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# Safety Analysis of the Los Alamos Critical Experiments Facility:

## Burst Operation of Skua

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# CONTENTS

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# SAFETY ANALYSIS OF THE LOS ALAMOS CRITICAL EXPERIMENTS FACILITY: BURST OPERATION OF SKUA

by

J. D. Orndoff, H. C. Paxton, and T. F. Wimett

## ABSTRACT

This report provides detailed consideration of the Skua burst assembly, thereby supplementing the facility safety analysis report covering the operation of other critical assemblies at Los Alamos. As with these assemblies the small fission-product inventory, ambient pressure, and moderate temperatures in Skua are amenable to straightforward measures to ensure the protection of the public.

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## 1. INTRODUCTION AND GENERAL DESCRIPTION OF FACILITY

### 1.1. Introduction

Los Alamos critical assemblies are presently covered by a facility Safety Analysis Report (SAR), LA-6206, Vol. I and II.[1] A separate SAR (LA-4797-MS)[2] for a recently discontinued assembly, "Kinglet," is incorporated by reference. The facility report is augmented by Experimental Plans which detail the special features of each assembly and present discussions of the safety of planned experiments. Sequential Experimental Plans are used as assemblies are modified and experiments are developed. In this manner the SAR is effectively maintained current without a great quantity of repetitive documentation.

This addendum is presented because Skua has certain features that distinguish it from previous systems, and operations in the burst mode are somewhat more sensitive (as in Godiva) than the normal experiments near delayed criticality. In this application an annular metal assembly, with a polyethylene or zirconium hydride flux trap inside, is intended for fast burst operation. As in the case of our previous assemblies, with Skua we will approach any unproven operations in a stepwise fashion, and a series of Experimental Plans, each of which takes advantage of previous experience, will add to the nuclear safety documentation. Preliminary critical experiments have been completed so that precise information is already at hand concerning Skua's neutronic characteristics.

The original concept of this burst reactor grew out of work in Group J-10 involving a program to study atmospheric phenomena. The reactor was to be used for rapid vaporization of 100 g of U-235 in a highly oxidizing atmosphere in order to study the infrared signature of uranium. Part of the plan was to carry the reactor on a re-entry vehicle and perform the experiment at an altitude of about 75 km. This plan has been temporarily abandoned but the technique will be pursued in the laboratory. For the present purposes the reactor may be employed to vaporize various compounds which are enriched in U-235.

## 1.2. Facility Description

The facility insofar as it relates to Skua operation is adequately described in LA-6206. Skua is located in Kiva 3 along with Godiva IV and PARKA. Kiva 3 differs from the other two Kivas in that 0.46-m-thick concrete walls provide about an order-of-magnitude radiation shielding. This shielding more than compensates for the shorter distance between Kiva 3 and occupied buildings. This shielding also permits access to the outside of the Kiva shortly after high level operation.

## 2. SITE CHARACTERISTICS

Site characteristics are presented in LA-6206. The impact of Skua on the site characteristics is essentially the same as the other critical assemblies at Pajarito.

## 3. REACTOR

### 3.1. Description

Skua consists of a stack of U(93) rings reflected by copper on the outer radius and at the ends. An annular hydrogenous flux trap inside the fuel rings is used to generate an intense thermal neutron flux in an irradiation cavity at the center. The flux trap may use either zirconium hydride or polyethylene to moderate the high energy fission neutrons.

The Skua assembly and actuating machinery are mounted on 64-mm-thick aluminum shelves supported by four posts of 127-mm-diam hollow steel pipe. Three safety blocks consist of 76-mm-thick copper reflector segments which are driven radially by hydraulic cylinders. Three rotary copper (or aluminum) reflector cylinders act as control elements, one of which is driven pneumatically to act as a burst drum; the other two are rotated by stepping motors for fine-increment control.

The machine power circuit, hydraulic system, and scram chain logic are typical of the other Pajarito assemblies as described in the site SAR.

### 3.2. Reactor Design

Figure 3.1 is a photograph of the Skua critical assembly machine installed in Kiva 3. Vertical and horizontal cross-sectional views are shown in Fig. 3.2. The fuel ring composition is the same U-Mo(1.5 wt %) alloy that has been used

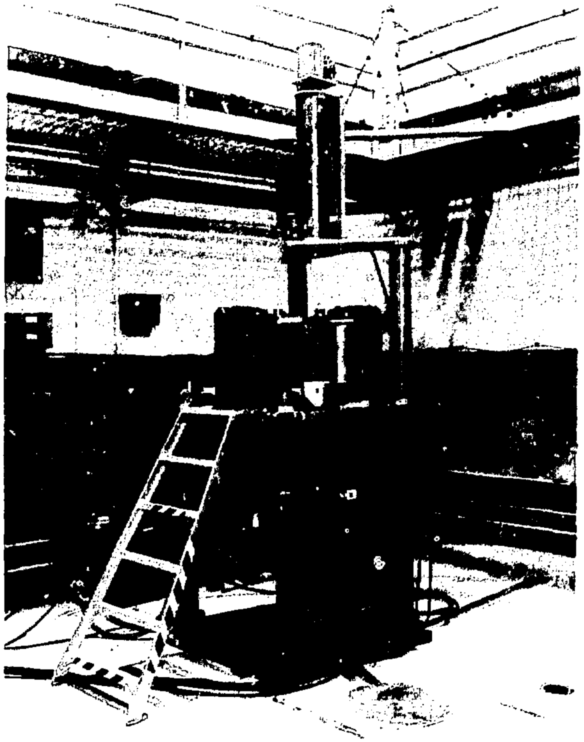

Fig. 3.1. Skua in Kiva 3.

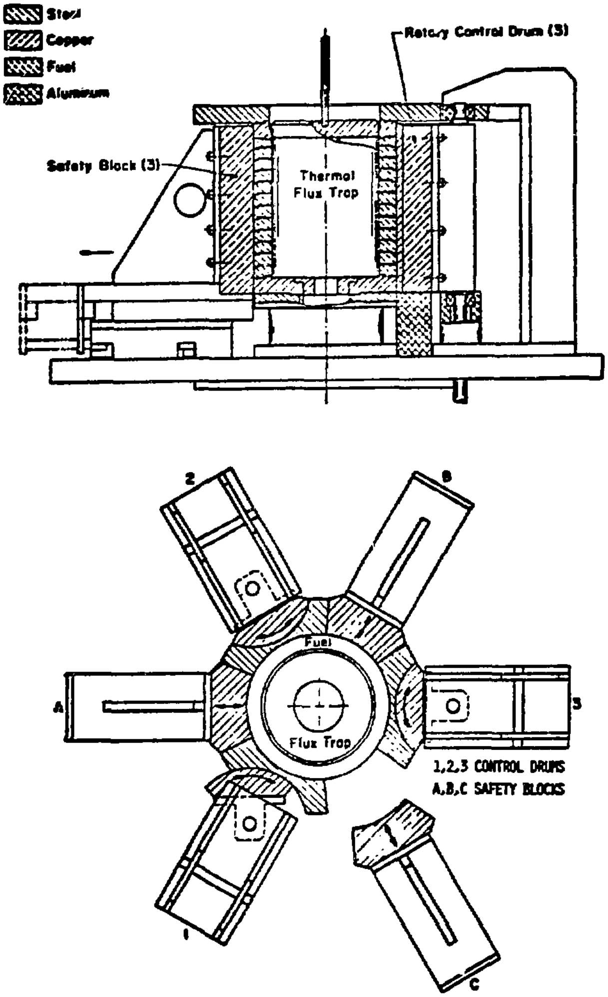

Fig. 3.2. Vertical and horizontal cross-sectional view of Skua.

previously in Godiva IV. Twelve fuel rings are available. These were 0.318-m-o.d., 38 mm in annular thickness, and 31 mm axial thickness in the initial configuration. Detail of the flux trap composition is shown in Fig. 3.3. The cadmium, boral (boron-aluminum), and uranium-loaded graphite sleeves, indicated in the diagram, are designed to absorb low energy neutrons from the flux trap in order to avoid excessive fission peaking in the uranium rings. The entire flux trap is encased in an aluminum can. A cylindrical irradiation cavity at the flux trap center is 76 mm in diameter. Both zirconium hydride and polyethylene ($CH_2$) components are available for use in the flux trap as moderator.

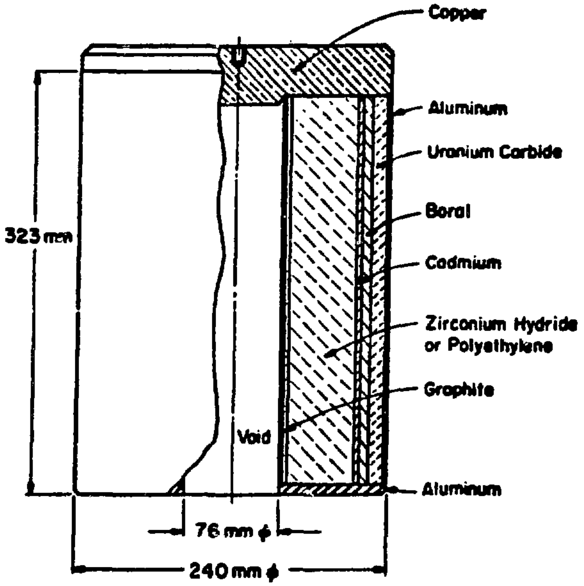

Fig. 3.3. Schematic of Skua Flux Trap.

## 3.3. Nuclear Design

Early calculations on Skua assumed a reflector of beryllium, since beryllium combines light weight with good nuclear properties. Later, beryllium was rejected in favor of copper in order to eliminate preinitiation of bursts by ($\gamma$ ,n) neutrons in beryllium and to avoid long neutron life-times associated with neutron slowing down time in the reflector. Copper appears to be the best reflector material, per unit volume, of various candidate metals. The reflector functions primarily to supply a means of control. In addition it plays a useful role in isolating the reactor from the reactivity effects of external objects. Quenching in fast burst reactors results principally from the reactivity change associated with expansion and consequent density reduction of fuel as temperature increases. Reflection reduces the quenching action so it is important that the reflector not be too effective. As quenching is reduced, burst width is increased for a fixed energy release.

Flux traps utilizing hydrogen as a moderator may introduce large reactivity contributions, either positive or negative, depending upon the amount of moderator used. The most effective flux trap in Skua has been found to introduce many dollars worth of poison so that it is not simple to design the assembly for use either with or without the flux trap in place. This dual mode of operation is an attractive option but the neutronic behavior is considerably different for the two cases.

Sizes of the uranium rings that were fabricated for Skua were determined by transport calculations of the system. The annular thickness was fixed conservatively so that the final shimming in reactivity can be accomplished by remachining the inside or outside of the rings.

Initial critical operations have confirmed the Skua design. The Experimental Plan for the initial assembly and delayed critical operation of Skua is attached as an Appendix. We attained criticality with a stack of ten of the twelve possible fuel rings. We then replaced the eighth fuel ring with a depleted uranium substitute and were able to complete the fuel stack and obtain a critical configuration with one control drum at 35 (where 0 is "in"). We will adjust reactivity to the desired level by machining material from the fuel rings until the depleted uranium ring can be replaced by a U(93) ring.

Reactivity worths of the various copper reflector controls were then measured and rough confirmation of predictions by TWOTRAN calculations resulted. Total shutdown by the three safety blocks is 9.9$, which is well in excess of the 5$ required by "Technical Specifications for the Pajarito Site Critical Experiments Facility."[3] The rotary vernier control drum worth curve, plotted in Fig. 3.4, was obtained by adding reactivity with the drum being measured and then subsequently removing reactivity with the other identical control, so the resulting curve may be influenced by interaction between the drums.

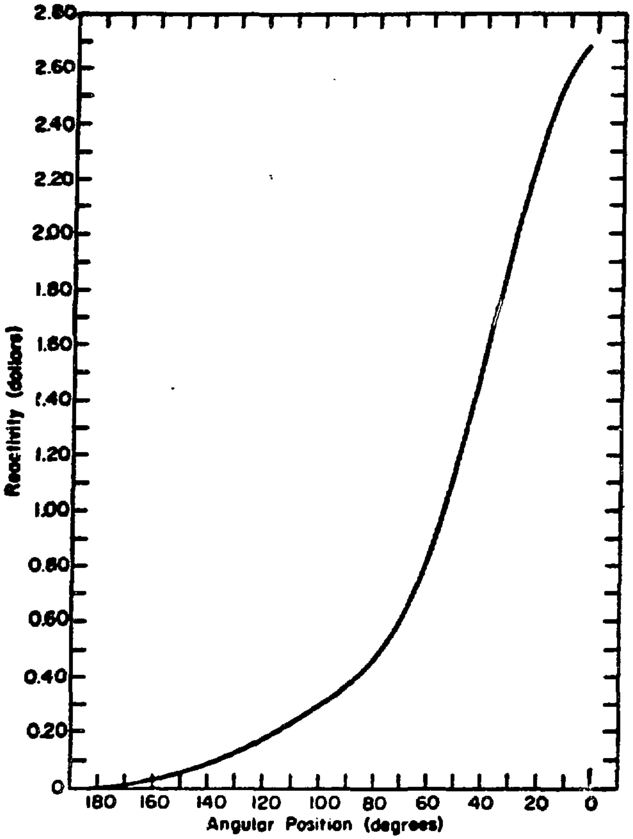

Fig. 3.4. Control drum worth curve for Skua.

We made criticality measurements with the central flux trap in and out for both zirconium hydride and polyethylene moderator components. These were identical in size but hydrogen density is higher in the polyethylene. The zirconium hydride system acted as a poison of 2$ in reactivity, while with polyethylene the flux trap acted as a poison of 8$.

TWOTRAN calculations were run to estimate the neutron lifetime in the Skua geometry with a zirconium hydride flux trap. The computed value for the prompt neutron lifetime is 12.8 x $10^{-8}$ seconds obtained by evaluating dk/d . This factor of twenty longer than for Godiva IV leads to correspondingly longer prompt burst widths in Skua. The expected reduction in quenching due to the Skua reflector will broaden the bursts even more. On the basis of present knowledge we expect the radiation pulse widths from the most energetic Skua bursts to be about a millisecond wide.

## 3.4. Thermal and Hydraulic Design

No special cooling following bursts is planned for Skua other than external fans even though the fuel rings will reach temperatures as high as 500 C during the most intense bursts.

As is the case with Godiva, the burst repetition rate will be limited by cooldown time. Air flow directed to the accessible regions of Skua is relatively ineffective in reducing the temperature of the fuel. Possible energy depositions for an intense burst have been computed for a Skua geometry along with temperatures throughout the assembly and are illustrated graphically in Fig. 3.5. The 110°C temperature increase shown for boral will be considerably reduced in the present design which employs a cadmium barrier inside the boral. The central irradiated uranium foil thickness was 0.3 mm for the calculation.

Temperature rise in the fuel rings provides a fundamental measurement of burst yield in Skua. Knowledge of the fission distribution in the fuel allows the yield to be related to a single thermocouple reading, as has been done with Godiva. One or more chromel-alumel thermocouples located in the fuel rings will provide the basic yield measurement for Skua bursts. This instrumentation has been well checked out in Godiva. The temperature measurement is important in obtaining reproducible yields since any temperature change between the time that reactivity is checked and the time of the burst must be taken into account. These changes are not of a magnitude, however, to constitute a significant hazard.

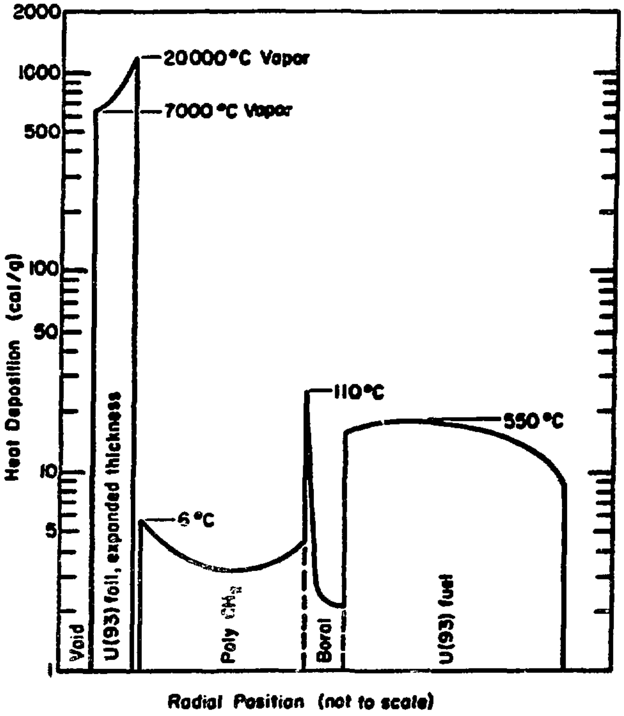

Fig. 3.5. Computed head deposition and temperature rises in Skua.

## 3.5. Integrity of Reactor Assembly

Discussion of this subject in LA-6206 applies to Skua as well. Strengths of materials is in general not a problem with our small critical assemblies, since the supports and structures are greatly over-designed for strength. The most critical component in Skua is the burst drum which must be rotated rapidly into its most reactive position. It is important that the final position of the burst drum in initiating a burst be identical to that during the preceding reactivity check. A mechanism is being designed to move the burst drum into position accurately, with the requisite speed, and without oscillation. Specific checks of the proper operation of the burst drum will be carried out prior to burst operation.

## 3.6. Reactor Vessel and Appurtenances

No reactor vessel as such is used with Skua. A container to confine oxidized uranium dust has been installed on Godiva but this has only been essential when the intermetallic aluminum coating applied to the surface is defective. With properly coated fuel rings, dispersal of oxide should not be a problem. If necessary an enclosure to confine dust will be used.

## 3.7. Components and Subsystem Design

The general discussion of this subject in LA-6206 is applicable to Skua. The machine power circuit logic provides power to the Skua assembly by means of a relay at the Kiva as shown in Fig. 3-3(A) in the above reference.

The hydraulic power package energizing the Skua actuators is a standard unit of a type used with other Pajarito assemblies. Three nitrogen gas accumulators are incorporated for pressure backup to assure that the system is fail-safe in case of hydraulic pump or power failure. These operate independently for each safety block.

### 3.8. Instrumentation Application

The standard Kiva instrumentation is utilized with Skua and is discussed in LA-6206. Specialized instrumentation used (a) to provide a signal for fast scram, (b) to measure the prompt period for a check on reactivity, and (c) to display the overall burst shape on an oscilloscope, is discussed in Sec. 5.

## 4. ENGINEERED SAFETY FEATURES

This subject is covered in LA-6206 and the discussion there is applicable to Skua.

## 5. INSTRUMENTATION AND CONTROLS

### 5.1. Introduction

The discussion of this subject in LA-6206 is directly applicable to Skua. In addition, for burst operation, there are specific instrumentation requirements which have been identified in Section 3.8. This instrumentation is identical to that used with Godiva for the same purpose and hence, has undergone extensive development and testing.

As with Godiva it is important to provide fast scram action to minimize the fissions occurring in Skua immediately following the burst. In the case of Godiva the fast scram is triggered automatically (in addition to electrically) by a "block bounce" phenomenon associated with rapid expansion of the fuel. We will trigger a fast scram in Skua at low radiation levels using a plastic scintillator-photomultiplier radiation detector. Because of the order-of-magnitude or so slower time scale for Skua, the scram action need not be as rapid as for Godiva. The design of Skua does not lend itself to the "block-bounce" type of fast scram boost.

Instrumentation is provided for routine measurements of the magnitude of the prompt period. This consists of a plastic scintillator-photomultiplier radiation detector and a timing circuit for measuring the rate of rise of the signal. The initial period prior to any significant generation of heat supplies a direct check of the reactivity setting for the burst, assuming that preinitiation has not occurred.

We will display the burst shape on an oscilloscope and photograph it for permanent record. The half width of the radiation spike is a measure of initial period, again assuming no preinitiation. Furthermore, the spike amplitude is a check of relative yield. A plastic scintillator-phototube combination serves as the detector for this burst shape display.

## 5.2. Reactor Trip System

The discussion of this subject in LA-6206 is applicable to Skua. In addition to the conventional reactor trip system discussed in LA-6206, the fast scram described in the preceding section is utilized to minimize the amount of radiation following a burst. The fast scram does not contribute to safety except as it supplies additional redundancy in scram initiation.

The Skua control logic, diagrammed in Fig. 5.1, illustrates the interaction between the control system, control interlocks, and the scram chain.

## 5.3. Engineered Safety Systems

Not applicable.

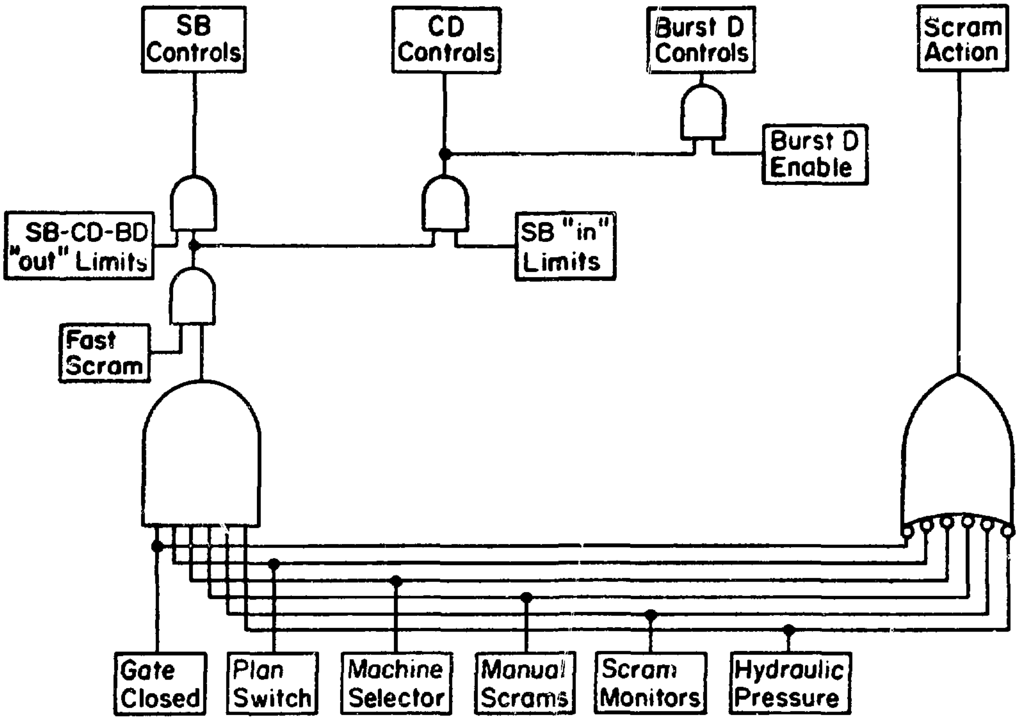

Fig. 5.4. Systems required for safe shutdown.

The discussion in LA-6206 is applicable. Independent accumulators on each of the safety blocks assure fail-safe shutdown in case of malfunction or power failure. The control drums provide some redundancy since they are adequate to shut the system down safely even if the safeties do not scram.

## 5.5. Safety-Related Display Instrumentation

The discussion in LA-6206 covers the application of this subject to Skua.

## 5.6. All Other Systems Required for Safety

The discussion in LA-6206 is applicable.

### 5.7. Control Systems

The control systems are described in Sec. 3.1. The general discussion of this topic in LA-6206 is applicable to Skua.

### 5.8. Power Systems

The discussion in LA-6206 is applicable.

## 6. AUXILIARY SYSTEMS

### 6.1. Fuel Storage and Handling

Due to the inaccessibility of the fuel rings in Skua we plan to store the material in place even if the assembly is not in use. Any extra fuel will be kept in the Kiva 3 vault.

### 6.2. Fire Protection System

The discussion in LA-6206 is applicable.

### 6.3. Communication System

The discussion in LA-6206 is applicable.

## 7. EXPERIMENTS: DESCRIPTION AND PURPOSE

The major experiment with Skua is that of bringing it up to the burst mode of operation and investigating its response for various pulse yields. As mentioned in Sec. 1.1, some experiments will vaporize uranium foils or compounds in the flux trap by means of the fission energy developed. The extremely high slow neutron flux available will stimulate many experiments directed at nuclear pumping of lasers and overpower failure of power reactor fuel elements. Other applications are associated with the nuclear weapons program. There may be some requirements to burst Skua without the flux trap present in order to generate a high flux of energetic neutrons rather than the degraded neutrons from the flux trap. If this operational mode should be required, its distinguishing safety features will be covered in a special Experimental Plan.

The procedures for approaching the prompt burst mode will be spelled out in an Experimental Plan. Generally, after the initial experiments, irradiation type investigations will be relatively routine; however, if any of these present new safety considerations, we will write Experimental Plans to describe their execution in accordance with the requirements of "Operating Procedures for the Pajarito Site Critical Assembly Facility."[4]

## 8. RADIOACTIVE WASTE MANAGEMENT

Other than direct radiation, no radioactivity associated with Skua bursts will be detectable outside the Kiva. Some minor contamination inside the building will result from oxidized uranium dust and fission fragment dispersal. This contamination is kept within tolerable limits by our routine housekeeping activities.

## 9. RADIATION PROTECTION

The discussion in LA-6206 is applicable to Skua.

## 10. PROCEDURES FOR BURST PRODUCTION

We have modeled the operation of Skua after that of Godiva which has proven to be reliable and effective over several years of burst production. These procedures are included because the exact steps involved in producing bursts must be specified before valid accident scenarios can be identified.

It is appropriate to have a burst drum reactivity increment somewhat over a dollar. One of the three control drums is the burst drum which is inserted rapidly to produce a burst. Another is the yield-adjustment drum which is used for setting the magnitude of the burst. The third drum, the delayed-critical drum, is adjusted to obtain the pre-burst critical check. The procedure for producing bursts is summarized as follows.

1. Criticality Check. With the burst drum fully inserted we adjust the delayed-critical drum until a stable critical condition is achieved. The yield-adjustment drum for this critical check is set at a value which has previously been calibrated to result in the desired yield. For example, if a 0.1$ superprompt critical burst is desired, the k for the yield-adjustment drum from its setting at critical to its setting during the burst (fully in) will be 1.10$.

2. Cooldown. We withdraw the burst drum to its out position and withdraw one or more safeties. We allow the neutron level to decay to its background value. This requires about twenty minutes. If the neutron level is too high, preinitiation will result while the burst configuration is being established.

3. Reactivity Adjustment. We run the yield adjustment drum to its fully in position. This will increase reactivity by an amount equal to the reactivity desired for the burst. At burst time (the next step) all other drums will be at their delayed critical settings. Since the delayed-critical drum is untouched following the criticality check and the remaining drums are all "in" at burst time, it is only the reproducibility of the "in" positions that governs the reproducibility of burst reactivity. The magnitude of the burst is determined by the position of the yield-adjustment drum at the delayed critical check.

4. Burst. We insert the burst drum to produce the burst. This drum must be capable of insertion in a fraction of a second in order to avoid preinitiation.

The advantage of the procedure established above is obvious. Other than an incorrect setting of the yield-adjustment drum for the delayed critical check, only the "in" position of any drum is capable of affecting the burst and any deviation from the normal "in" position will likely be in the direction of decreasing the yield. Various postulated accident sequences are presented in the succeeding sections.

## 11. ACCIDENT ANALYSIS

### 11.1. Hazards Summary

Calculations and measurements show that a fission yield of $10^{19}$ fissions in one of the Kivas is required to give a whole body dose of 3 rem at the exclusion area entrance for a normal critical operation. The "Kinglet Safety Analysis" (LA-4797-MS)[2] concludes that the release of all fission products from a 10 s run of 1.3 x $10^{18}$ fissions under the most adverse atmospheric conditions produces doses less than 5 rad to the whole body or 20 rad to the thyroid at 300 m. Based on these estimates the "Technical Specifications for the Pajarito Site Critical Experiments Facility" specifies a safety limit and an operating limit.[3] The operating limit is that fission integral which results in fission product power generation of 600 W when averaged over the first hour after shutdown. For a burst this would correspond to $10^{18}$ fissions. The safety limit corresponds to a Kiva operation that generates a total of $10^{19}$ fissions within one hour. From the practical point of view, no significant hazard exists until the site safety limit is exceeded. On the other hand a yield of $10^{18}$ fissions in a Godiva burst would destroy the assembly. In the case of Kinglet a yield greater than $10^{18}$ fissions would have been possible without damage. Clearly it is most important to avoid exceeding either the safety limit or the yield which will damage an assembly. In Skua the damage threshold corresponds to about 3 x $10^{17}$ fissions in a burst, and partial melting would occur with $10^{18}$ fissions.

## 11.2. Conceptual Accidents

One can generate various scenarios for Skua that would lead to inadvertant reactivity changes and hence, potentially, to excessive fission yields. These could result from operator error, assembly malfunction, or shifting of some Skua component or part of an experiment during operation. Certain of these hypothetical events can be ruled out on the basis of probability and others by procedural requirements. In any case it is appropriate to examine such occurrences in order to determine what measures are required to assure reliable operation and whether or not a significant hazard is inherent in Skua burst operation.

1. Operator Error. In this example the operator mis-sets the yield-adjustment drum during the pre-burst critical check. This type of error is not likely since previous experience would tend to alert the operator to any serious deviation in critical condition. We will use a graph of burst yield vs. yield-adjusting drum position to establish the proper setting for the desired yield. We will limit the reactivity available with this drum, hence the possible accident consequences will have an upper bound.

2. Equipment Malfunction. Equipment malfunctions that lead to an incorrect setting of the yield-adjustment drum would result in a corresponding error in the burst yield. We will

require that the yield-adjustment drum be equipped with two independent position indicating instrumentation systems, hence, an unambiguous incorrect setting would require two simultaneous failures. Furthermore, a significant error in the yield-adjustment drum setting would be reflected in anomalous delayed-critical check conditions and would indicate to the operator that something was not normal.

The "in" position of the burst drum and the yield-adjustment drum is fixed by positive stops. If these stops shift, the burst yield will be affected but in the direction of reduced magnitude.

Should one of the safety blocks stick during the pre-burst check and subsequently function properly when reinserted at burst time, a larger yield then planned would result. The magnitude of this type of malfunction is restricted by the "in" limit switch on the safety blocks. Interlock logic requires that these limit switches be actuated before the control drums can be operated.

If the safety blocks should fail to scram as a result of some common mode failure in the scram system, the power following a burst will remain at a higher than normal level due to the high multiplication of delayed neutrons. If this malfunction were to occur following a high-level burst, higher than desirable temperatures in Skua would result. Scram action of the burst drum, the yield-adjustment drum and the delayed-critical drum serves to mitigate the effect of safety block failure. These three drums receive their scram signal from the "fast scram" detector and are actuated by a separate scram relay, hence, they are completely isolated from a common mode failure in the normal scram chain. The burst drum actuator is driven pneumatically, and hence is independent of the hydraulic system used for the safety blocks.

The yield-adjustment and the delayed-critical drums scram under spring action following the release of a magnetic clutch.

Common mode failure on the hydraulic side of the safety blocks is inconceivable because of the separate accumulators and pressure switches used for each safety.

Assuming failure of the safety blocks and a total scram contribution of 3$ for the three control drums, burst yield will be increased by less than 50%. Although the resulting temperature would be higher than expected, safety block failure is not considered to be a serious accident.

3. Shifting of Equipment. With the flux trap in place most materials inside are expected to have little effect on reactivity. Without the flux trap this is not the case and a serious accident could result if an experiment were to shift between the delayed critical initial check and the burst. To counteract this possibility we will require that an Experimental Plan be written to show what protection is provided to assure stability whenever the test geometry contributes significant reactivity (for experiments either with or without the flux trap in position).

We do not consider perturbations outside the copper reflector to be of concern because of the distance from the fuel and the shielding effect of the copper.

4. Hydrogen Loss from Flux Trap. Reactivity increases as hydrogen is removed from the flux trap, therefore, hydrogen loss during a burst could boost the yield. Instantaneous heating by neutron and $\gamma$-ray interactions in the moderator is not significant. Heat transfer from the fuel rings to the moderator through the cadmium and the boron is too slow to be effective until after the reactor has scrammed following a burst. Even melting of polyethylene moderator would hardly affect reactivity since it is confined in the flux trap container. Zirconium hydride requires high temperatures to release its hydrogen and there is no mechanism for raising its temperature that high. In the case of an accident, the lag in moderator

temperature rise associated with conduction from the fuel rings guarantees that the accident will be terminated before loss of hydrogen can contribute reactivity to the system.

Shifting in position of the flux trap would perturb reactivity; however, lateral shifting of the components is limited and can have little effect, and since the flux trap rests on the same supports as the fuel rings, vertical misalignment is not conceivable.

### 5. Loss of Poison from Flux Trap

Neutron absorptions in the cadmium and boral components of the flux trap result in a large negative reactivity contribution. Loss of this poison during a burst would, therefore be undesirable. To lose boron the aluminum matrix would have to melt and allow the boral cylinder to slump. Calculations show that normal operations will not result in enough energy deposition in the boron to cause melting. Furthermore, the cadmium buffer is effective in eliminating the high thermal neutron absorption spike in the boral. Little energy remains in the cadmium when neutrons are absorbed as this reaction results in an energetic -ray, therefore, cadmium melting can not conceivably occur promptly. There appears to be negligible chance that poison loss can result in a boosting of the burst yield.

### 6. Improper Seating of Fuel Rings

If thermal shock during a burst were to shift the fuel rings to a higher density stacking, the resulting reactivity gain would increase the burst yield. We will minimize this possibility by carefully comparing reference reactivities following any disassembly and reassembly. Since the fuel cylinder is held together by bolts it is not conceivable that the geometry can change once the correct fit has been achieved. We do not consider fuel ring shifting to constitute a significant hazard in Skua operation.

## 11.3. Design Basis Accident

We consider the Design Basis Accident (DBA) to be an incident resulting from improper setting of the yield-adjustment drum either through operator error or equipment malfunction. Other potential accidents discussed in Section 11.2 have either been shown to be of low probability or are susceptible to control by administrative action. We will choose the DBA, somewhat arbitrarily, to be a burst of $10^{18}$ fissions in Skua, which is sufficient to destroy the assembly functionally, but will not evaporate uranium or produce significant effects outside the Kiva. We will establish conditions and administrative procedures to assure that $10^{18}$ fissions cannot be exceeded in this accident. The limit of $10^{18}$ fissions for the DBA has been selected to allow as much flexibility as possible in the operation of Skua without presenting a significant hazard to personnel or potential for damage to the site.

We will establish the upper bound to the DBA by limiting the amount of reactivity available with the yield-adjustment drum. This will be achieved either by design of the drum or by means of mechanical or electrical positive stops. As discussed in Section 10, only the yield-adjustment drum position is of concern since the delayed-critical drum is not changed following the criticality check and only the "in" position of the burst drum can affect burst yield.

At this writing we are unable to establish the relationship between burst yield and reactivity since Skua reactivity quench characteristics are not known and can only be determined with certainty by experiment. In this regard, the experiments to be conducted in approaching the burst mode of operation (mentioned in Section 7.) will establish these required dynamic quench characteristics. Extension into the self-limiting burst regime is essential for this determination. The operating procedures for these experiments will be specified in an Experimental Plan. Excess reactivity corresponding to a $10^{18}$

fission burst will be deduced by extrapolation of test results through previously validated accident computing codes.

Compensation for reactivity effects of experiment components in or around Skua will be accomplished with the delayed-critical drum. If the range of this drum should be inadequate to handle an experiment then additional means of shimming reactivity will be utilized.

The maximum DBA thus corresponds to a burst for which the yield-adjustment drum has been at its out limit for the delayed critical check and then is run to the fully in position for burst production. This outer position is unlikely to occur, simply because it is a singular position and as such would come to the attention of the operators.
Furthermore, we should emphasize again that a significant error in the setting of the yield-adjustment drum would result in a corresponding anomalous delayed critical check. Consequently, the DBA is unlikely to result in the extreme yield of $10^{18}$ fissions.

In LA-4797-MS[2] we show that if all fission products are released from the Kinglet solution to the atmosphere immediately after a 10 second run of $1.3 \times 10^{18}$ fissions under the most adverse atmospheric conditions, doses at the closest approach during operation would be less than 5 rad whole body or 20 rad to the thyroid. Only a fraction of the gaseous fission products would escape from Skua fuel following a DBA and the Kiva is a much more confining structure than the Kinglet building. The slow release of gaseous fission fragments from the Kiva would result in insignificant doses at the exclusion area boundary.

## 12. QUALITY ASSURANCE PROGRAM

The discussion in LA-6206 is applicable to Skua.

## REFERENCES

1. H. C. Paxton, "Safety Analysis of the Los Alamos Critical Experiments Facility," Los Alamos Scientific Laboratory report LA-6206, Vol. I (February 1976), Vol. II (August 1976).

2. T. F. Wimett, R. H. White, H. C. Paxton, and J. D. Orndoff, "Kinglet Safety Analysis," Los Alamos Scientific Laboratory report LA-4797-MS (October 1971).

3. H. C. Paxton, "Technical Specifications for the Pajarito Site Critical Experiments Facility," Los Alamos Scientific Laboratory report LA-6016-SOP (November 1975).

4. J. D. Orndoff and H. C. Paxton, "Operating Procedures for the Pajarito Site Critical Assembly Facility," Los Alamos Scientific Laboratory report LA-4037-SOP, Rev. (January 1973).

## APPENDIX A

### EXPERIMENTAL PLAN NO. 197

### Assembly and Delayed Critical Operation of

### SKUA Assembly

Operational Limits: Delayed critical and positive periods down to 10 s, Class II operation.

Required Personnel: Chief and Crew Member

Purpose: To establish a critical stacking and evaluation of reactivity control elements for eventual prompt burst operation of Skua.

## I. CORE DESCRIPTION

The active material is U(93)(with 1.5 w/o molybdenum) in the form of an interlocking stack of annular sections, 0.3176 m o.d., 0.2413 m i.d., and 0.37 m in height. Inside this hollow cylindrical stack is a neutron moderating assembly as shown in Fig. A acting as a thermal flux trap. Because the outer layers include boron and cadmium, flux trap reactivity contribution is expected to be about 5$ negative. Copper reflectors are used as control elements and are expected to supply 6-8$ reactivity control.

Masses of the fuel rings presently available are given in the table.

TABLE A-1

WEIGHTS OF SKUA COMPONENTS

| Part No. | | Alloy wt. (kg) |
|---|---|---|
| 1 | (Bottom ring) | 16.972 |
| 2 | | 15.687 |
| 3 | | 15.679 |
| 4 | | 15.677 |
| 5 | | 15.690 |
| 6 | | 15.677 |
| 7 | | 15.664 |
| 8 | | 15.674 |
| 9 | | 15.672 |
| 10 | | 15.668 |
| 11 | | 15.670 |
| 12 | (Top ring) | 14.543 |
| | Total fuel | 188.273 |
| | Total U(235) | 172.060 |

## II. STORAGE OF ACTIVE MATERIAL

Each of the twelve annular fuel pieces (rings) is boxed separately in metal cans which will be stored in the Kiva 3 vault when not mounted in the SKUA machine.

## III. ASSEMBLY MACHINE

The Skus assembly and actuating machinery are mounted on 64 mm thick aluminum shelves supported by 4 posts of 127-mm-diam hollow steel pipe. Three safety blocks (A, B, C in Fig. A-I) consist of 76-mm thick external copper reflectors which are driven radially by hydraulic cylinders. Three rotary copper reflectors (1, 2, 3 in Fig. A-I) act as control elements one of which is driven hydraulically to act as a burst or pulse rod; the other two are rotated by stepping motors for fine incremented control. One safety and one rotary rod are shown in elevation in Fig. A.2. Three nitrogen gas accumulators are used for pressure back up in case of hydraulic pump failure and operate independently for each safety block.

The machine power circuit, hydraulic system and scram chain logic are typical of the other Pajarito assemblies as described in the site SAR (LA-6206, August 1967).

Electrical interlocks prevent any operation until all control rods and safeties are at their outer (least reactive) positions. Rotary rod speed on two rods is such as to limit reactivity insertion to 0.05 \$/s in conformity with Technical Specifications (LA-6016-SOP).

The third rotary rod which will eventually act as a pulse rod under burst mode conditions is now actuated by a throttled hydraulic system that limits its reactivity insertion rate to a value less than a single-safety withdrawal rate.

One safety block is equipped with intermediate position indication and will be throttled to slow speed by means of a manual valve. This permits insertion to a preselected position and stopping for neutron counting.

## IV. PROCEDURE

A needle source ($^{238}$Pu-Be, Q-2x10$^{6}$ n/s) will be mounted in the crack between two stationary copper pieces having an opening toward the fuel plates. It will be positioned about midway up whatever stack of rings is in place. Neutron detectors will be located on the opposite side of the assembly. With the flux trap and the bottom copper plate in position, the fuel rings will be stacked in numerical sequence as given in Table A-1. The neutron count rate will be observed by at least two counters, and a running plot maintained of reciprocal count rate versus total ring mass added for two conditions, viz., (1) all reflectors "out" and (2) all reflectors "in".

The procedure for inserting reflector elements is: Two control rods will be inserted (watching count rate) one at a time. One will be withdrawn and the pulse rod inserted followed by reinsertion of the withdrawn control rod. All three will be withdrawn and one fast safety inserted. (One safety is estimated to be roughly equal to two control rods.) Now three control rods are added stepwise as before and withdrawn before a second safety is inserted. The same procedure will permit insertion of the remaining safety if subcriticality is still demonstrated. After all fuel plates are in position plus the top copper reflector, the steel clamping plate will be installed when determined to be safe by placing it on aluminum spacer rings starting with a 25-mm spacer. If extrapolation to 13-mm spacer appears appropriate, the 25 mm spacer will be replace by 13 mm, etc., through 65 mm and no spacer. All steps will be guided by reciprocal multiplication. The top plate is estimated to be less than 1/4 the total worth of Cu reflection or 2$. Finally, the six assembly bolts will be inserted.

Assuming a reasonable critical stacking is achieved, the central moderator assembly or flux trap will be attached to a screw-driven lifting mechanism. The electrical power for this device is interlocked such that the assembly cannot be reset until the screw is in the down position. With mechanical stops at 25-mm increments, the flux trap will be lifted to evaluate reactivity worth as a function of position.

To prevent inadvertent insertion of fast moving elements, the following actions will be taken: After half the fuel pieces are in place, the electrical line, which powers the hydraulic valves that permit inward motion of the burst rod and two safeties, will be temporarily disconnected in the Kiva building. After the slower elements (two control rods and one safety) have been inserted and evaluated, the Kiva will be re-entered and those three circuits reactivated. At this point, the rapid insertion of one safety and the burst element have been demonstrated to lead to a known subcritical state. It will then be safe to add more elements keeping within the 0.05$/s limit of Technical Specifications by simply interchanging a slow element with a faster one.

## V. SPECIAL SAFETY CONSIDERATIONS:

The assembly, auxiliary equipment, housing as well as administrative and operating procedures, satisfy the proposed safety standard ANS 14.1 "Operation of Fast Pulse Reactors," January 1976, even though it is not proposed to pulse this machine at this time.