cylindrical beryllium reflector incorporating Rover-type control drums.

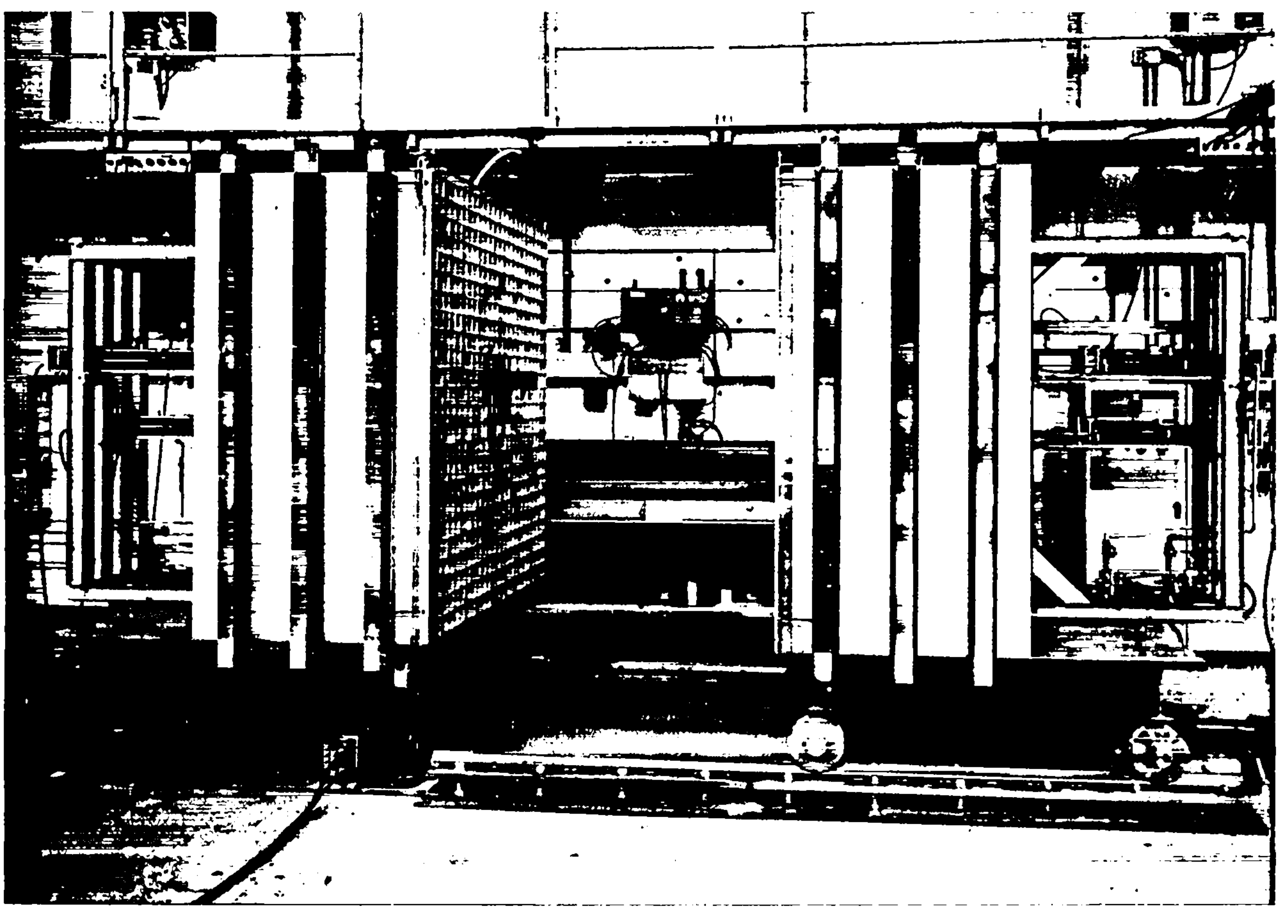

*Fig. 5.*
*Honeycomb split-table assembly machine.*

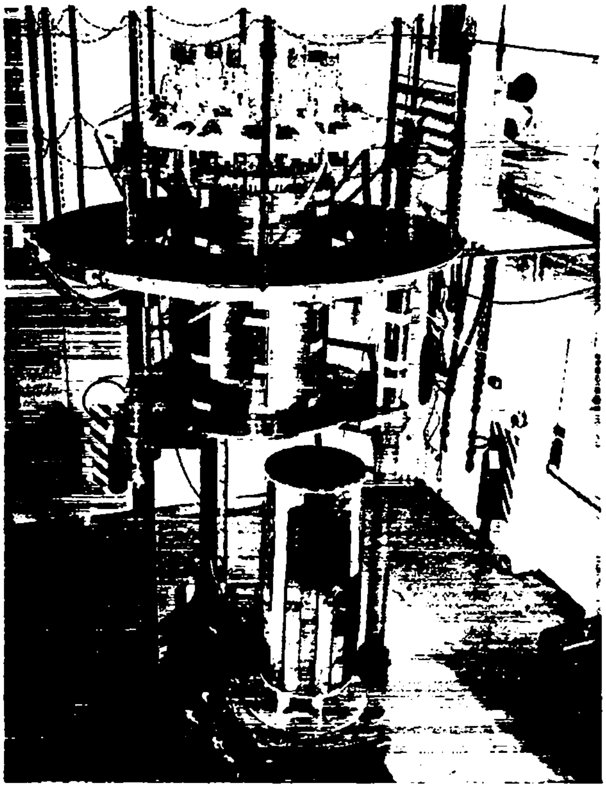

*Fig. 6.*
*Pewee Zepo. Invar strips are attached temporarily to the retracted core.*

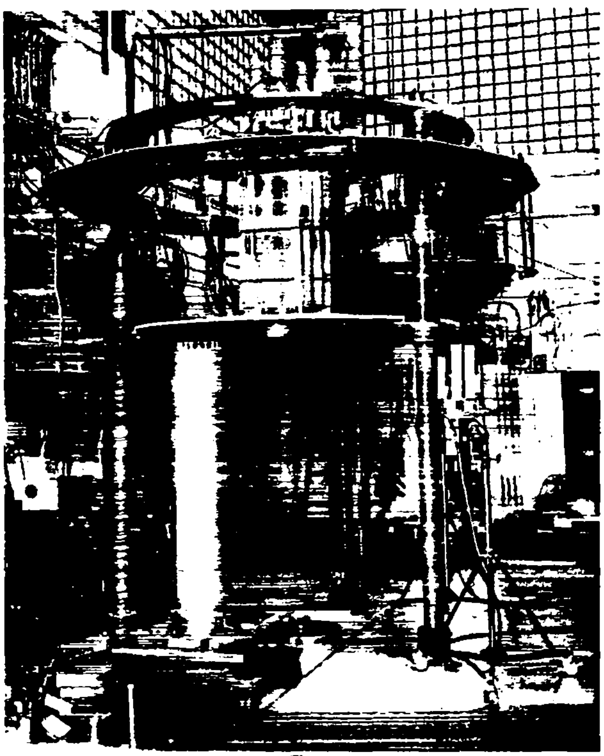

*Fig. 7.*
*NFF Zepo. Mock-up of Nuclear Fuel Furnace with core retracted.*

*Fig. 8.*
*Core of NFF Zepo. Fuel capsules extend above water tank.*

The first version of NFF Zepo, containing 37 fuel capsules, is being modified to accommodate 56 elements. Like Pewee Zepo, the core is separated from the reflector except during remote operation, and the standard procedures for loading maintain a large subcritical margin whenever the core is retracted. Again, like Pewee Zepo, scram action drops the core out of the reflector and, as backup, inserts controls. The control swing of the new version is predicted to be greater than 6$ (versus 15$ for the 37-element model), of which about one-half will be available for shutdown.

4. Kinglet: The Kinglet assembly will be set up in special weather-protective housing outside Kiva 1. The purpose is to provide a feasibility check of the KING high-flux reactor concept, with emphasis on dynamic stability. Like KING, the fuel is a circulating enriched-uranium solution (at about 75 g $^{235}$U/liter), but scalled down in dimensions and with operational limitations such that no heat exchanger is required. The critical region (Fig. 9) is a Zircaloy nozzle surrounded by a beryllium reflector (to keep the critical diameter small and the attainable linear velocity of solution reasonably large). Other piping and vessels are stainless steel. Solution ejected from the nozzle drains into an annulus dimensioned to be subcritical, from which the pump forces it into another cycle.

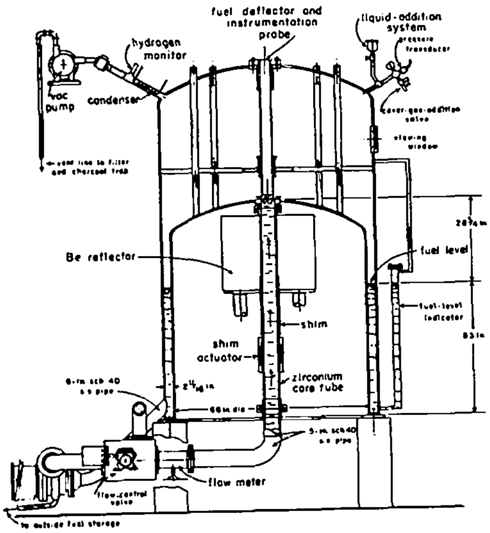


*Fig. 9.*
*Kinglet circulating solution assembly.*

The design of a control cylinder between the Zircaloy nozzle and the beryllium reflector will be based on the results of static tests to be conducted on the Comet machine in Kiva 2. Other static tests, in the course of initial loading, are intended to confirm subcriticality of all regions except the beryllium-reflected nozzle. Successive operations will advance by small reactivity increments so that instabilities which might arise would be detected and countered at an early stage. It may be noted that the sweeping out of delayed-neutron precursors might contribute to oscillations.

A feature of this assembly, different from others at Pajarito Site, is that appreciable volatile fission-product activity can be released as a result of runs within the restrictions of our Operating Limits (p.16). Because of this, radioactive gases that collect within the envelope of the system will be held, then flushed out only under conditions that representatives of Group H-1 judge to be acceptable. Safety considerations associated with the unusual features of Kinglet will be emphasized in the Experimental Plan for this assembly.

. Kiva 2 (Fig. 10). Kiva 2 is similar to Kiva 1 in that masonry walls afford only nominal shielding; consequently, the same distance from the nearest occupied building was maintained. The assemblies in this Kiva, listed below, are generally related to the weapons program instead of Rover. Several of these assemblies (Jezebel, Flattop, and Big Ten), unlike those of Kiva 1, are not subject to major modification.

Critical assembly machines in Kiva 2 are:

1. Jezebel (Fig. 11): Jezebel, an unreflected

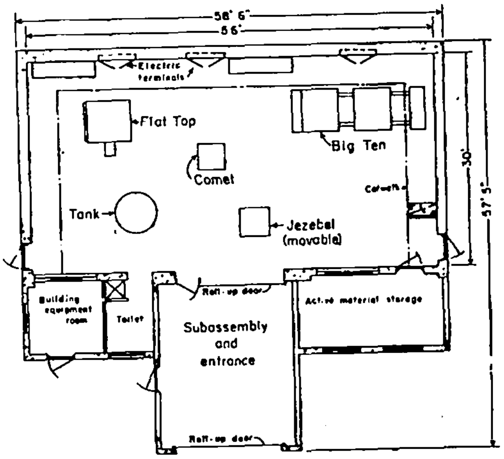


*Fig. 10.*
*Kiva 2 floor plan.*

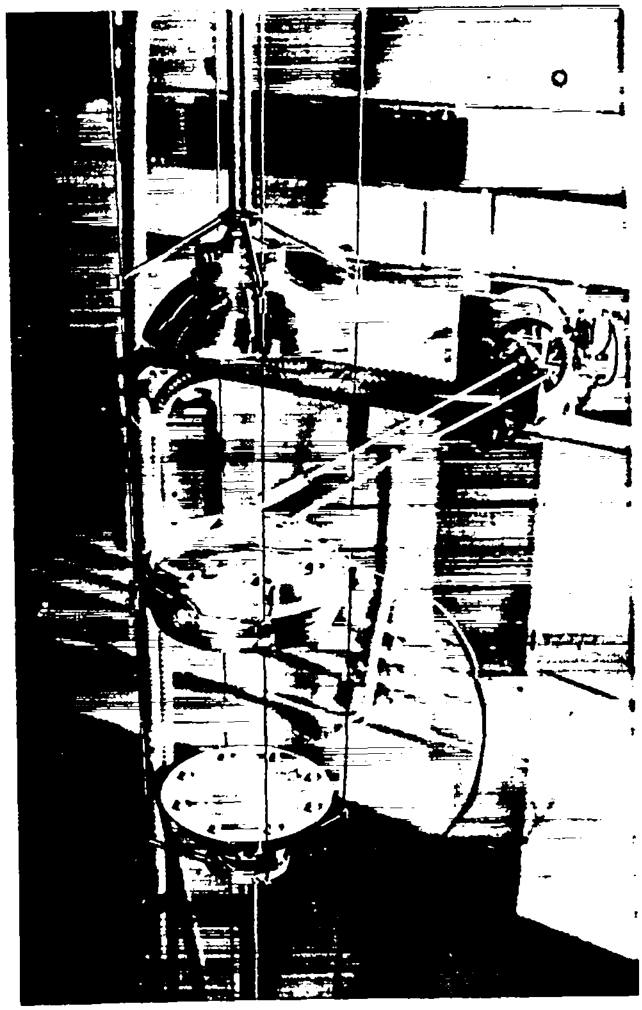

*Fig. 11.*
*The Jezebel bare-plutonium assembly.*

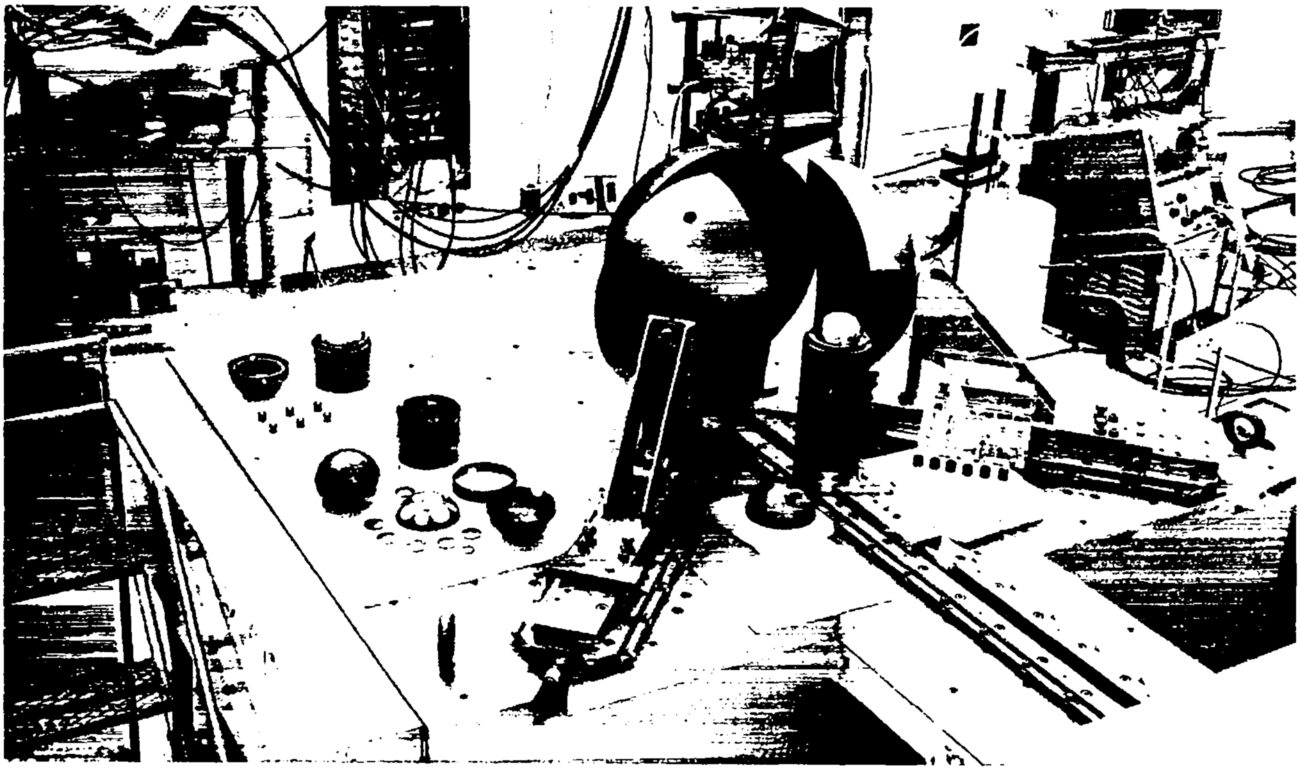

*Fig. 12.*
*Flattop. The plutonium core is in position, other cores and adapters are at left foreground.*

near-spherical assembly of δ-phase plutonium, is used for reactor physics investigations. The original plutonium components, still available, contain 4½% $^{240}Pu$, and another interchangeable set with 21% $^{240}Pu$ exists, Experiments with another Jezebel assembly, $^{233}U$ metal, have been completed and the uranium parts were diverted to another program. An essentially portable machine, Jezebel was first installed in Kiva 1. The scram effect is achieved by separation of the sphere into three nearly equal portions by the independent motion of both polar caps of plutonium. The plutonium control rod, which is worth about 0.7$, does not contribute to the scram action.

2. Flattop (Figs. 12 and 13): The Flattop series of assemblies has interchangeable spherical cores of U(93), $^{233}U$, or plutonium metal, surrounded, during remote operation, by a reflector of thick natural uranium. The reflector is subdivided into a stationary hemisphere into which the core is recessed, and two movable quadrants. Natural uranium control rods, one worth about 1.5$ and two others about 0.6$ each, enter the fixed hemisphere from below. Flattop is used for fundamental reactor-physics studies, and, by irradiations in the known neutron spectra, to provide samples for radiochemical research.

Upon scram, both quadrants of reflector retract rapidly to the normal "disassembled" condition.

3. Big Ten (Fig. 14): Big Ten, a large cylindrical metal assembly is being mounted, with axis horizontal, on a split-table machine that was used originally in the CANEL Project of Pratt and Whitney. The purpose of the assembly is to provide cross-section data for a fast-neutron spectrum that extends to lower energies than the spectra of small metal systems such as Jezebel and Flattop.

A large part of the 21-in.-diam core (Fig. 15) will consist of interleaved plates of U(93) and natural uranium that are sized to give an average $^{235}U$ enrichment of 10%. Inserts of homogeneous U(10) will contain all regions of internal measurement so that the interpretation of data will not be complicated by effects of heterogeneity. The core is to be surrounded by a 6-in.-thick reflector of depleted uranium within which low-value control rods and safety rods of the same material are inserted. A more effective uranium control rod enters the core along its axis.

For calibration and kinetic measurements, during which reactivity changes will be significant, a temporary large-value rod, also on the axis, will combine safety and control functions (Fig. 16). After such measurements are completed, this rod will be removed so as to reduce perturbations during delicate reactivity-coefficient measurements that depart little from delayed criticality.

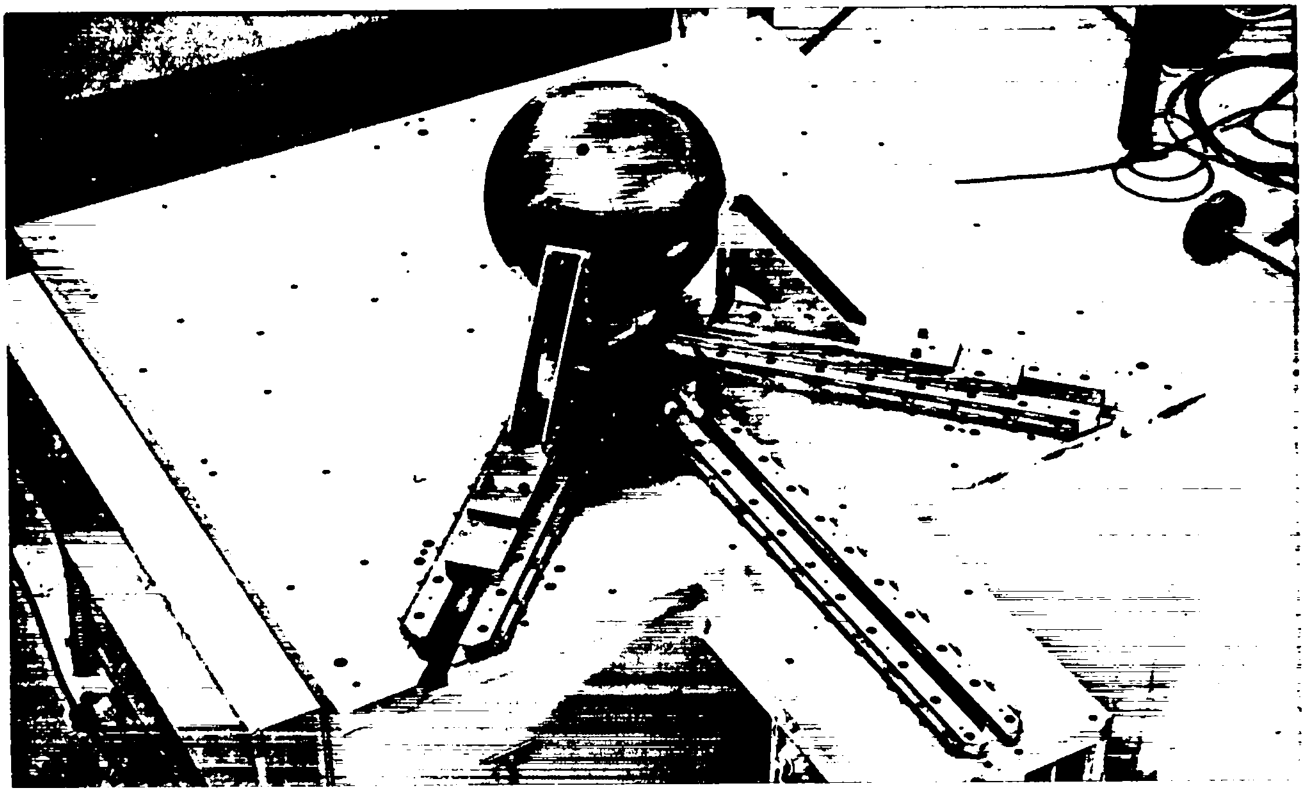

*Fig. 13.*
*Flattop as it appears during remote operation.*

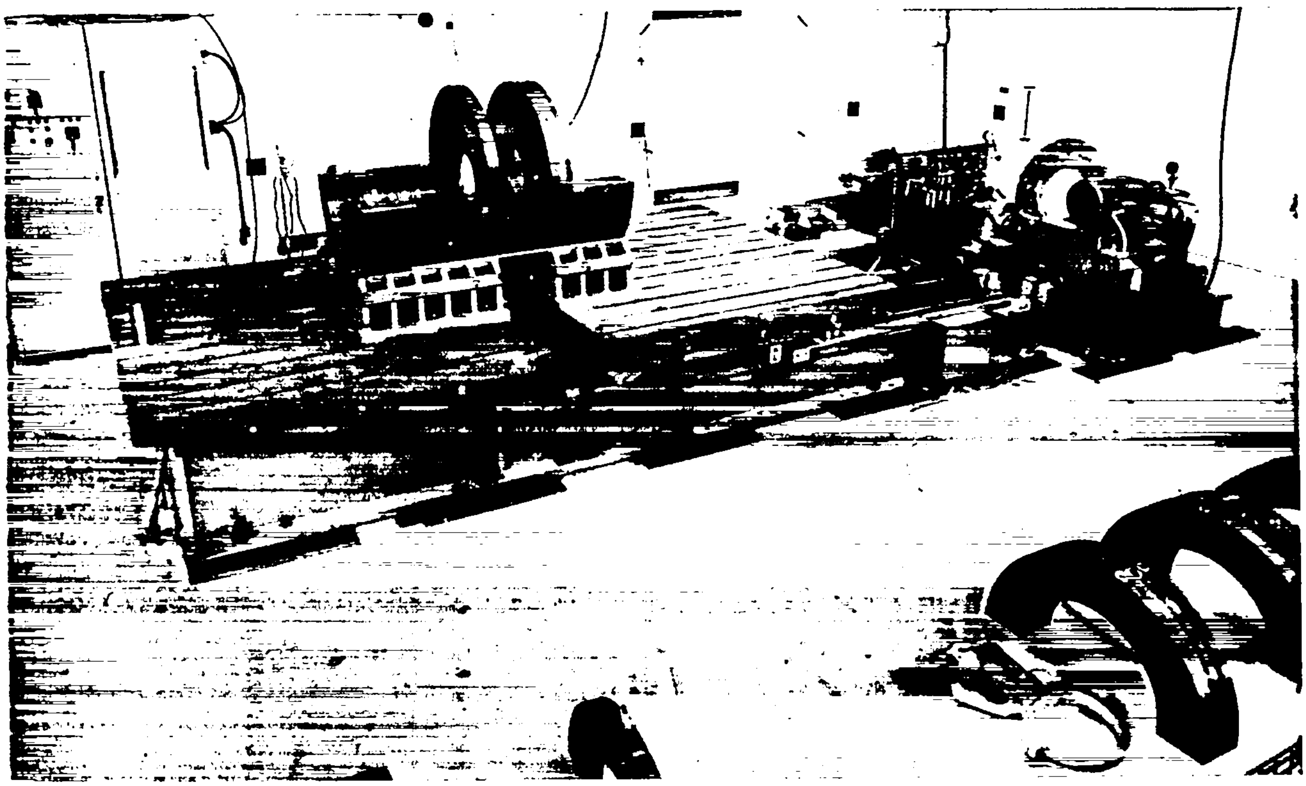

*Fig. 14.*
*Big Ten split-table support as reflector was being mounted.*

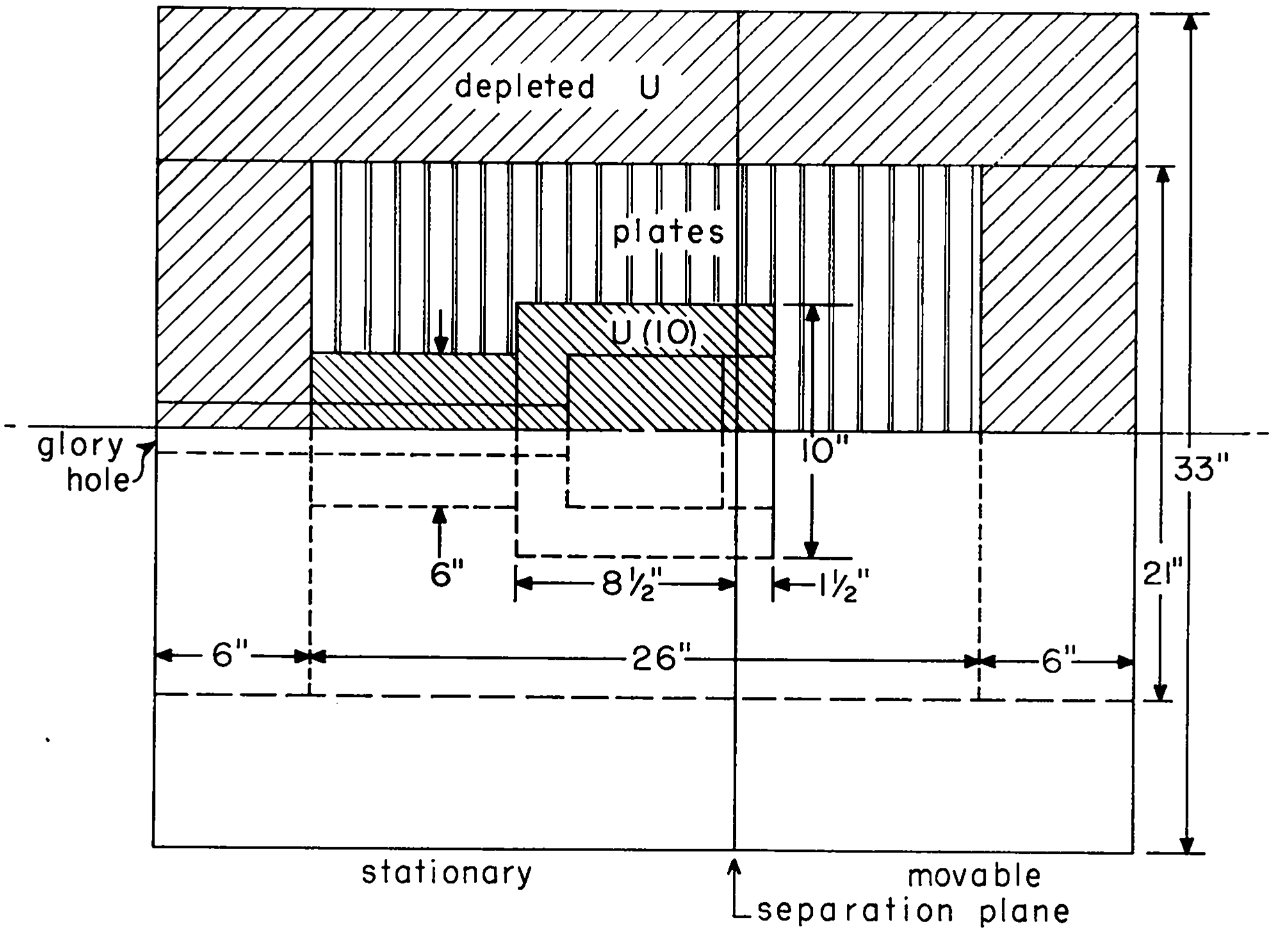


*Fig. 15.*
*Basic Big Ten assembly.*

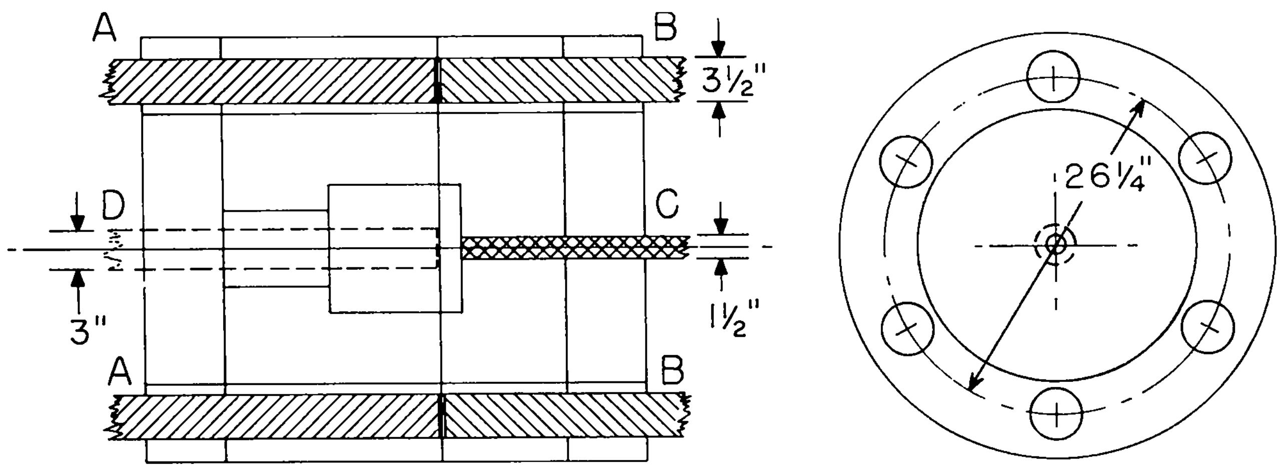


*Fig. 16.*
*Big Ten control and safety rods. Rods A are safety, B and C are control, and D is the temporary combination rod for kinetic experiments.*

The major scram mode will be subdivision of the assembly by retraction of the movable part of the support. This will be backed up by the withdrawal of reflector rods worth an estimated 0.3$, and, throughout kinetic measurements, by a portion of the temporary rod worth 0.7 to 1.3$.

4. Comet (Fig. 17): The Comet assembly machine is a hydraulic lift and surrounding supports for an assortment of superstructures that includes thin, taut diaphragms, heavy-duty platforms, and an A-frame. It is adapted to a variety of assemblies by supporting part of the material on the remotely controlled lift and part on an appropriate superstructure. Although intended primarily for subcritical measurements such as weapons safety tests, several temporary critical assemblies have been mounted on Comet (Figs. 18 and 19). Each of the latter type had provision for a backup scram (in addition to automatic dropping of the lift), and for a vernier control. As mentioned, static tests preliminary to Kinglet will be conducted with this machine.

5. Tank (Fig. 20): The Tank system is basically a water tank with appropriate remotely controlled inlets and drains, for use in checking the criticality safety of single or multiple fissile units when flooded. The tank is required primarily for tests of weapons or components, but has been used for confirming the safety margin of an Omega West fuel storage arrangement, and for checking the safety of Rover shipping-cask inserts when loaded with fuel and flooded with water. For the last of these measurements, a secondary scram device (the primary scram drains the tank)

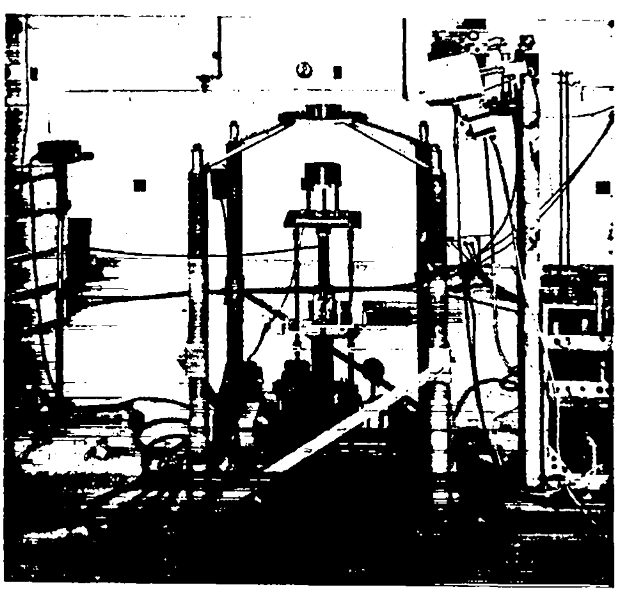

*Fig. 17.*
*A typical subcritical assembly on Planet (a retired assembly machine like Comet).*

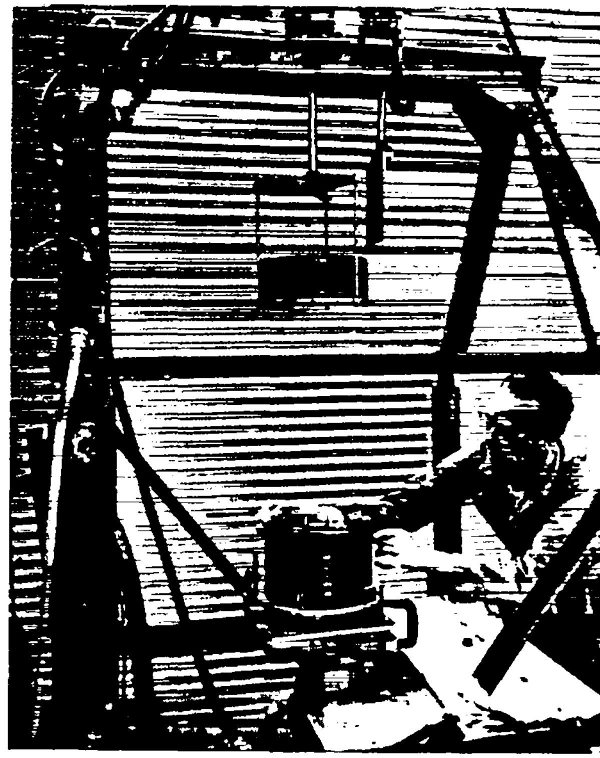

*Fig. 18.*
*Jemima U(37) critical assembly on Comet.*

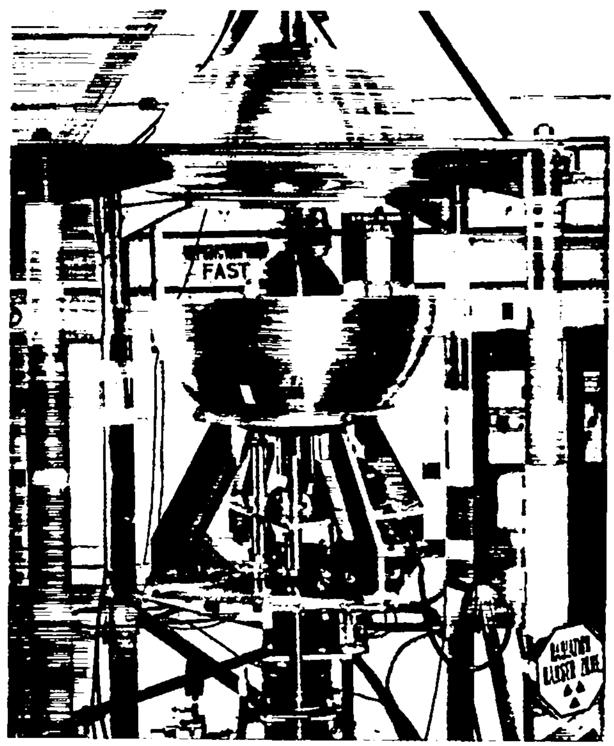


*Fig. 19.*
*Ichiban critical assembly mounted on Comet. In this assembly for radiation calibration, backup safety cylinder retracts at the top, and control cylinder enters below.*

and control vane were added to permit critical operation that confirmed the reliability of cell calculations.

6. Hydro (Fig. 21): The Hydro assembly is set up outside Kiva 2 in a retractable weather cover. It was originally used as a source for uranium exponential columns, and was placed outdoors to eliminate perturbing effects of neutrons that would be scattered back by surrounding walls. More recently it served as a neutron source for a thermal column, for detector studies, and for activating radiochemical samples.

The core of Hydro is a U(93)-metal cylinder containing a pair of copper disks that help conduct heat to a layer of cooling water against the lateral surface. A further thickness of water reflects the side and, with a polyethylene control block, the base. This combination is mounted on a hydraulic lift that, for remote operation, raises it out of a concrete shield and against the system to be irradiated. It is capable of operation at a power greater than 5 kW.

Because the object to be irradiated constitutes the upper reflector of Hydro, any changed configuration is approached with the caution of a new assembly. Upon scram, the hydraulic lift drops, the polyethylene control block (0.3$) retracts, and the lateral reflector water drains.

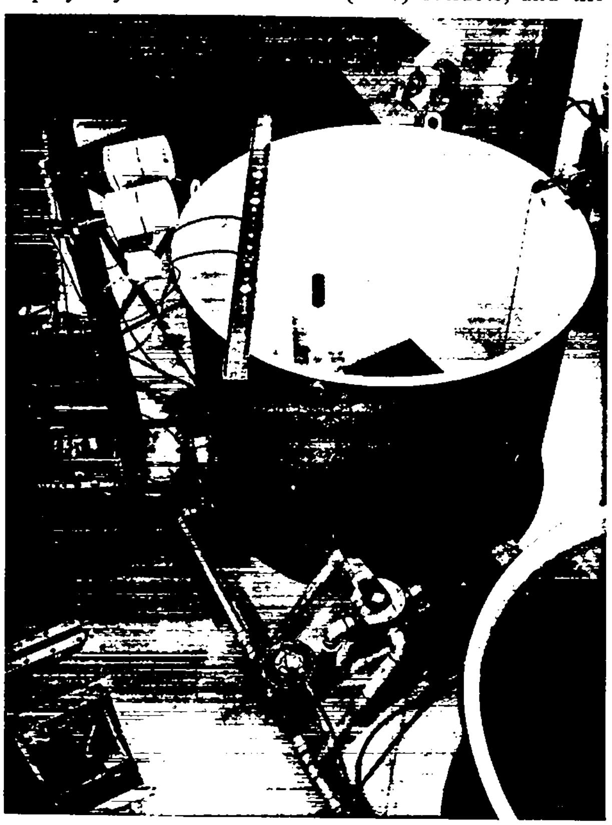

*Fig. 20.*
*Tank setup for safety tests of water-flooded fissile systems.*

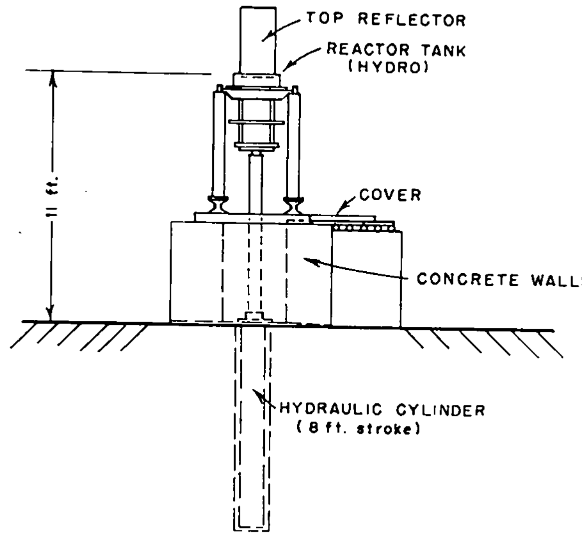


*Fig. 21.*
*Hydro in outdoor facility.*

Kiva 3 (Fig. 22). Kiva 3 is the only Kiva with significant shielding, having 18-in.-thick walls and ceiling. The purpose of this shielding is to compensate for a distance to the nearest occupied building, 560 feet, that is less than for the other Kivas. Construction is such that reasonable confinement is expected in case of a relatively severe excursion. The one entrance into the main room is designed as a tunnel so that radiation scattering to the outside will be small, and orientation is such that it does not point toward the most frequently occupied areas.

An environmental chamber, designed to cool to -85°F and heat to 700°F, is a major feature of this building. (Temperature is the only controlled parameter.) Its purpose is to subject critical assemblies to other than ambient temperatures, at which most previous experiments have been done. The planned temperature range is sufficient to provide information on models sensitive to neutron temperature without being so extreme as to introduce operational problems. Auxiliary equipment for the chamber is housed in a masonry block section of the building, and semiautomatic control permits operation from the Kiva 3 control room.

A major activity in Kiva 3 has been the preassembly and checkout of Rover reactors before Nevada tests. This operation, illustrated by Fig. 23, has been conducted for Kiwi B-1A, -1B, -2A, -4A(twice), -4B, -4D, and -4E; TNT; Phoebus-1B; Phoebus 2; and Pewee 1; and is expected to be repeated for other Rover test reactors. As these activities permit, the following assemblies may be operated in Kiva 3.

1. Parka (Fig. 24): The Parka device is essentially a

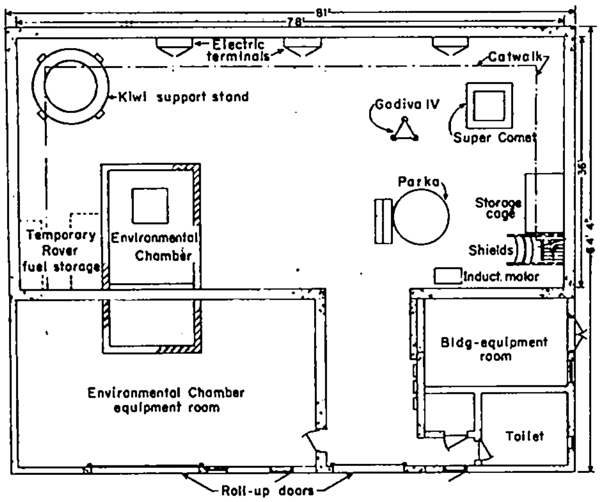


*Fig. 22.*
*Kiva 3 floor plan.*

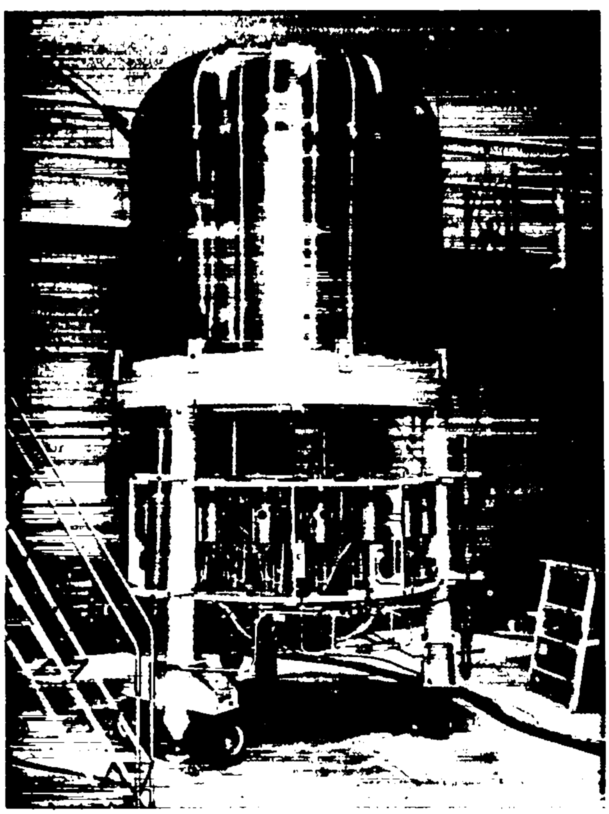

*Fig. 23.*
*Phoebus 2 as preassembled in Kiva 3.*

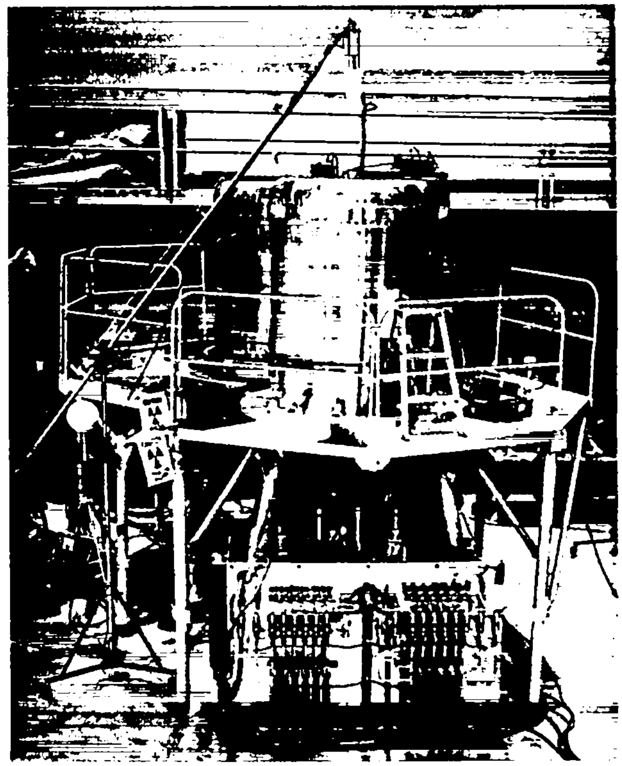

*Fig. 24.*
*Parka in foreground with TNT positioned behind for interaction experiments.*

Phoebus 1 reactor (without pressure vessel) that is used as a critical assembly, largely for the measurement of neutronic influences of new types of Rover fuel elements. The system for actuating combined control and safety drums is a duplicate of that used for Nevada tests, with the following exception. For the measurement of transfer function, there is the provision for continuous rotation, over a large range of speed, of a special drum adjusted to have a reactivity swing of ± 0.1$.

This feature was used during an unusual series of experiments in which Parka and the similar TNT reactor were operated simultaneously to measure neutronic interaction at various separation distances. The purpose was to evaluate complications that might arise as a result of clustering reactors in a propulsion vehicle.

Because the core of this assembly does not drop out of the reflector, any change that might increase reactivity is made in steps that are small relative to the protective capability of the control drums. These drums have a total reactivity swing greater than 7$, of which at least one-half is available for scram.

2. Godiva IV (Figs. 25 and 26): The Godiva IV assembly is a successor of Lady Godiva with which reproducible super-prompt-critical bursts were demonstrated, and of Godiva II that was designed

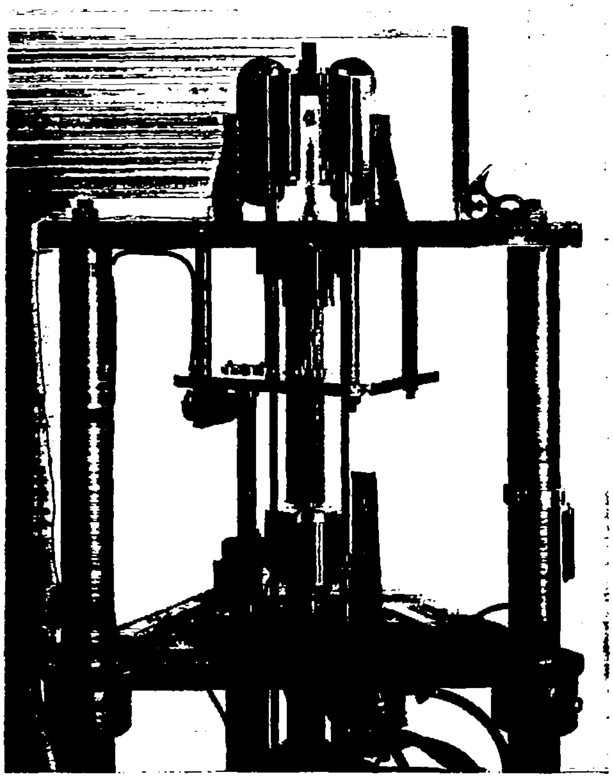

*Fig. 25.*
*Godiva IV experimental fast-burst assembly. C-clamps provide center-of-shock mounting for the uranium-alloy head.*

specifically for fast burst production. The purpose of Godiva IV is to test design features, including material selection, that are expected to increase resistance to shock damage.

The two major U(93)-alloy parts of Godiva IV, a stationary head and a movable safety block, form an essentially unreflected cylinder when brought together remotely. Under this condition, delayed criticality can be attained by the adjustment of two U(93) control rods (each worth about 1.5$) that enter the head. From this state, a burst may be produced by a slight change of control-rod position followed by a sudden reactivity addition of 1$ brought about by insertion of an interlocked U(93) burst rod. Thermal expansion terminates the burst.

The production of a burst of known magnitude involves a well-defined cycle that includes a delayed-critical check, retraction of the safety block for decay of the neutron population, reinsertion of the safety block, control adjustment to trim excess reactivity as required for the desired burst while allowing for temperature drift, and, finally, burst-rod insertion. Interlocks prevent major departures from this cycle. The burst actuates a scram signal, which drops the safety block and ejects the burst rod.

3. Supercomet (Fig. 27): Supercomet is a general-purpose assembly machine, similar to Planet of Kiva 2 except for a longer stroke of the hydraulic lift. The

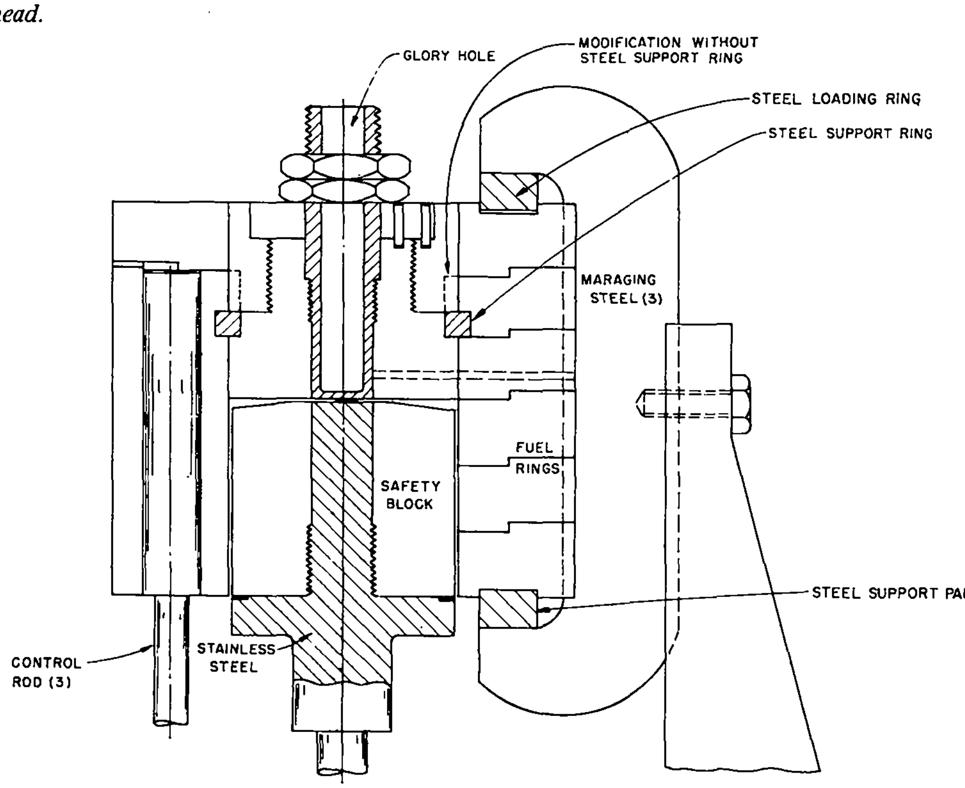


*Fig. 26.*
*Godiva IV fuel assembly.*

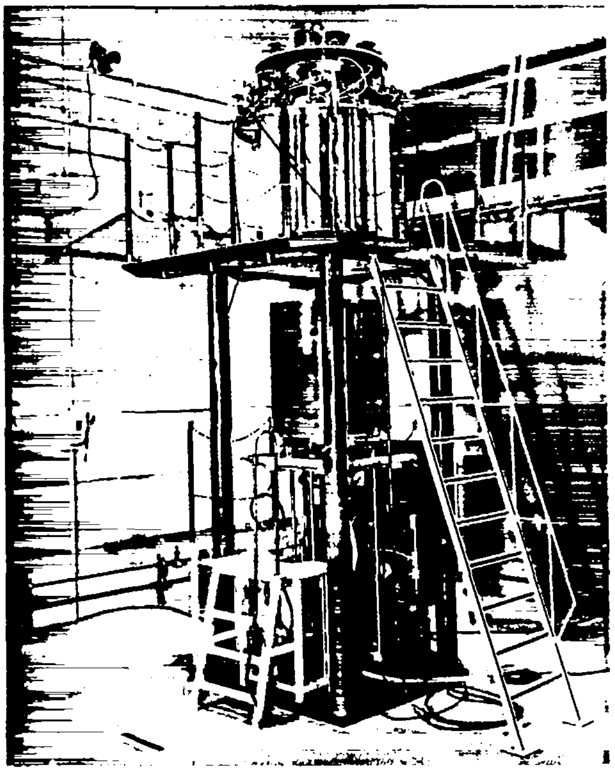

*Fig. 27.*
*Supercomet with mock-up of plasma-thermocouple reactor. Water tank on lift raises to surround fuel structure mounted above.*

principal automatic disassembly action is dropping of the lift.

Assemblies set up on this machine have been the mock-up of a conceptual reactor fueled with plasma thermoelectric cells, a preliminary version of Pewee Zepo, and a system for precisely establishing the critical mass of an $\alpha$-phase plutonium sphere in water. Although there is no present plan for operation of Supercomet, the machine remains available.

## Group N-2

Although Group N-2 conducts critical experiments, it is also concerned with computational programs that parallel these experiments, with radiation effects and shielding studies that are primarily computational, with the development of specialized instrumentation, and with neutron physics research that does not involve criticality. Consequently, only about one-half of the nearly 40 members of the Group perform critical experiments. Of these, only five have been with the Group less than ten years and the briefest tenure is greater than five years. There are no "operators" as a class, just experimentalists and designers.

As a result, training is not a severe problem. Persons assigned to the Group temporarily, as for summer employment, and those who assist with experiments for other Los Alamos groups serve as extra members of operating crews until judged by the N-2 Group Leader to be capable of formal participation. In any event, an experienced permanent member of the Group is in charge of operation.

Everyone within Group N-2 is encouraged to become familiar with each critical experiment and to express his thoughts about it. One of the objectives, of course, is to reduce the possibility of "blind spots" concerning safety matters. Interest is broadened by discussions at weekly Group meetings, by making pertinent documents available, and by activities of an internal Nuclear Safety Committee that is advisory to the N-2 Group Leader. Because a major function of this Committee is to assist in the satisfactory blending of safety provisions with other objectives of a critical experiment, discussions are generated which go beyond the persons immediately concerned with design and operation. The Committee also alerts the Group to possible safety deficiencies that show up in the course of operation.

Discussions such as these seem to contribute to a continuing respect for fissile material, and certainly improve understanding of the hazard involved and of methods for its control.

In the view of Group N-2, twenty-some years of experience with critical facilities has dispelled most of the mystery associated with this hazard, and has refined and confirmed practices for criticality control. An extension of this view is that the philosophy underlying conventional industrial safety is appropriate for criticality safety. Certain aspects of this philosophy that members of Group N-2 try to keep in mind are:

*Safety is an acceptable balance of risk against benefit (it is meaningless as a concept isolated from other goals); a corollary, implied earlier, is that safety should be considered as one of the goals of design and operation, not something superposed.*

*Safety provisions should be based upon experience and upon the responsive awareness of those performing operations; the protection of people has priority over protection of property.*

*Safety responsibility (and commensurate authority) should be close to the operation; the attitude that "someone else is taking care of us" must be avoided. While it is inevitable that authority and responsibility for an operation be assigned to an individual, a feeling of responsibility by all concerned with the operation should be nurtured.*

*Where alternatives exist (as is usual for criticality control), simple, convenient safety provisions are more effective than complex or awkward arrangements; any* *rule that arbitrarily requires one of the alternatives should be avoided.*

*Contributions to safety that cost little in money or convenience should be searched for and adopted even if they seen redundant.*

### Operating Procedures

The Pajarito critical facility and its operating group were born with documentary requirements, imposed as a natural reaction to two fatal hand-assembly accidents that had occurred. The scope of operation and general procedures were defined by Pajarito Operating Regulations from which no departure was permitted. Supplementary procedures specific to an experiment were covered by an approved Experimental Plan as required by the Regulations. It is still a requirement that each critical or near-critical operation be covered by an Experimental Plan (an example appears as Appendix A).

As experience accumulated and demands for critical experiments broadened, it was inevitable that the Regulations of 1947 evolve so as to become less rigid but hopefully more effective. In the course of this evolution, the Regulations became general operating procedures, generated within the Critical Assemblies Group, but requiring approval at higher level. Departures from the procedures are permitted if spelled out in Experimental Plans that are also subject to the higher-level approval. In general, changes of content were consistent with development of the safety philosophy outlined in the previous section. For example, the contribution by a "Safety Man," aloof from other experimental objectives, was recognized as marginal, As further illustration, a complex emergency plan was replaced by a simple but more flexible plan based on local diagnostics, as the understanding of hazards improved.[1]

The current (1968) version of the old Regulations is the Los Alamos document LA-4037-SOP, entitled "Operating Procedures for the Pajarito Site Critical-Assembly Facility,"[2] which supplements this Safety Analysis Report.

Briefly, these Procedures are in accordance with the American Nuclear Society Standard, "A Code of Good Practices for the Performance of Critical Experiments," but provide much more detail than appears in the Standard (Appendix B). In the view of Group N-2, the most important function of the Procedures is to protect people handling fissile material. For this purpose, the emphasis is upon a "hand-stacking limit" that corresponds to a value of 10 for idealized neutron multiplication (or three-quarters of a critical mass, where that has more significance). Storage and transfer practices are in accordance with USA Standard N16.1-1969(Rev.), "Nuclear Criticality Safety Standard for Operations with Fissionable Materials Outside Reactors," and are designed to be far below the quoted hand-stacking limit. Manual operations, such as loading the parts of an assembly, must be monitored and controlled so that the hand-stacking limit will not be exceeded. The monitoring requirements and associated procedures are consistent with the recent USA Standard N16.3-1969, "Standard for Safety in Conducting Subcritical Neutron Multiplication Measurements in Situ."

Next in importance are provisions for backing up protective features built into the facility, that is, to maintain effectiveness of the isolation area during remote operation. These provisions include survey of the Kiva area before operation, interlocks to prevent operation with the Kiva-area gate open, captive-key actuation of the switch that controls power for the machine and the same key required to open the gate, alarms to signal imminent operation, and flashing lights at the gate during operation.

Departures from procedures in the above categories would be permitted only for special systems, such as certain weapon configurations, that are known to remain subcritical under all conditions to be encountered. Provisions for departures (as permitted by Experimental Plans) are intended to apply primarily to the second category of procedures whose purpose is to avert accidental excursions during remote operation or to limit consequences if such excursions should occur. Minimum scram capability and fail-safe scram actuation, with duplicate sets of radiation monitors and with multiple scram mechanisms for critical operation, are called for. Interlocks serve to (1) prevent the assembly of major components unless vernier controls are at minimum reactivity and a scram monitor is active, (2) establish the assembly sequence, and (3) prevent control operation before major parts are brought together. Also specified are two channels of startup instrumentation and one for automatically recording the neutron flux level during critical operation, as well as appropriate selector switches, position indicators, and indicator lights at the control console. Multiplication limits apply to subcritical assemblies, and for critical assemblies there are limits on overall reactivity and rates of reactivity addition. Principal modifications of the Procedures by Experimental Plans are adjustments of these limits where justified by reproducibility of the system, and as required for kinetic or dynamic measurements. A noteworthy example is Godiva IV where the purpose is to produce controlled excursions.

As stated in the Operating Procedures, the LASL Reactor Safety Committee (as of 1968) is responsible for general surveillance of Pajarito Site activities, including matters of technical execution as well as policy. The N-2 Nuclear Safety Committee, mentioned before, is solely to satisfy the needs of the Group, and is a technical resource of the Group Leader.

Finally, the Operating Procedures and content of Experimental Plans are constrained by overall limitations that appear in the document, "Operating Limits for the Los Alamos Critical-Assembly Facility." This document, reproduced as the next section, was revised in 1968 and has AEC approval. No departure from its provisions is permitted without formal concurrence of the AEC's Albuquerque Operations Office through the Manager of the Los Alamos Area Office. Accompanying the Operating Limits was our commentary, which appears on pp. 17 to 19. This commentary gives background for the Operating Limits and for the choice of an unusual limitation on fission-product inventory, explains why the concept of the maximum credible accident is of little safety significance for a critical facility, and sets the stage for a final section that brings together conclusions about the safety of Pajarito Site operations.

**Operating Limits for the Los Alamos Critical-Assembly Facility.** (Approved March 28, 1968, by the Area Manager, Los Alamos Area Office.)

The Operating Limits are intended to specify measures that are sufficient for the protection of the general public, and for the control of risk to personnel at the Pajarito Site.[3] An acceptable property risk is also implied.

**Definitions.** The following definitions of critical facility and critical assemblies appear in AECM-8401:

*"A critical facility is the housing and equipment devoted to the operation and maintenance of one or more critical assemblies."*

*Critical assemblies are special nuclear devices... designed and used to sustain nuclear reactions. Critical assemblies are not operated at significant steady state power levels; do not contain appreciable fission product inventories; have little or no heat removal capability; may be subject to frequent core and lattice configuration changes; and may be used frequently as mockups of reactor configurations."*

To make these definitions more specific, we add: The fission-product activity of components is limited such that the following characteristics of an assembly are maintained:

1. No auxiliary shielding of the assembly is required to protect personnel while performing normal local operations.

2. No special cooling of the assembly is required to prevent melting of components by fission-product activity.

The first requirement is interpreted in accordance with LA-1835, "General Handbook for Radiation Monitoring," 3rd Ed. The second requirement is satisfied by a limit that is more specific, but generally less restrictive, which appears below under **Fission-product limitation.**

**Protection Offered by the Facility.** Protective features of the Pajarito facility are described in "Hazards Evaluation for the Los Alamos Critical Assembly Facility."[2] The effectiveness of protection is demonstrated by the extrapolation of dose rates measured immediately outside control rooms (line of sight to the Kivas) during normal critical operations. Extrapolated excursion yields that give the LASL "administrative" dose limit (3 rem whole body) range from $10^{19}$ fissions to $2 \times 10^{20}$ fissions, depending upon the type of assembly and the degree of shielding by Kiva walls. (Hydro, outside Kiva II, does not give the most extreme exposure.) Immediately outside gates to the Kiva exclusion areas the exposure might be doubled, and within a control room it would be down by a factor of five because of added shielding by concrete walls.

Operating experience demonstrates that this degree of built-in protection is sufficient to allow for a multitude of obscure mishaps during remote operation. Of the 18 accidental prompt bursts in critical facilities, which are described in the literature,[1] yields of seven bursts were $10^{17}$ fissions or greater, with the maximum $3.8 \times 10^{17}$ fissions. Damage incurred in all these bursts was so small as to represent an acceptable risk. The roughly two orders of magnitude between the maximum accidental yield and the yield required to induce an exposure of 3 rem at Pajarito Site constitutes a low-risk buffer zone. Provided that the practices which have grown from experience with critical operations are retained, this generous buffer allows the flexibility required for multipurpose experiments.

**Pajarito Safety Policy.** Consistent with the above background and in accordance with the responsibility assigned by Director's Office Memorandum Number 10,[4] the leader of Group N-2 affirms the following safety policy:

The ANS standard, A Code of Good Practices for the Performance of Critical Experiments (Appendix B), the Pajarito Plan for Radiation Emergency (Appendix C), and the following supplementary operating limits will be observed, unless an exception is approved specifically by the ALO Operational Safety Division.

**Supplementary Operating Limits**

**Administrative controls.** Pajarito operations fall under the general surveillance of the LASL Reactor Safety Committee which represents the Laboratory Director. This committee reviews operating procedures and any proposed changes of Operating Limits.

Each critical (or near-critical) experiment is covered by a written Experimental Plan which is approved by the Chairman of the N-2 Nuclear Safety

Committee, the N-2 Group Leader, and the N-Division Leader.

Each operating crew that performs experiments is appointed by the N-2 Group Leader, and consists of a crew chief who is experienced in Pajarito methods of operation, and at least one other competent person. The crew chief is responsible for all aspects of the crew's operation and is to consider personnel safety of paramount importance.

**Fission-product limitation.** Item 2 under Definitions is satisfied by the following requirement. The fission-product generation in any assembly, when averaged over the first hour after shutdown, will not exceed 600 watts. This limit is the first-hour average that would follow a burst of $10^{18}$ fissions.

**Operational limits.** The following limits supplement the ANS standard, A Code of Good Practices for the Performance of Critical Experiments (Appendix B):

1. Two independent disassembly (scram) devices and a vernier control device are required for critical operation. An assembly that does not satisfy this requirement is maintained subcritical by a margin stated in the Experimental Plan.

2. The excess reactivity of an assembly does not exceed the worth of remote controls.

3. For an assembly in which the effectiveness of a prompt shutdown mechanism is doubtful, the excess reactivity does not exceed the value corresponding to a positive period of 5 sec.

4. For an assembly in which the effectiveness of a prompt shutdown mechanism is clear, the reactivity margin below prompt criticality is at least three times the reproducibility demonstrated by a series of disassembly and reassembly operations, unless further requirements for super-prompt-critical operation are satisfied.

5. The further requirements for super-prompt-critical operation are that the fissile material be limited to enriched uranium, and that the demonstrated reproducibility (adjusted to constant temperature) be within ± 0.2 cent for a solid assembly or ± 2.0 cents for a solution assembly. Above prompt criticality, an increase of reactivity beyond a value previously attained does not exceed 1.0 cent for a solid assembly or 10 cents for a solution assembly.

**Commentary on Revised Pajarito Operating Limits**

We hope to satisfy a recommendation in the 1966 appraisal of ALO reactor safety activities, which was referred to us by the Operational Safety Division, ALO:

> *"An operating limit should be included which specifies in some manner the maximum risk that Pajarito will present. A statement which defines the operation such that the calculated Maximum Credible Accident (MCA) will never exceed that presented in the Safety Analysis Report (SAR) or a statement redefining 'critical facility' to conform with the definition in AECM-8401 would be acceptable solutions (§2.0)."*

Because we have problems with the concept of the MCA and its safety significance, we prefer the second of the suggested alternatives. The definition in AECM-8401 (with which we do not quarrel) is qualitative, so we presume that a more nearly operational definition is desired. Practical limitations of a critical assembly are such that the assembly does not require shielding after shutdown and that meltdown does not result from fission-product afterheat. We had proposed the more restricitive of these characteristics--that there be no need for shielding–as the required operational definition, but encountered objections because it does not lead conveniently to comprehensive numerical limits. It is easier to find a specific fission-product limitation which satisfies the second characteristic--that meltdown cannot occur.

Accordingly, we believe that items 1 and 2 in the introduction of the Operating Limits constitute the desired operational definition, and that the maximum value of fission-product power generation under **Fission-product limitation** constitutes the desired numerical limit. It may be noted that the alternative units, curies of fission-product activity and total fission history, have been considered and do not seem as significant as the power. We have tabulations that conveniently translate any fission history to fission-product power at any time afterward, which are summarized in Fig. 28.

It has been suggested that the safety significance of the introductory portion of our Operating Limits, **Protection Offered by the Facility**, may not be as apparent as we had assumed. We had supposed that some experimentally based index of the degree of protection built into our facility would interest anyone concerned with the safety of our operation. This is the reason for indicating that the direct radiation from something like $10^{19}$ fissions could result in the limiting "administrative" dose during remote operation (roughly an order of magnitude less than the emergency dose limit). The margin between this value and the largest accidental prompt burst that has occurred, it seems to us, has greater safety significance than any other quantity that can be proposed. We believe this says that there is a vanishingly small probability that we will approach our limit of built-in protection.

More nearly quantitative conclusions are suggested by Fig. 29, which shows the distribution of frequency of

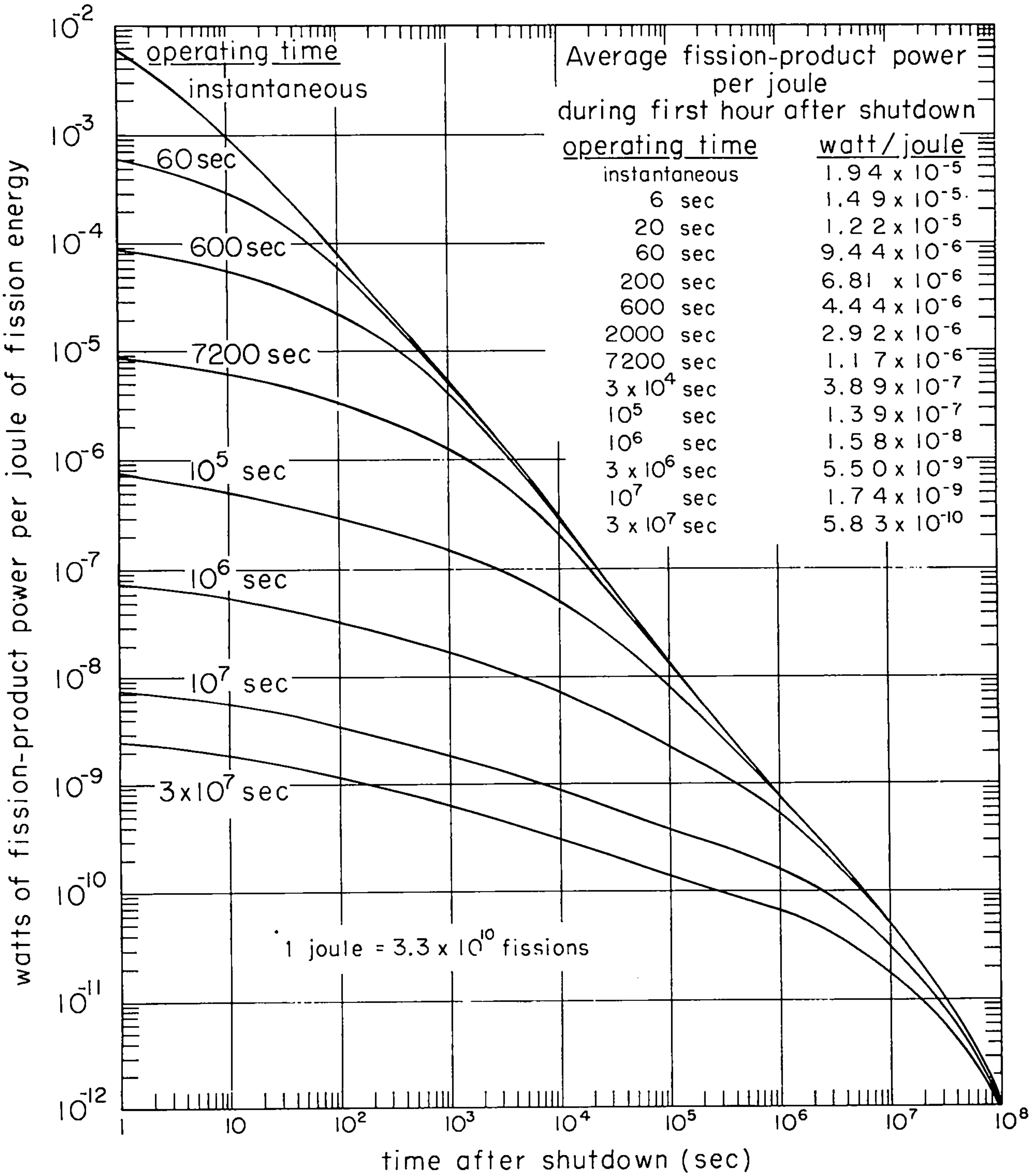


*Fig. 28.*
*Fission-product power.*

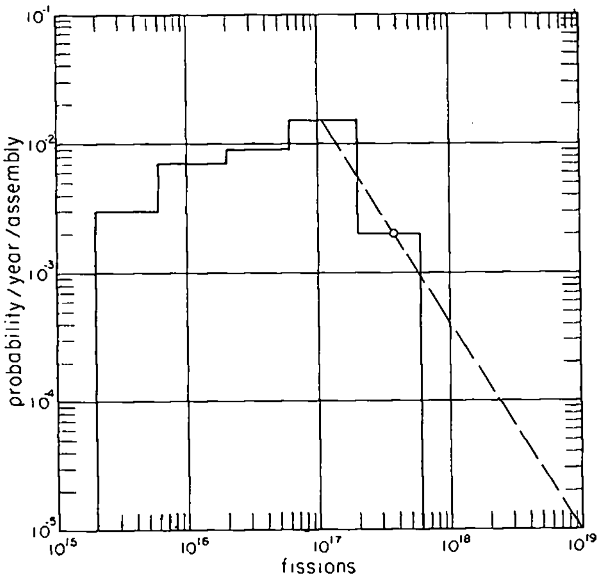


*Fig. 29.*
*Accidental prompt bursts with critical assemblies.*

accidental prompt bursts against ranges of fission yield.* (Accidents that predated current facilities are included.) The ordinate of the graph is scaled according to our estimate that total experience exceeds 500 assembly-years (tallied over the active life of each assembly).

Before proceeding, it should be noted that precise conclusions cannot be expected from the accident statistics, because there are so few high-yield incidents, and because of the practice of avoiding causes of past accidents (this effect tends to make probability estimates larger than they should be). As we shall see, however, precise conclusions are not required to tell how we stand with regard to safety.

If the dashed line on the graph represents a plausible extrapolation (such a form is usually assumed), we conclude that the probability of an accidental prompt burst yielding $3 \times 10^{18}$ fissions is less than $10^{-4}$/year/assembly. For small assemblies such as Godiva, a burst of this size might damage the Kiva. Even severe losses in the range of hundreds of thousands of dollars would combine with the indicated probability of occurrence to represent a risk of $10 to $100 per year. This risk would still be a small fraction of the value of operation, even if our conclusions were in error by an order of magnitude.

Instead of including the above cumbersome argument in the introduction of our Operating Limits, we felt that it should mean almost as much to point out the significant margin between the largest accidental prompt burst which has ever occurred in a critical facility and the protective capability of our facility.

Now, what about the MCA? Relative to a power reactor with its specific fission-product inventory, we are at a disadvantage in finding a source term for estimating the MCA. The indisputable limit, fissioning of a few percent of the atoms present ($\sim 10^{20}$ fissions per gram of fissile material), is too large to help us. Because of various conceivable mechanisms, we cannot generally claim a cutoff below such a limit without accepting a probability of occurrence that is not zero. As soon as a probability is associated with the MCA, we know of only two alternatives: either a general argument based on experience (like our discussion of the accident frequency distribution), or a time-consuming game with arbitrary rules.

The excuse for emphasis on the MCA in power-reactor safety is lack of adequate experience. There is no such excuse for critical assemblies with fission-product inventories that are minute by comparison. Our safety considerations need not remain hypothetical when there is a generous 500 assembly-years of experience to provide practical guidance.

**Pajarito Accident Experience**

The general review of accident experience which led to crude statistical conclusions of the preceding section may be broken down specifically for the Los Alamos remote-control facility. The eight accidental prompt-critical excursions* at this facility are identified in the Table. In addition to the usual total yield, fission density (per liter enriched uranium) is included because of its closer relationship to damage.

The only personnel exposures were incurred upon Kiva reentry and were within acceptable limits. Damage of any value resulted only from the two Lady Godiva incidents that involved prompt-burst operation. Property risk associated with this mode of operation is known to be greater than for usual critical experiments.

After the first of these incidents, the cost of returning Lady Godiva to operable condition was about $600. Direct cost of $2,400 reported for the other incident includes the estimated loss of U(93) as a result of oxidation, as well as cleanup labor, loss of electronic gear too contaminated for service, and damage to the Lady Godiva framework. When a proper burst machine, Godiva II, became available, the forced retirement of Lady Godiva was considered a benefit instead of loss. Although indirect costs such as investigation and reporting also have beneficial aspects, part of them, say $200 for each of the eight incidents, probably should be added to the direct costs.

The resulting $4,600 total is distributed over 21

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*Three sluggish power excursions in very large low-enrichment or natural uranium assemblies are not included because of their typically nonviolent nature. In these cases, prompt criticality probably was not exceeded.

*The present program of planned excursions with Godiva IV follows about 1000 prompt bursts each with the original Lady Godiva and Godiva II.

ACCIDENTAL EXCURSIONS AT PAJARITO SITE
(after W. R. Stratton, Ref. 1.)

| Date | Assembly | Total Fissions | Fission Density (per liter U) | Damage |
|---|---|---|---|---|
| Feb. 1951 | Aquarium, two U(93) cylinders in water | $1.0 \times 10^{17}$ | $3.0 \times 10^{16}$ | Slight oxidation |
| April 1952 | Jemima, bare stack of U(93) plates | $1.5 \times 10^{16}$ | $0.3 \times 10^{16}$ | None |
| Feb. 1954 | Lady Godiva, burst-mode operation | $5.6 \times 10^{16}$ | $2.0 \times 10^{16}$ | Slight warping of U(93) pieces |
| July 1956 | Honeycomb, U(93) foils in graphite | $3.2 \times 10^{16}$ | $1.0 \times 10^{16}$ | None |
| Feb. 1957 | Lady Godiva, burst-mode operation | $1.2 \times 10^{17}$ | $4.1 \times 10^{16}$ | Warping, oxidation, center near melting |
| June 1960 | Planet weapon study, reflected U(93) cylinder | $6 \times 10^{16}$ | $2.3 \times 10^{16}$ | Trivial |
| Dec. 1962 | Kiwi Zepo, U(93) foil and loaded graphite fuel | $3 \times 10^{16}$ | $0.3 \times 10^{16}$ | None |
| May 1967 | Pewee Zepo, fuel U(93) beads in graphite | $4.1 \times 10^{16}$ | $0.5 \times 10^{16}$ | None |

years of operation, an estimated 60,000-70,000 individual operations (startups), or, in the terms used in the preceding section, about 134 assembly-years. The indicated risk ∿ $220 per year, although on the high side of the range suggested earlier, represents about 0.02% of the annual value of operation.

It had been speculated that the Pajarito incidents from 1951 through 1957 might have been influenced by a strong feeling of urgency that held over from the early weapons program. As part of an attempt to moderate this feeling and to discourage slapdash operations, the N-2 Nuclear Safety Committee was established in 1959 and given the functions mentioned before. Although there was little evidence of resulting improvement through the early 1960's, the record of only one incident within the last six years seems noteworthy.

## Conclusions

We submit that safety provisions for the Los Alamos Critical-Assembly Facility are commensurate with the radiation hazard which exists; in other words, we conclude that experience-based protective features provide a favorable balance of risk against benefit. There has been no significant exposure of persons, and the indicated property risk (including some incidental costs) is about 0.02% of the annual value of operation.

Although the controls of hazard outlined in this report are considerably more numerous and stringent than corresponding practices for conventional industrial safety, they allow reasonably convenient and flexible operation and are generally supported by the members of Group N-2. Thus, they do not invite deviation.

The radiation protective capability of the facility exceeds the requirements based on abundant experience by about an order of magnitude, supporting the contention that straightforward experience-based controls are appropriate. Small fission-product inventory* eliminates the concern about public disaster which characterizes power reactors, whether the presumption is self-failure or escalation of a natural disaster that might arise from severe wind, flood, earthquake, or fire.

## References


1. W. R. Stratton, "A Review of Criticality Accidents," USAEC Report LA-3611, Los Alamos Scientific Laboratory, 1967.
2. P. G. Koontz, J. D. Orndoff, and H. C. Paxton, "Operating Procedures for the Pajarito Site Critical-Assembly Facility," USAEC Report LA-4037-SOP, Los Alamos Scientific Laboratory, 1968; also W. U. Geer, P. G. Koontz, J. D. Orndoff, and H. C. Paxton, "Hazards Evaluation for the Los Alamos Critical Assembly Facility," USAEC Report LAMS-2698, Los Alamos Scientific Laboratory, 1962.
3. U. S. Atomic Energy Commission, "Safety of AEC-Owned Reactors," AEC Manual, Chapter 8401.
4. N. E. Bradbury, "Nuclear Criticality Safety Standards," Director's Office Memorandum Number 10, Revision 2, June 15, 1962; Revision 3, June 18, 1962.


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*Note that $3 \times 10^{18}$ fissions, with which a probability of $10^{-4}$/year/assembly had been associated, is the number of fissions produced by a 1000 MWe power reactor in 0.03 sec.

# APPENDIX A

N-2-8276 April 10, 1969

EXPERIMENTAL PLAN NO. 170

STATIC CRITICAL EXPERIMENT FOR THE KINGLET ASSEMBLY

| | | |
|---|---|---|
| OPERATIONAL LIMIT: | Stage 1: | multiplication $\leq$ 100. |
| | Stage 2: | delayed critical operation with positive periods $\geq$ 10 seconds. |
| Assembly Machine: | Comet in Kiva 2 | |
| Required Personnel: | two | |
| Expected Starting Date: | May 1, 1969 | |

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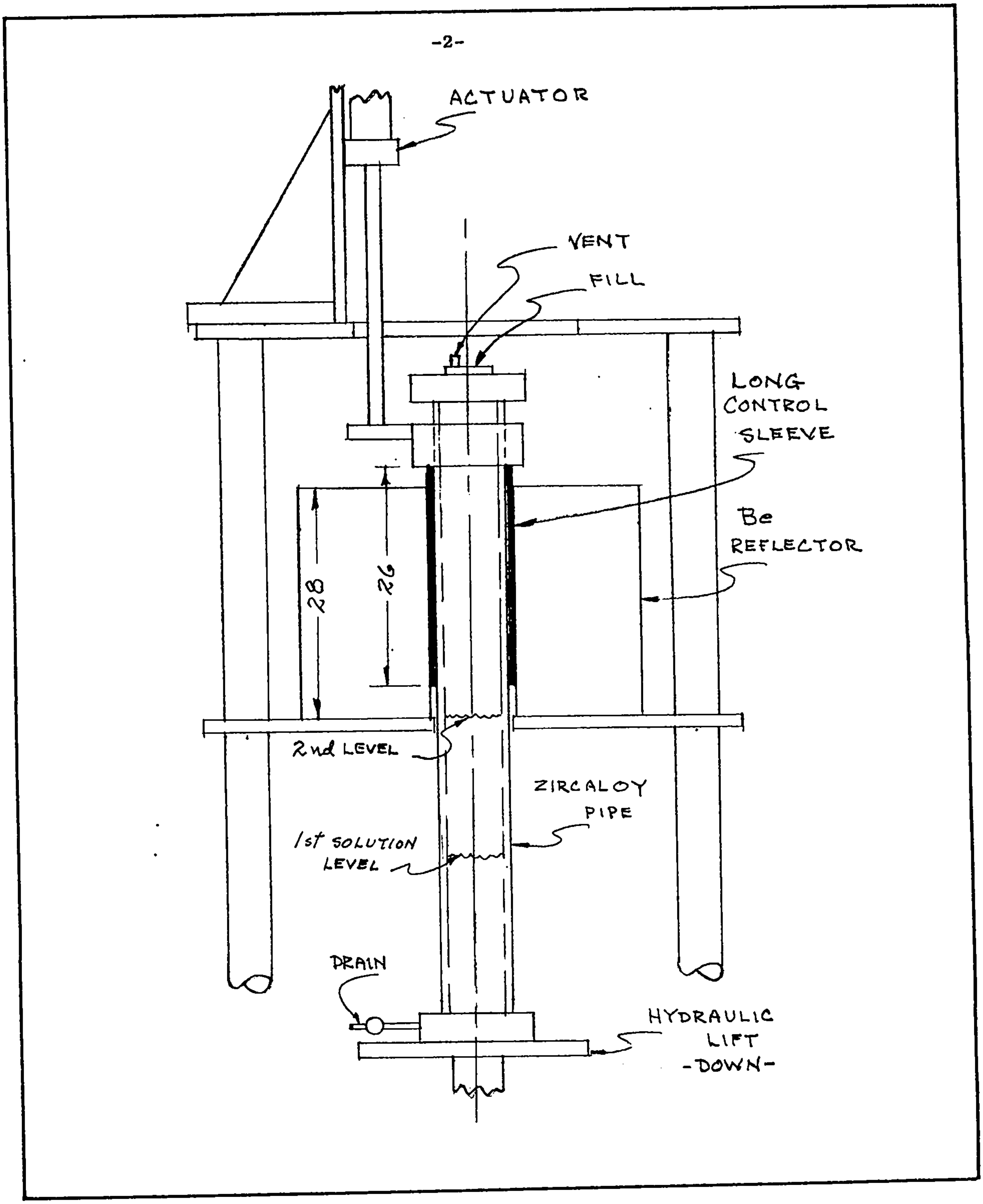
<u>Purpose</u>. To establish criticality conditions of liquid fuel ($^{235}U$ sulfate solution) contained in beryllium-reflected Zircaloy pipe to be used in the dynamic experiment (KINGLET) for the KING reactor concept.

<u>Active Material</u>. Initial fuel will be 12 liters of sulfate solution at 75 grams per liter $^{235}U$. The expected composition is 0.3188 $\underline{M}$ $UO_2SO_4$ + 0.50 $\underline{M}$ $H_2SO_4$ + 0.05 $\underline{M}$ $Fe_2(SO_4)$ + .01 $\underline{M}$ $CuSO_4$. As the experiment progresses, it may become necessary to modify the $^{235}U$ concentration. This solution will be provided by CMB-8 and stored in a ~5.5-in.-diam container known as "rocket".

<u>Assembly Description</u>. The fuel solution will be contained in a 5-in.-diam, 72-in.-long Zircaloy pipe as shown in Figure 1. The pipe is supported on the hydraulic lift of Comet. A near-cylindrical beryllium reflector with a radial thickness of ~12 in. and height 20 in. surrounds the pipe. The reflector is fabricated from Be blocks bolted together to form a solid reflector with an axial hole to accommodate the fuel pipe and a reactivity control shim surrounding it. The shim is a longitudinally split sleeve of stainless steel with ~30 mils Cd plated on its outer surface. Vertical motion of this control is provided by a linear hydraulic servo actuator mounted on top as shown. Remote position indicators for both shim and lift are located in the control room.


-2-
ACTUATOR
VENT
FILL
LONG
CONTROL
SLEEVE
Be
REFLECTOR
28
26
2nd LEVEL
ZIRCALOY
PIPE
1st SOLUTION
LEVEL
DRAIN
HYDRAULIC
LIFT
-DOWN-

In this experiment the fuel level will be no more than needed to extend above the upper reflector surface when the pipe or core is raised by the lift. Calculations indicate that reactivity is reduced by ~40% Δk by dropping the core below the reflector. A reduction of nearly that amount is expected when the 26-in.-long Cd shim is positioned in the reflector with the lift up.

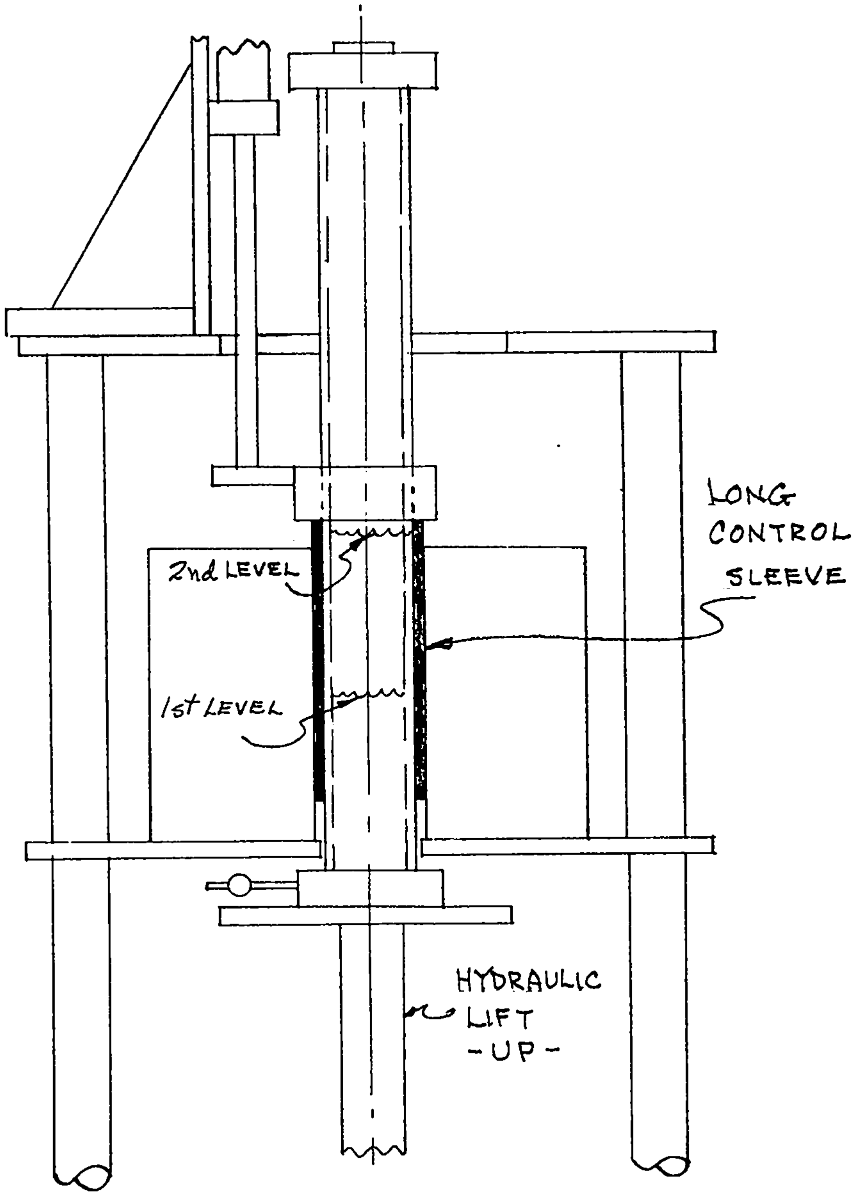
Procedure.

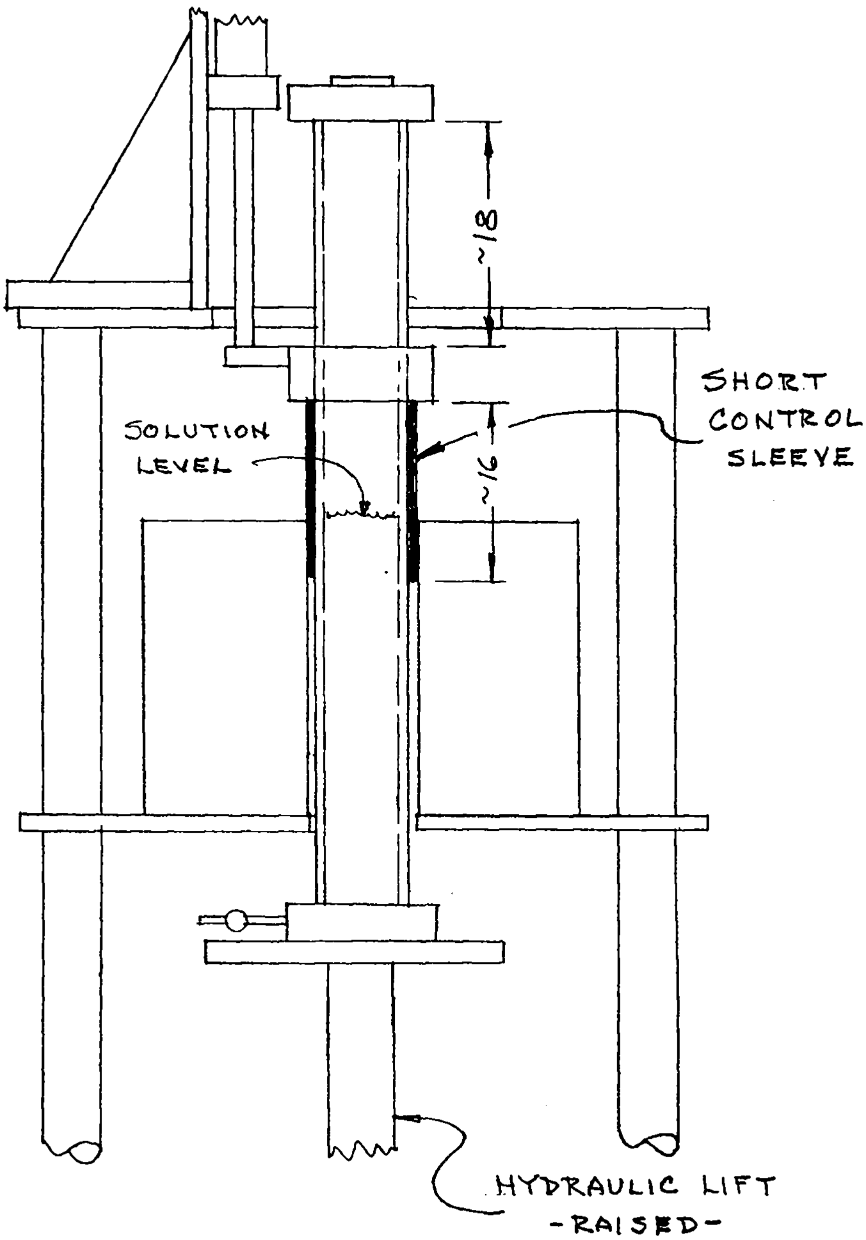
Stage 1: For this series of measurements, the length of the shim will be 26 in. With the lift down, the fuel solution will be poured into the pipe by adding ~one liter at a time through an orifice at the top. A neutron source will be located inside the pipe during this procedure, and neutron multiplication monitored by $BF_3$ counters placed around the pipe. When the level reaches ~16 in., filling will stop. With the control shim in the down position (See Figs. 1 and 2), the lift will be raised by remote control and neutron multiplication observed as the fuel enters stepwise into the reflector. For these measurements, detectors will be relocated at the reflector surface. Next the shim will be raised in steps monitored by neutron multiplication. (Neutron multiplication will be determined using unmultiplied detector response from the same geometry but with water in place of fuel solution.)

Successive fuel additions, shown by preceding measurements to be within hand-stacking limits followed by remote measurements as above, will continue until extrapolation to criticality is reliable.

If necessary to change the fuel concentration, solution will be drained through a valve indicated in the drawings at the bottom of the pipe. Refueling will be accomplished in the same manner as for the first filling. Solutions will always be stored in "rockets" when not in the assembly.

Stage 2: Based upon results from Stage 1, the length and travel of the shim will be reduced, and the fuel level adjusted, such that release of either the shim or lift will provide adequate shutdown. See Fig. 3, which indicates the configuration that simulates conditions in Kinglet. This permits ~18 in. free lift travel for shutdown.


LONG
CONTROL
SLEEVE
2nd LEVEL
1st LEVEL
HYDRAULIC
LIFT
-UP-


~18
SHORT CONTROL SLEEVE
SOLUTION LEVEL
~16
HYDRAULIC LIFT -RAISED-

With two independent means for shutdown established, the shim will be raised slowly toward the extrapolated critical position. After criticality is attained, the reactivity effectiveness of components at various positions will be measured. In particular, the control shim will be calibrated over its permissible supercritical travel. Such calibrations will be accomplished by positive period measurement with periods > 10 seconds.

A possible modification, in addition to change of solution concentration, may arise from the need to test a control cylinder with different materials than specified above. If any such modification is not known to decrease the reactivity of earlier configurations, Stage 1 measurements will be repeated before entering Stage 2.

Safety Precautions. Although calculations predict a neutron multiplication less than ten for the entire core filled with fuel if the control shim is in its shutdown position, no more than a liter of fuel is allowed to be present at any time within the reflector during the manual filling operation. By pouring through a funnel or orifice, only a narrow stream of fuel is permitted.

The Zircaloy pipe will be fitted with a vent in the top cap to prevent overstressing from an accidental pressure buildup.

It is important to avoid any manual operation that would raise solution into the reflector. This will be prevented, except by remote control, because the solution pipe will be anchored to the lift. The only occasion for raising the pipe in the presence of personnel would be for replacement of the split shim. In this event, the solution will be drained beforehand.

Central-source multiplication, which is used as a safety index, is usually distorted for solution measurements because neutron moderation and absorption effects on "unmultiplied" and "multiplied" responses generally differ. In this case, however, ORNL flux measurements in the 5-in.-diam HFIR island indicate that such distortion will be small.

(see signatures on next page)

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# STANDARD

## ANS-STD. 1-1967

## A CODE OF GOOD PRACTICES FOR THE PERFORMANCE OF CRITICAL EXPERIMENTS

### 1. Scope

This Code of Good Practices is for guidance in the performance of critical experiments. It is intended for catholic applicability and is formulated in general terms in order to avoid imposing undue limitations on specific local experiment practices.

### 2. Definitions

2.1 Limitations.

The definitions given below should not be regarded as encyclopedic. Other terms whose definitions are accepted by usage and by standardization in the nuclear field are not included.

2.2 Glossary of Terms.

2.2.1 Shall, Should, and May.

The word "shall" is used to denote a requirement, the word "should" to denote a recommendation, and the word "may" to denote permission, neither a requirement nor a recommendation. In order to conform with this standard all operations shall be performed in accordance with its requirements, but not necessarily with its recommendations.

2.2.2 Critical Experiment (Experiment).

An experiment or series of experiments performed with fissionable material which may be at or near the critical state.

2.2.3 Critical Assembly (Assembly).

A device or physical system, containing fissionable material, with which critical experiments are performed.

2.2.4 Nuclear Excursion.

The liberation of an undesirable quantity of energy as the result of a criticality accident.

2.2.5 Assembly Area.

A region in the vicinity of a critical assembly where there would be inadequate personnel protection in the event of a nuclear excursion.

2.2.6 Neutron Source.

Any material, combination of materials, or device emitting neutrons, including materials undergoing fission.

2.2.7 Safety Device.

A mechanism designed to reduce the reactivity of a critical assembly.

2.2.8 Scram.

A rapid reduction of reactivity to subcriticality.

### 3. Administrative Practices

3.1

Responsibility for the safety of a critical experiment shall be assigned unambiguously by management.

3.2

Each new experimental program shall be reviewed in a manner approved by management with particular emphasis on safety features.

3.3

Before an experiment begins, an experiment plan shall be reviewed by all who are expected to take part in the experiment.

3.4

At least two persons shall be present while a critical experiment is being performed.

3.5

Manual operations with fissionable material, such as storage, transfer, and nonremote addition of reactivity to an assembly, shall be in accordance with USA Safety Standard for Operations with Fissionable Materials Outside Reactors, USA N6.1-1964.

3.6

Additions of reactivity beyond those permitted by 3.5 shall be made by remote operation. Such additions of reactivity shall be reversible and continuously adjustable except when the resulting assembly will be subcritical or supercritical by a known amount.

3.7

No person shall enter an assembly area during the performance of a critical experiment without the approval of the person responsible for safety. During an addition of reactivity that requires remote operation, personnel shall be protected from unacceptable consequences of a nuclear excursion.

3.8

If anyone participating in the operation of an experiment expresses doubt of the safety of a particular action or step, the experiment shall be suspended until the doubt is resolved.

3.9

A record of the status and operation of the assembly, with particular reference to its safety features, shall be maintained.

3.10

An emergency plan approved by management shall be in effect.

3.11

Adequate personnel radiation monitoring shall be provided.

## 4. Equipment Criteria

4.1

There shall be safeguards against operation of critical assembly equipment by unauthorized personnel.

4.2

Communication shall exist between personnel at the control console and those who may be at the critical assembly.

4.3

A signal audible to personnel within the assembly area shall provide an indication of the neutron level during adjustments affecting reactivity.

4.4

A source of neutrons sufficient to produce a meaningful indication of multiplication shall be present during any approach to criticality, except that special experiments in which reactivity effects are known may be performed without a source present.

4.5

Each assembly shall be provided with a safety device that is actuated automatically at a preset radiation level and can be actuated manually. This safety device shall be capable of removing reactivity more rapidly than it can be added by any normal operation.

4.6

At least two radiation monitors shall be capable of independently initiating a scram of the assembly at a preset radiation level.

4.7

Loss of actuating power to any safety device shall produce a scram.

4.8

A scram signal shall prevent further significant increase of reactivity.

4.9

During critical experiments there shall be at least two instruments providing indication of the neutron level within the assembly. These may be the same as those required by paragraph 4.6.

4.10

The status of any variable for fine control of reactivity shall be continuously displayed at the control console. The limiting conditions or positions of safety devices shall also be displayed.

## 5. Operational Practices

5.1

The satisfactory performance of newly installed or significantly altered control equipment or safety devices shall be established before achieving initial criticality.

5.2

The proper functioning of the required number of safety devices shall be established prior to starting operations each day that an experiment is to be initiated. In the course of these tests or early in each day's operation, the response of each required detector system to a change in neutron or gamma-ray level shall be noted.

5.3

Additions of reactivity requiring remote operation shall be guided by neutron detector response. During an initial approach to criticality, a reactivity addition shall not be made unless the effects of any preceding additions have been observed and understood.

5.4

Any unexpected behavior of the assembly or its associated equipment should be evaluated promptly.

5.5

Additions of reactivity requiring remote operation shall not be made simultaneously by two or more persons, unless the effect of such additions has been measured.

5.6

Additions of reactivity requiring remote operation shall not be made simultaneously by two or more distinct methods (e.g., by rod motion and by water addition), unless the effect of such additions has been measured.

# APPENDIX C

3/28/66

PAJARITO PLAN FOR RADIATION EMERGENCY

The only true radiation emergency that is foreseen at Pajarito would result from an accidental excursion during handling of fissile material at a Kiva*. Such an event would be indicated as follows.

1. Falling material, abnormal counter response, shock effects, or blue glow will be apparent to those involved.

2. The radiation alarm in the H-1 office, Rm 117 Bldg 30, will alert personnel outside the Kiva area.

Action to be observed

1. Necessary rescue operations by persons at hand will be guided by a high-level radiation detector located near the Kiva entrance.

2. The Kiva area will be evacuated promptly, and persons involved will report to an H-1 representative.

3. The senior H-1 representative at the site (or the H-1 Group Leader) will advise the N-2 Group Leader about further action.

4. The N-Division Leader and the LASL Director will be notified promptly.

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*An excursion during remote operation constitutes no immediate radiation hazard, and action is covered adequately by LAMS-2698, HAZARDS EVALUATION FOR THE LOS ALAMOS CRITICAL ASSEMBLY FACILITY (April 1962), p 57. Except when in Kivas, fissile materials are in containers designed for safe handling.

H. C. Paxton

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P. G. Koontz

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