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A Division of North American Aviation, Inc.

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DISTRIBUTION		STATEMENT OF PROBLEM This document supersedes NAA-SR-6345, Rev. II, and incorporates all changes that have been made in feasibility procedure since NAA-SR-6345, Rev. II, was issued.	
J. R. Armstrong 1 R. L. Ashley 2 J. K. Balkwill 5 M. H. Binstock 1 D. C. Campbell 1 T. E. Cartt 2 H. D. Decker 1 J. J. Droher FALL D. L. Henry 1 C. E. Johnson 5 N. Ketzlach 1 T. S. Kirsch 1 J. C. Lang 4 C. A. Martin 1 W. G. Martin 1 K. L. Mattern 4 D. T. McClelland 1 G. W. Meyers 1 R. M. Petersen 1 A. R. Piccot 5 E. L. Reed 1 H. Rood FALL F. C. Schrag 1 W. H. Timmerman 1 W. R. Vaughn 2 R. F. Wilmes 3 A. R. Yarrow 1 J. M. Young 1 J. E. Caldwell 1 W. E. Nagel 1 W. Sawicky 1			
		ABSTRACT: The general requirements for the SNAP Reactor Cores include the fabrication of fuel elements. These elements consist nominally of 90 w/o zirconium 10 w/o highly enriched uranium (93% U-235) rods hydrided to an N _H of 6.0-6.5 and final machined. Alloying will be accomplished by triple arc melting. Forming will be done by extrusion, massive hydriding by techniques developed at Atomics International, and cladding by conventional means.	

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I. FACILITIES

Facilities for all of the required fabrication operation, with the exception of extrusion, are located at Atomics International Headquarters. Most of these operations will be performed in the SNAP limited area located in Building 001 and, more specifically, in the rooms designated in Figure 5. Operations to be carried out outside of this area include extrusion which will be done in an isolated room at Torrance Brass Foundry, Inc., 1825 West 213th Street, Torrance, California; radiography of certain components and elements which will be done in Room 1471, Atomics International Headquarters, Building 001; and analytical work to be done in the designated areas of Building 004, Figures 2 and 3.

II. DESCRIPTION OF PROCESS AND CRITICALITY CONTROLS

A. General

The handling of all fissionable materials will be done in accordance with Section B-16 of the Atomics International Standard Operating Policies (SOP), NAA-SR-TDR 5468 by J. C. Lang, NAA-SR-MEMO 7001 by N. Ketzlach and "Health and Safety Considerations for Fuel Fabrication Facilities". Handling of all fuel materials will be done at designated work stations (work stations are separated by a minimum distance of 3 feet (see page 51, paragraph 2 and 3, and page 34, Figure 5) in criticality control areas and with less than one-half a minimum critical mass (MCM) as determined by criticality studies. Fueled materials may be moved and stored only in birdcages containing less than one-half a minimum critical mass.

A work station is an area or piece of equipment having defined boundaries within which certain operations may be performed with fissionable materials. The work stations required for the fabrication of SNAP fuel are shown on the area layout, which is contained in this TDR. Only one safe batch or handling unit will be handled or stored at any work station, with the exception of hydride loading stations 14 and 15. At these stations, six rod boats will be loaded with SNAP 2, 10-type rods (five rods constitute a safe handling unit independent of container geometry or degree of water flooding) by first loading five rods in the boat and then transferring a single rod to the boat from another work station. The boatload of six rods is safe by virtue of its configuration, all the rods being contained within a four-inch diameter (see page 48, paragraph 3).

Consecutive loading of hydriding boats for SNAP 2, 8, or 10 require that additional rods be brought to the work station in amounts less than a full birdcage to avoid having more than one safe handling unit present at the station. Thus, if two SNAP 8 boats of eight rods each are successively loaded from a 12-rod birdcage the four rods required to complete the second boatload must be obtained by bringing the rods, one at a time,

II. DESCRIPTION OF PROCESS AND CRITICALITY CONTROLS (Con'd)**A. General (Con'd)**

from another work station in the same area. This will be done only by the area's criticality designate, and will avoid making the total number of rods at the station greater than a safe handling unit (by bringing a 12-rod cage to the station). The same reasoning applies to loading of 6-rod SNAP 2, 10 boats from 5-rod birdcages.

1. Criticality Control Areas

Criticality control areas are designated areas for the handling of fissionable materials. These areas are generally rooms, but may consist of a portion of a room or more than one room depending upon the requirements. A criticality control area may contain several work stations and/or a designated birdcage storage area. Birdcage storage areas are at least 1½ feet removed from the nearest work station when containing no more than two birdcages, and at least 6 feet removed when containing more than two birdcages.

2. Birdcages

A birdcage is a three dimensional frame having a centrally positioned cell for containing a quantity of fissionable material and used for the storage and movement of materials. Dimensions of the cells and frames are such that a safe decoupling distance for contained material is maintained when birdcages are grouped for storage.

B. Movement of Material

Movement of material between criticality control areas is the responsibility of the MBA custodian. The responsibility for movement within an area is vested in a criticality designate appointed by the area supervisor. For operations requiring special transfers between stations (i.e., loaded hydriding boat from work station to hydriding furnace), movement will be under direct supervision of the criticality designate. Movements between work stations, except where specifically authorized for furnace loading, will be in birdcages. Movement of material within a room or between rooms may be made only if a work station or birdcage hold area is vacant to receive it (no exceptions). Each workday morning, the criticality designate for each room or the MBA custodian will inventory all materials in his room and report this quantity to the criticality coordinator by phone. The criticality coordinator will make frequent checks on materials in each room and may at any time request an inventory.

II. DESCRIPTION OF PROCESS AND CRITICALITY CONTROLS (Con'd)

B. Movement of Material (Con'd)

1. Raw Materials

All uranium metal will be received at AI by the SS storage vault in unopened shipping containers. After the contents of each container have been identified by shipping papers, the contents are removed from one container at a time, weighed and stored according to practices set forth in the "Nuclear Materials Storage Vaults Operations Handbook", 2nd edition, January 1, 1961. On request from SNAP personnel and by permission of the criticality coordinator, 1 Kg quantities of uranium metal in the form of 3/16-inch cubes will be weighed and transferred to Room 1252 for blending with zirconium metal.

Zirconium metal, in the form of Kroll process reduced sponge meeting AI specification NBO 170-020, will be brought into Room 1252 in 75 pound pails, as required, for blending with the uranium.

OVER 2 Kg HIGHLY ENRICHED U ARE REQUIRED FOR MINIMUM CRITICAL MASS (MCM) WHEN IN THIS FORM, SEE PAGE 45, APPENDIX II.

2. Compacted Bars

Nine hundred grams of zirconium sponge is compacted in a "V" block die at 100 tons pressure. Two hundred sixteen grams of uranium metal cubes and another one hundred grams of zirconium sponge are deposited into the "V" compact and compacted into a 1½" x 1½" x 10" bar at 500 tons pressure in Room 1252. A maximum of 7 bars will be handled or stored as a unit.

MORE THAN FORTY-FOUR 1½" x 1½" x 10" COMPACTED BARS CONTAINING 2.8 Kg HIGHLY ENRICHED U ARE REQUIRED FOR A MCM. SEE NAA-SR-TDR 6872 by N. KETZLACH (APPENDIX I).

3. Compacted Electrode

Three compacted bars will be welded end-to-end to a connector, forming a compacted electrode 1½" x 1½" x 30" long. Two compacted bars will be welded end-to-end to a connector, forming a compacted electrode 1½" x 1½" x 20" long. Two such 20" electrodes will be made. All welding will be done in a vented glove box under an argon atmosphere. No more than 3 electrodes (1-30", 2-20") or 7 compacts containing 1.4 Kg U-235 will be handled at a time.

JUSTIFICATION FOR HANDLING THIS QUANTITY OF MATERIAL IS GIVEN UNDER (2) ABOVE.

B. Movement of Material (Con'd)

4. Primary Ingots

One compacted 30" electrode will be consumably melted on top of 200 grams alloy (Zr-10% U) starting charge forming a primary ingot 3 inches in diameter by 7 inches long, weighing approximately 6 Kgs. The two 20" compacted electrodes will be consumably melted on top of 200 grams alloy (Zr-10% U) starting charge to form a primary ingot 3 inches in diameter by 10 inches long, weighing approximately 8.5 Kgs.

These two primary ingots will then be transferred to the Hot Shop, Room 1273, for removal of the ~~sp~~ter rings and facing on the lathe so that they may be welded together to form an electrode. A maximum of four 3 inch ingots can be transferred at one time.

Machine scrap will be collected as it accumulates and placed in cans not to contain more than 150 g U-235 each. No more than two of these cans may be handled as a unit.

FROM FIGURE 2, APPENDIX II, IT IS SHOWN THAT SEVEN 3 INCH DIAMETER X 7 INCH LONG RODS (4.2 Kg U-235) OR FIVE 3 INCH DIAMETER X 10 INCH LONG RODS (4.25 Kg U-235) ARE REQUIRED TO FORM A MAXIMUM SAFE HANDLING BATCH; THUS, FOUR INGOTS CONSTITUTE A SAFE HANDLING UNIT. JUSTIFICATION FOR THE HANDLING OF 150 G U-235 CONTAINED IN MACHINE SCRAP PER CAN AND THE SAFE HANDLING OF TWO CANS IS REFERRED TO IN FIGURE 3, APPENDIX II.

5. First Remelt Ingot

Two primary ingots are welded end-to-end to a connector to form an electrode 3 inches in diameter by approximately 17 inches long, weighing approximately 15 Kgs. No more than two electrodes of these dimensions may be handled at one time. One electrode will be consumably melted on top of 350 g alloy chips to form an ingot 4 inches in diameter x approximately 11 inches long, weighing approximately 15 Kgs. A maximum of three 4 inch ingots containing a total of 5.1 Kg U-235 may be safely handled as a unit. (FIGURE 2, APPENDIX II).

6. First Extrusion Billet

The remelted ingots are machined into extrusion billets 3.735 inches diameter x 10 inches long, weighing 13.3 Kg, in the Hot Shop. A maximum of four billets containing a total of 5.2 Kg U-235 may be handled as a unit. Machine scrap will be packed in cans to contain no more than 150 g U-235 each. Clean chips will be used as arc melting starting charge in batches of 200 and 350 g. JUSTIFICATION GIVEN UNDER (4) & (5) ABO

B. Movement of Material (Con'd)

7. 1.125-Inch Diameter Rod

Four extrusion billets at a time will be transported to Torrance Brass Company, 1825 W. 213th Street, Torrance, California for extrusion. While there, they will be sprayed with a lubricant, placed in an electrically heated furnace until they reach 1000°F and then extruded into 1.125-inch diameter x approximately 120-inch long rods plus an extrusion heel. Four 1.125 inch diameter x 120-inch long rods containing approximately 5.2 Kg U-235 constitutes a safe handling unit. FROM PAGE 48 AND FIGURE 5, APPENDIX II, IT IS SHOWN THAT MORE THAN 8 RODS OF THESE DIMENSIONS ARE LESS THAN HALF A MINIMUM CRITICAL MASS.

8. Electrode for Final Melt

After the extruded rods are returned to A.I. they are cut into 4 equal lengths (approximately 30" each) and cleaned of adhering lubricant by gritblasting. For SNAP 8 use each cut rod is welded to a connector for final melting. For SNAP 10A/2 the four rods are clustered and welded to a single connector for final melting. Cutting will be done with an abrasive cut-off saw in Room 1256 and grit-blasting will be done in Room 1252. No more than four-30 inch single electrodes, or one 30-inch clustered electrode will be handled as a unit.

FOUR 1.125-INCH DIAMETER X 30 INCH LONG RODS ARE SAFE AS IN (7) ABOVE. If more than one rod is to be placed in the gritblaster at a time, this number is to be determined by the following formula:

$$\text{Number of Rods} = 4 - 4 \left(\frac{\text{grams U-235 in grit}}{250} \right)$$

No more than 150 g contained U-235 will be accumulated in the grinding sludge or 250 g in the gritblaster. THE MINIMUM CRITICAL MASS OF FINELY DIVIDED FUEL UNDER OPTIMUM CONDITION IS IN EXCESS OF 750 GRAMS U-235. SEE PAGE 42 AND FIGURE 2, APPENDIX II (HOMOGENEOUS MIXTURES).

9. Final Melt and Extrusion Billet

Each of the 1.125 diameter rod electrodes for SNAP 8 will be consumably melted on top of 300 g alloy chips starting charge to form an ingot 2-inches in diameter x 8 inches long weighing approximately 3 Kg each. The four rod clustered electrodes will be consumably melted on top of 300 g alloy chips starting charge to form an ingot 4-inches in diameter x 11-inches long weighing approximately 12 Kg each.

B. Movement of Material (Con'd)

9. Final Melt and Extrusion Billet (Con'd)

Extrusion billets 1.9-inches diameter x 7½-inches long will be machined from the 2-inch diameter ingots, while extrusion billets 3.950-inches diameter x 10½ inches long will be machined from the 4-inch diameter ingots in Room 1273. No more than nine of the 1.9-inch diameter billets or more than 4 of the 3.950-inch diameter billets containing respectively 2.7 Kg and 4.8 Kg U-235 will be handled as a unit. USE OF FIGURE 2, CURVE B, APPENDIX II SHOWS THE ABOVE WEIGHTS ARE A SAFE HANDLING UNIT.

10. Extruded Rods

At Torrance Brass Foundry, a maximum of nine 1.9 inch diameter x 7½ inch long billets are extruded into .60-inch diameter x approximately 6 ft. long rods plus an unextruded heel; or a maximum of four 3.95 inch diameter x 10½ inch long billets are extruded into 1.25-inch diameter x approximately 8 ft. long rods plus an unextruded heel. Prior to extrusion the billets are sprayed with lubricant and heated in an electric furnace to 1000°F. After extrusion, rods and heels will be returned to AI for further processing. THIRTEEN RODS 0.60-INCH DIAMETER X 6 FT. LONG OR 7 RODS 1.25 INCH DIAMETER X 8 FT LONG ARE A SAFE HANDLING UNIT: SEE PAGE 48 AND FIGURE 5, APPENDIX II.

11. Rod Cutting

The extruded rods are taken to Room 1256, HQ-1, and cut into approximately 13-18 inch lengths and sample wafers using a totally enclosed and vented abrasive cut-off wheel. As the .60 diameter rods are cut off, they are placed in a birdcage fabricated to contain no more than twelve short rods (fuel rods); this number of rods will constitute a handling unit. As the 1.25 diameter rods are cut off, they are placed in a birdcage fabricated to contain no more than five short rods (fuel rods); this number of rods will constitute a handling unit. Cutting sludge will be collected in a filter. When a maximum of 250 grams highly enriched U has been collected, as evidenced by weight difference from the log maintained on the machine, the filters will be cleaned and the sludge sent to storage.

THE MAXIMUM SAFE BATCH SIZE FOR .60 INCH DIAMETER X 15 INCH LONG RODS IS 17; FOR 1.25 INCH DIAMETER X 13 INCH LONG RODS IS 10. SEE PAGE AND FIGURE 2, APPENDIX II. THE MCM OF FINELY DIVIDED, HIGHLY ENRICHED U CONTAINED IN SLUDGE IS IN EXCESS OF 750 GRAMS. SEE PAGE 43 FIGURE 2, APPENDIX II.

B. Movement of Material (Con'd)**12. Sandblasting of Fuel Rods**

Preparatory to rough machining, the fuel rods will be grit-blasted to remove adhering extrusion lube in Room 1252. The maximum number of rods handled at a time will be twelve of the .60 inch diameter size, or five of the 1.25 inch diameter size. After cleaning, the rods will be replaced in their birdcage for storage until machined. When a maximum of 250 grams highly enriched U has accumulated in the grit, it will be discarded to storage for reclamation. JUSTIFICATION FOR THESE HANDLING PROCEDURES ARE THE SAME AS THOSE GIVEN FOR STEPS (8) AND (11) ABOVE.

13. Rough Machining of Fuel Rods

Preparatory to hydriding, the fuel rods will be rough machined on a belt grinder in the Hot Machine Shop (Room 1273). The maximum number of rods handled at a time will be twelve of the .60 inch diameter size, or five of the 1.25 inch diameter size. After machining, the rods will be replaced in their birdcage for storage until hydrided. When a maximum of 250 grams highly enriched U has accumulated in the grinding sludge, it will be discarded to storage for reclamation. JUSTIFICATION FOR THESE HANDLING PROCEDURES ARE THE SAME AS THOSE GIVEN FOR STEPS (8) AND (11) ABOVE.

14. Hydriding the Rods

Hydriding the .60 inch diameter size fuel rods to an N_H of 6.0; and hydriding the 1.25 inch diameter size fuel rods to an N_H of 6.35 will take place in Room 1279, HQ 1, in eight retorts 4 inches diameter. These retorts are spaced at least two feet apart on center and constitute a planned geometric space storage array. No more than twelve .60 inch diameter size rods containing a maximum of 0.64 Kg U-235, nor more than five 1.25 inch diameter size rods containing a maximum of .85 Kg U-235 will be placed in a retort at one time. TWELVE .60 INCH DIAMETER SIZE HYDRIDED RODS, OR FIVE 1.25 INCH DIAMETER SIZE HYDRIDED RODS CONSTITUTES A MAXIMUM SAFE BATCH SIZE. SEE PAGES 43 and 48 AND FIGURE 2, APPENDIX II.

15. Grinding Fuel Rods

After hydriding, the fuel rods are ground to final dimensions in a centerless grinder in the Hot Machine Shop (Room 1273). The rods will be removed from the birdcage one at a time, ground to final dimensions (.520" - .540" diameter by 13.5" - 16.5" length for the small rods; 1.210 inches diameter by 12.25 inches length for the large rods). The rods are

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B. Movement of Material (Con'd)

15. Grinding Fuel Rods (Con'd)

replaced in the birdcages after machining. End cuttings are used as samples for analysis and microscopic examination while the grinding sludge will be collected from the filter in the coolant circulating system in quantities not to exceed 250 grams contained highly enriched U. JUSTIFICATION FOR THE SAFE HANDLING OF THESE QUANTITIES OF RODS AND SLUDGE HAS ALREADY BEEN GIVEN IN THE PRECEDING STEPS.

16. Cladding of Fuel Rods

Ground hydrided fuel rods will be placed inside Hastelloy N cladding and sealed by welding inside a totally enclosed and vented retort. No more than a safe handling batch of twelve .534 inch diameter rods containing a maximum of 0.56 Kg U-235, nor more than five 1.210 inch diameter rods containing a maximum of 0.83 Kg U-235 will be placed in the welding retort at one time. Clad and welded elements will be returned to their birdcage on removal from the retort. Cladding will be done in Rooms 1266, HQ 001.

SEE FIGURE 2, PAGE 48 APPENDIX II. IT IS SHOWN THAT TWELVE .534 INCH DIAMETER RODS, OR FIVE 1.210 INCH DIAMETER RODS CONSTITUTES A SAFE HANDLING BATCH.

17. Testing of Fuel Rods and Fuel Elements

After cladding, the fuel elements are tested for hydrogen leaks in permeation furnaces. The furnaces are arranged in 4 rows of 4 furnaces each with a minimum center to center spacing of 16". Maximum cross-sectional area of a SNAP 10A type element is 1.23 in²; therefore, the lattice fraction occupied by the fuel is less than .05. For cases in which some furnaces contain SNAP 8 instead of SNAP 10A elements the margin of safety is greater. SEE FIGURE 5, PAGE 34 APPENDIX II FOR JUSTIFICATION.

The procedure for loading and unloading the permeation furnaces is the following: A birdcage of either SNAP 8 (.534 dia.) or SNAP 2/10A (1.210 dia.) type elements are brought to the hood (work station 42). One element at a time is placed in a furnace fixture inside the hood and then transferred to an empty furnace in either work station 27 or 43. Unloading follows the reverse procedure, except that several elements (no more than 12 SNAP 8 or 5 SNAP 10A/2) at a time may remain in the hood for cooling prior to being replaced in a birdcage. In no case will both SNAP 8 and 10A/2 elements be permitted in the hood at one time. SEE FIGURE 2, APPENDIX II FOR JUSTIFICATION.

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B. Movement of Material (Con'd)

17. Testing of Fuel Rods and Fuel Elements (Con'd)

At numerous points during the fabrication process, the fuel rods will be inspected for dimensions, defects and other physical properties. All of these tests will be conducted in Room 1261, HQ 001. At no time will more than one safe handling unit at a time be permitted at a work station. For testing and/or inspection operations to be carried out outside of the SNAP limited area, all movement of materials will be in birdcages that contain no more than a safe handling unit. Only one safe handling unit will be permitted in an outside work area at a time. After testing, the birdcaged fuel elements will be stored in the SS vault until they are required at the Santa Susana test facility. THE SAFE HANDLING UNIT FOR A PARTICULAR SHAPE AND COMPOSITION REPRESENTS LESS THAN ONE-HALF AN MCM AND IS SAFE UNDER ALL CONDITIONS OF GEOMETRICAL ARRAY AND MODERATION AND REFLECTION BY WATER ONLY.

III. ACCOUNTABILITY

Accountability of fissionable materials is controlled by material transfer vouchers and monthly physical inventory. Materials are transferred only by the custodians of material balance areas (MBA). For SNAP fabrication operations, there are four accountability areas involved: the SS vault, Hot Machine Shop, SNAP Fabrication Area and Metallurgical Laboratory in Building 001 and the Analytical Chemistry Laboratories in Building 004. While being extruded at Torrance Brass Foundry and radiographed (Room 1471, Building 001) all accountable material will be attended by and remain in the custody of SNAP personnel. Material may be moved from one room (Criticality Control Area) to another only by a ledger entry and from one MBA to another only by means of a transfer voucher and is assigned to one person who is then responsible for its custody.

All uranium is received by the SS vault and is assigned a quota number corresponding to its intended use. All SNAP material will be withdrawn from its designated quota and transferred to the fabricating personnel as required. As processing of the material proceeds (Figure 4), it is moved from station to station, accompanied by transfers and ledger entries as required. All materials are accounted for by direct weight during processing, including machining, grinding and sandblasting scrap. At the end of each month, a physical inventory is made. Final balancing of the account is obtained when recovery of uranium from the scrap has been effected.

IV. HEALTH PHYSICS CONTROL PROCEDURES FOR SDR-I MATERIAL PROCESSING**A. General Description****1. History**

Atomics International's main facility is located in the western end of the San Fernando Valley, an area that is characterized as being largely residential but having some light industry; test facilities are situated in an isolated section of the Santa Susana Mountains, a few miles away. Because of the nature of the work to be done by Atomics International, a Health Physics Unit was included in the early company organization. It is the responsibility of this unit to safeguard the health of the employees and surrounding populace and protect company property.

2. Organization

The Health and Safety Section of the Health, Safety and Radiation Services Department at Atomics International provides services as well as protection of employee's welfare. These services include monitoring of work areas, equipment, components, etc. for radiation and contamination levels. To carry out the required functions of this section, there are approximately 40 employees, including engineers, technicians and administrative personnel.

3. Radiation Safety Standards

The basic objectives in the radiation safety program is the practical minimization of all personnel exposure both to external and internal sources, and maintenance of control is predicated on preventative measures rather than "after the fact" assay. Guides for radiation exposure and permissible contamination levels are in accord with local, state and AEC regulations. The recommendations set forth in the NAA-SR-TDR 5468 by J. C. Lang, Health and Safety, will be followed where applicable.

B. Operational Procedures Applicable to SNAP Fuel Element Fabrication**1. General**

The subject operations will be performed at two locations: AI Headquarters and Torrance Brass Foundry. Melting of the alloy, machining, testing and cladding operations will take place in Rooms 1252, 1256, 1261, 1266, 1273, 1279, 1216 1485, 1486 and 2052, 1471 (Building No. 001) at Headquarters of Atomics International. Analysis of raw materials and alloys will be carried out in Building 004. Extrusion and attendant processing will be carried out at the Torrance Brass Foundry, Torrance, California.

IV. HEALTH PHYSICS CONTROL PROCEDURES FOR SDR-I MATERIAL PROCESSING**B. Operational Procedures Applicable to SNAP Fuel Element Fabrication****1. General (Continued)**

All of the above mentioned rooms in Building 001 are grouped together and are completely segregated from the remainder of the building, with the exception of Room 1471, as shown in Figure 1. All floors are covered with asphalt tile for ease of decontamination. This region has been designated as an AEC limited area by Plant Security. Access is limited to authorized personnel who are equipped with and instructed in the use of protective clothing and personnel monitoring device. These personnel monitoring devices are described below.

The Torrance Brass Foundry, Inc., Torrance, California will extrude the alloy billets. Processing attendant to extrusion includes furnace preheating and the application of a frit-type lubricant. These operations will be carried out in an isolated facility that the company normally uses in handling radioactive and special materials. All equipment used and areas adjacent to this equipment will be monitored by an AI Health Physicist before and after use to ascertain the extent of contamination, if any, and supervise decontamination, if necessary. All contaminated gloves, paper floor coverings, wipers, etc., will be returned to AI for disposal. Other fissionable materials will not be permitted in this area at the same time that SNAP materials are being processed.

2. Radiation Control**a) Personnel Monitoring Devices**

All personnel involved in the uranium handling operations will be issued standard beta, gamma film badges. Routinely, these badges will be collected and evaluated every four weeks. If a condition of overexposure is suspected, the badge will be immediately pulled for development and evaluation. Continuous film badge records will be maintained to insure that cumulative exposures do not exceed the permissible limits. In the event of an overexposure the employee will be removed from all radiation areas for the required interval.

b) Area Surveys

Periodic surveys will be made of the AI Headquarters Complex and complete surveys will be made of the applicable Torrance Brass Foundry facilities at the end of each visit. In addition, an AI Health Physicist will be in attendance during extrusion operations at Torrance.

2. Radiation Control (Continued)

c) Other Procedures

Cotton, rubber or leather gloves will be worn during any direct handling of the uranium to reduce beta hand exposures as well as skin contamination. Location film will be placed in any area where it may be useful in assaying existing radiation fields. Appropriate warning signs will be used to designate existing or potential hazards, such as high radiation fields, excessive surface contamination, excessive airborne contamination, active waste depositories, etc. Appropriate instructive signs will be used to remind employees of the basic radiation safety rules applicable in the area, such as use of hand and foot counters, protective clothing, film badges, etc.

3. Contamination Control

a) Working Surfaces and Equipment

Periodic surveys will be made of the entire SNAP area using smear techniques. Areas of removable contamination exceeding 75 d/m (B, γ) or 15 d/m (γ) per 100 cm² will be decontaminated to a point below these limits. Portable instrument surveys will be made to a point below these limits. Portable instrument surveys will be made to supplement smear surveys when necessary. Any tool or material to be removed from the area will be monitored by Health Physics for contamination and will not be released if it has more than 30 d/m (B, γ) or 1 d/m (γ) per 100 cm² removable contamination.

b) Personnel Contamination

Lab coats and canvas shoe covers will be worn at all times in the controlled area; other protective clothing will be issued as required. A change room will be provided at the entrance to the controlled area. All garments will be monitored before being released to commercial laundering facilities. Contaminated garments will be ultimately disposed of through regular active waste channels.

Hand and foot counters will be maintained in the change room and/or other areas where their use may be warranted. Smoking, eating, drinking and the application of cosmetics will not be permitted in the controlled area. Respirators will be worn in areas of known or suspected airborne contamination.

3. Contamination Control (Continued)**c) Airborne Contamination**

The occurrence of excessive airborne radioactive contamination will be minimized by two basic means; good housekeeping and adequate ventilation. In particular, large accumulations of saw or lathe scrap will not be permitted, and general cleanliness of the area will be enforced. These rooms are completely enclosed and include ventilation designed to produce 6 to 19 air changes per hour while maintaining a negative pressure in the rooms with respect to surrounding areas. Effluent air is drawn through an absolute filter bank before being exhausted to the exterior of the building. The face velocities at all hoods will be maintained at not less than 100 linear ft./min. A routine air sampling program will be maintained for the assay of airborne activity.

Spot sampling will be used in the vicinity of potential air contamination sources as warranted. General activity concentrations in excess of permissible values will be sufficient cause for evacuation of the affected area until remedied. If operations are required in local areas of excessive airborne contamination, approved respirators must be worn.

d) Waste Disposal

Appropriately constructed and marked containers will be located in the area for the collection of all radioactive waste. These containers shall consist of 55 gallon drums containing plastic removable liners for dry waste and 5 gallon polyethylene bottles enclosed in metal secondary containers for liquid waste. Other sizes of specially constructed containers will be obtained if necessary.

Packaged waste will be collected as necessary and stored for ultimate disposal. When desired, the waste will be incorporated into the general flow from the laboratory for burial in an approved manner already established at Atomics International.

e) Biological

All AI personnel involved with the fuel fabrication process will have a complete physical examination by the Atomics International Medical Unit prior to commencement of work, and at least one year thereafter during their employment in the controlled area. Routine urine samples will be taken at intervals not greater than those recommended by TDR 5468.

3. Contamination Control (Continued)

e) Biological (Continued)

Analysis of the samples for uranium content will be made by the Health Physics and Safety Department. If more specific analysis appears to be warranted in particular cases, samples will be submitted to a qualified commercial laboratory for the appropriate measurements. The maximum allowable amounts of contamination, recommended by TDR 5468 and based on results reported in UR-515 and HASL-5B in a 24 hour urine sample, should not exceed the following: Natural U - 100 disintegrations per minute or 67 micrograms. Highly enriched U - 100 disintegrations per minute or 0.59 micrograms. Specimens will also be taken in the event of an incident involving radioactive materials where an overexposure is suspected.

C. General Operational Services

1. Environmental Surveys

Monthly environmental surveys, including air, water, soil and vegetation samples, are routinely made by the Health Physics and Safety Department. These surveys extend for several miles in all directions from the AI Headquarters complex and form the basis for judging any fluctuation of radioactivity beyond the facility proper.

2. Emergencies

Firemen and security personnel are available on a 24-hour basis. Equipment and supplies necessary for handling emergencies in the work area, as well as emergencies in adjoining areas, will be maintained in or near the laboratories. A supply of G-1 powder will be maintained at Torrance Brass Foundry for use in extinguishing zirconium-uranium alloy fires if they should occur.

In the event of an accident or emergency, the primary course of action will be the notification of the AI Headquarters Industrial Security Control Center which is maintained on a 24-hour 365 days-a-year basis. This center will then extend the notifications to the Fire, Security, Medical, Health Physics and Management Units as necessary. Signs displaying the emergency telephone number will be prominently located throughout the building. The responsibility of the initial notification to the Control Center is vested in all operations personnel.

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C. General Operational Services (Continued)

3. Records

Complete and continuous records will be maintained of all radiation and contamination surveys, personnel exposures, urinalysis, waste disposal and any other information that pertains to the radiation safety of the program.

V. SECURITY CONTROL PROCEDURES FOR SNAP MATERIAL PROCESSING

A. General

Security requirements are predicated on the quantity of enriched fuel materials used, the application of unusual materials, and visual access to documents, components or assemblies which would reveal classified information.

B. Personnel Clearance

All employees engaged in handling fuel materials, classified documents, or classified aspects of the project will have "Q" clearances, including the sub-contractor personnel of Torrance Brass Foundry.

C. Work Areas

Classified work will be performed only in the SNAP exclusion area or in areas previously approved by the Security Office of CPAO.

Fuel Element Fabrication is divided into ~~six~~ processes, i.e.:

1. Alloying
2. Extrusion
3. Hydriding
4. Testing
5. Cladding
6. Machining

The alloying, hydriding, testing and cladding will be performed in approved areas established at AI Headquarters, Building No. 001. The SS materials used in the above mentioned processing phases will be stored in locked birdcages (when necessary) secured in the limited areas. The extrusion process and materials extruded are unclassified and will be performed in Torrance, California at the Torrance Brass Foundry. "Q" cleared employees of Atomics International will transport properly packaged SS materials to Torrance Brass Foundry in lots not exceeding 6 Kg contained U-235, remain with the material during the extrusion process, assure the recovery of all SS materials and return all materials to AI Headquarters Building No. 001 for storage. In no event will SS material be left at Torrance Brass Foundry unless approved storage facilities are provided. For these quantities of materials in these forms, no special security handling requirements are necessary, other than those mentioned above (AEC Manual, Chapter 2401, Appendix 071-D).

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V. SECURITY CONTROL PROCEDURES FOR SNAP MATERIAL PROCESSING (Continued)

D. Storage

1. Documents

All classified documents will be stored in metal file cabinets secured by metal crash-bars and three number combination padlocks. File cabinets will be located only in AEC approved security areas.

2. SS Materials

SS Materials in compact or fuel rod form may be stored in the SNAP exclusion area in unlocked birdcages or vaults, so long as the total contained U-235 present does not exceed 75 Kgs.

The 75 Kg limit includes the in-process storage vault (Room 1216).

A maximum of 5 Kgs. chopped stock may be stored unlocked in the SNAP fabrication area.

E. Shipment

SS Materials will be received at AI Headquarters Building No. 001 from the vendor via AEC courier, or other AEC approved means, for accountability and storage in the SS storage vault.

Inter and intra-plant transport of properly packaged SS materials will be accomplished in lots of no more than 6 Kg. of contained U-235, by "Q" cleared employees and only on the approval of the Industrial Security Department and the Criticality Coordinator.

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PAGE 18 OF 28TABLE ISAFE HANDLING UNITS FOR SNAP 2, 8 & 10

(Equal to or less than 45% of MCM for the type of material given)

	<u>No. Pcs.</u>	<u>Kg U-235</u>	<u>Work Station</u>
<u>Uranium Metal Cubes</u>	1 Bottle	.93	1,5
<u>Compacts (1½" x 1½" x 10")</u>	7	1.40	1,4A,47
<u>Compacted Electrodes</u>			
1½" x 1½" x 30"	2	1.20	47,8,4
1½" x 1½" x 20"	3	1.20	47,8,4
<u>Ingots, 90-10 Alloy</u>			
2" D. x 8"	9	3.00	2,4,6,7,8,10,11, 13
2.5" D. x 11"	6	3.37	2,4,8,10,11,13
2.5" D. x 32"	2	3.37	2,4,8
4" D. x 8"	5	5.61	4,8,10,11,13
4" D. x 11"	3	4.78	4,6,7,8,10,11,13
<u>Extrusion Billets, 90-10 Alloy</u>			
1.9" D. x 7½"	9	2.70	11,13,4, Torrance
3.735" D. x 10"	4	5.15	11,13,4, Torrance
3.950" D. x 10" or 7.5"	4	5.23	11,13,4, Torrance
<u>Extruded Rod</u>			
0.60" D. x 72"	9	2.63	10,48,38,35,4, Torr.
1.00" D. x 140"	4	5.05	10,48,38,4, Torrance
1.24" D. x 96"	4	5.20	10,48,38,4, Torrance
<u>Rod Electrodes</u>			
1" D. x 32"	4	1.17	2,3,4,8,47
1.24" D. x 32"	4	2.40	2,3,4,8,47
<u>Fuel Rods - Alloy</u>			
1.60" D. x 15"	12	.64	3,4,14,15,16,17, 18,29,24
1.24" D. x 12.75"	5	.85	3,4,5,14,15,16, 17,18,29,24

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	<u>No. Pcs.</u>	<u>Kg U-235</u>	<u>Work Station</u>
<u>Fuel Rods Machined</u>			
0.520-.540 D. x 14"-17"	12	.56	10,14,15,16,17, 32,31,37
.60-.70 D. x 15"-18"	5	.83	10,14,15,16,17, 31,32,37
<u>Fuel Rods - Hydrided</u>			
.65" D. x 15	12	.64	10,14,15,16,17, 31,32,27,43,37
1.34" D. x 13.13	5	.85	10,14,15,16,17, 31,32,27,43,37
<u>Machine Chips</u>	2 Cans	.30	10,11,13
<u>Grinding Sludge</u>	2 Cans	.30	12,13,37
<u>Extrusion Heels</u>	4.5 Kg Total	.42	3,4, (Room 1112)
<u>Chopped Alloy</u>	4.5 Kg Total	.42	4,8, (Room 1112)

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TABLE IICRITICALITY CONTROL FOR SNAP 2, 8 & 10

<u>Criticality Control Area</u>	<u>Work Station</u>	<u>Max U-235 Per Station</u>	<u>Max U-235 Per* Control Area</u>
Room 1252	1. Compacting	1.40 (Kg)	(Kg)
	47. Welding	3.37	
	2. Sandblasting	3.60	
	4. Bench	5.61	
	5. Weighing	5.61	
	7. Welding	4.78	
	46. Degreaser	.85	
			20.00
Room 1256	8-9. Arc Melt	5.61	
	48. Abrasive Cut-Off	5.20	
			20.00
Room 1273	10. Power Saw	5.61	
	11. Large Lathe	5.61	
	12. O.D. Grinder	.85	
	13. Weighing	5.61	
	37. Centerless Grinder	.36	
			20.00
Room 1279	14. Bench	1.02	
	15. Bench	1.02	
	16. Furnaces	4.08	
	17. Furnaces	4.08	
	18. Furnaces	2.77	
			15.00
Room 1266	19. Assembly	.85	
	20. Blending	.85	
	21. Weld	.85	
	22. Assembly	.85	
	23. Blending	.85	
	24. Cleaning	.85	
	25. Lathe	.85	
	26. Hone	.85	
			8.5
Room 1261	27. Permeation	2.64	
	28. X-Ray	.85	
	29. Vapor Degreaser	.85	
	30. Furnace	.85	
	31. Ultrasonic	.85	
	32. Balance	.85	
	33. Resistivity	.85	
	34. Inspection Area	.85 (Kg)	(Kg)
	35. Zyglo		16.00

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PAGE 21 OF 28TABLE II (Continued)

<u>Criticality Control Area</u>	<u>Work Station</u>	<u>Max U-235 Per Station</u>	<u>Max U-235 Per* Control Area</u>
Room 1486	40. Hydriding Furnace	4.08	12.00
	41. Hydriding Furnace	4.08	
	39. Bench	1.02	
Torrance Brass	Extrusion	5.61	
Room 1112	Roll and Chop	.45	.45
Room 1471	X-Ray	5.61	5.61

Met. Lab **

Chem Lab **

* This column lists arbitrary values of U-235 to be used as limits for the control areas for rooms shown on Figure 5 with the exception of Room 1273. Materials in designated birdcage hold areas are included in these limits. Since rooms 1112, 1471, and 1273 are not under the control of this project the values listed apply only to SNAP materials. The limits for these latter areas will be determined by the criticality coordinator and Criticality Safeguards Advisor who will take into account the requirements for other projects using them. In no case, however, will more than one safe handling unit be in a work station at a time.

** Although these samples contain only small quantities of U-235 (less than 100 grams) and do not require criticality control considerations, the criticality coordinator is aware of their movements and location at all times.

PROCESS FLOW DIAGRAM S-8

PROCESS FLOW DIAGRAM S-8
(Continued)

Figure 1. Building Area and Room Numbering Plan, Building 001
(Mfg. and Development Bldg.)

Figure 2. Building Area and Room Numbering Plan, Building 004 - 1st Floor (Laboratory Bldg.)

Figure 3 Building Area and Room Numbering Plan, Building 004 - 2nd Floor (Laboratory Bldg.)

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LAYOUT

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1. COMPACTING	25. LATHE
2. HYDRO-HONE	26. CLEANING
3. HYDRO-HONE	27. PERMEATION
4A. WEIGHING MATERIAL	28. X-RAY
4B. TESTING MATERIAL	29. VAPOR DEGREASER
5. WEIGHING MATERIAL	30. FURNACE
6. STORAGE	31. ULTRASONIC
7. WELDING	32. BALANCE & WORK AREA
8. ARC-MELT	33. RESISTIVITY
9. ARC-MELT	34. INSPECTION AREA
10. POWER SAW	35. ZYGLO
11. LARGE LATHE	37. CENTERLESS GRINDER
12. O. D. GRINDER	38. ROD STORAGE
13. WEIGHING	39. BENCH
14. BENCH	40. HYDRIDING FURNACE
15. BENCH	41. HYDRIDING FURNACE
16. HYDRIDING FURNACES	42. HOOD
17. HYDRIDING FURNACES	43. PERMEATION FURNACE
18. HYDRIDING FURNACES	44. LATHE
19. ASSEMBLY	45. STORAGE CABINET
20. BLENDING	46. DEGREASER
21. WELDING	47. WELDING
22. ASSEMBLY	48. RADIAC
23. BLENDING	
24. CLEANING	

ATTACHMENT I

NAA-SR-TDR No. 6872, NUCLEAR SAFETY IN HANDLING U-Zr COMPACTS, by N. Ketzlach, Department 779, dated November 16, 1961, pages 1 thru 6. G.O. 7570, S/A 2820. Unclassified.

ATTACHMENT II

NAA-SR-TDR No. 6345, Rev. II, by N. Ketzlach, Department 779, dated August 18, 1961, pages 39 thru 53. Unclassified. Also included is page 34 of 53.

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ATOMICS INTERNATIONAL

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NO. 6872
DATE 11/16/61
PAGE 2 OF 6**I. INTRODUCTION**

In an earlier report⁽¹⁾ criticality conditions for 1" x 1" "compacts" were presented. These criticality conditions were based on compacts having a volume void fraction of 14 percent. It was assumed that these voids would become filled with water if an assembly of compacts became water-flooded.

Nuclear safety criteria for water-flooded assemblies of 1½" x 1½" "compacts" are now requested. It is assumed that these compacts may have a void fraction as large as 20 percent (higher than that obtained experimentally). For a given compact cross section, the minimum critical mass will be smaller for water-flooded assemblies having the larger volume void fraction. An additional conservatism was taken into account by basing the calculations on compacts having a 1.45" x 1.45" cross section. The smaller the cross sectional area of this fuel the lower is the critical mass for water-flooded assemblies.

II. METHOD OF ANALYSIS

The method used in the present calculations was the same as that used in the earlier study,⁽¹⁾ using the IBM SN, MUFT-4 and AIM-5 Codes. The 1.45" x 1.45" compacts were assumed to have the same reactivity as rods of cylindrical cross section having the same area.

III. DISCUSSION OF RESULTS

The maximum safe batch size (45 percent of calculated critical) for these compacts is shown in Figure 1 as a function of water-to-fuel volume ratio. These calculations are based on spherical geometry. The maximum safe batch size at optimum water moderation is 1.68 Kgm contained U²³⁵. The data for the 1" x 1" compacts is included in this figure so that a direct comparison between the two sizes of compacts can be made. This compares with 1.4 Kgm contained U²³⁵ for the 1" x 1" compacts. It is interesting to note that, although the maximum safe batch size is larger for the larger compacts at optimum moderation, it is not so at all moderations (i.e., at a water-to-fuel volume ratio of 1 the smaller compacts have the larger maximum safe batch size).

FIGURE 1
MAXIMUM SAFE BATCH SIZE VS WATER-TO-FUEL VOLUME RATIO
(SPHERICAL GEOMETRY)

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The maximum safe mass per unit length of infinitely long compacts (1.45" x 1.45" in cross section) as a function of water-to-fuel volume ratio is shown in Figure 2. These values are also 45 percent of calculated critical. The maximum safe mass per unit length at optimum water moderation is 0.94 Kgm contained U^{235} /ft. Therefore, four of these compacts, independent of their length, are safe even at optimum water moderation. Larger numbers of shorter compacts are safe. Their safe number can be obtained from Figure 1. For example, compacts having this cross section that are 10 inches long contain 179 gm U^{235} . Based on Figure 1, nine such compacts would be safe independent of spacing or the degree of water flooding. The actual compacts may contain more than 179 gm U^{235} . This may be due to a lower void volume fraction, or the compact may be slightly larger than 1.45" by 1.45". In either case use of Figures 1 or 2 will give conservative results when applied to such compacts. For example, if each 10 inches long compact contains 200 gm U^{235} eight of them would be safe independent of spacing between them or the degree of water flooding.

The maximum safe mass per unit area of an infinite, single-plane array as a function of water-to-fuel volume ratio is plotted in Figure 3. These values are based on 45 percent of calculated critical. The maximum safe mass per unit area at optimum water moderation is 0.65 Kgm contained U^{235} /ft² of floor area. Therefore, maximum safe batches (batches containing no more than 1.68 Kgm U^{235}) are always safe in a single plane infinite array when the edge-to-edge separation between batches is at least 20 inches.

IV. REFERENCES

1. N. Ketzlach, "Criticality of Fuel in SDR-1 Processing" Appendix I to Feasibility Report for Fabrication of SNAP 8 Fuel Elements, NAA-SR-6345, Rev. II, August 18, 1961.

FIGURE 3
MAXIMUM SAFE MASS PER UNIT AREA VS WATER-TO-FUEL VOLUME RATIO
(45 PERCENT OF CALCULATED CRITICAL)
(1.45" x 1.45" COMPACTS)

MAXIMUM SAFE MASS/UNIT AREA (Kgm CONTAINED U^{235}/ft^2)

1.0
0.8
0.6
0.4
0.2
0

WATER-TO-FUEL VOLUME RATIO

4

5

ATTACHMENT II

NAA-SR-TDR No. 6345, Rev. II, by N, Ketzlach, pages 34 of 53
and 39 thru 53.

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* See text for definition

APPENDIX II

CRITICALITY STUDY OF SNAP FUEL RODS

By

N. Ketzlach

I. STATEMENT OF PROBLEM

A request has been made to establish nuclear safety criteria for the processing and storing of SNAP fuel rods as a function of fuel rod diameter for unhydrided as well as for hydrided rods having an N_H of 6.0 to 6.5×10^{22} atoms/cm³. The unhydrided rods have a density of 7.0 gm/cm³ and contain 10% uranium (93.5 per cent U²³⁵) and 90 per cent zirconium by weight.

II. ABSTRACT

Maximum safe batch sizes have been determined as a function of the degree of water moderation for a number of fuel rod sizes (six inches minimum length). The maximum safe batch sizes in grams of contained U²³⁵ for hydrided rods, independent of container geometry and degree of water moderation, are 490, 590 and 810 for 0.25-inch, 0.50 inch and 1.25-inches diameter rods, respectively. This compares with 680, 950 and 1900 gm container U²³⁵ for unhydrided rods of corresponding diameters having the same uranium to zirconium ratio. Larger masses are allowable for very long fuel rods.

The safe batch sizes and safe number of storage units in arrays are summarized in seven figures and one table. Criteria are also presented for safe spacing between long pieces of equipment (i.e., furnaces) containing fuel material.

Presently used birdcages are 30 in. x 30 in. x 30 in. Centered inside this framework is a container for the fuel. Criteria have been established for the safe number of storage units in a three-dimensional array of these birdcages when the fuel-bearing section of the container has a maximum cross-sectional area of 29 square inches and a maximum height of 15 inches. An array of this type can have a maximum of 125 birdcages, each containing the maximum safe batch size. If the cross-sectional area of the fuel bearing section is increased to 38 square inches (7.0 inches diameter cylinder) the maximum safe number of storage units in a three-dimensional array is reduced to seven. However, in a single-plane array, containers having a diameter as large as 10 inches and placed on 30-inch centers are safe in any number.

III. INTRODUCTION

Minimum critical masses and critical geometries as a function of fuel rod diameter for unhydrided U-90 w/o Zr alloy rods were reported earlier⁽¹⁾. This earlier study is now extended to long rods which can not be made critical in spherical volumes required for the critical masses reported. The present study also established nuclear safety

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criteria for processing the hydrided rods made from this alloy. The range of N_H for which these criteria are applicable for all rod diameters considered is 6.0 to 6.5×10^{22} atoms/cm³. However, the criteria for homogeneous mixtures of finely divided hydrided alloy and water are applicable to all hydrided fuel densities equal to or less than that in the present study.

IV. METHOD OF ANALYSIS USED

Criticality conditions for water-flooded lattices of fuel rods, hydrided and unhydrided, were calculated using S_4 (IBM cylindrical cell code for the calculation of thermal group constants), MUFT-4 (IBM code for the calculation of fast group constants) and AIM-5 (IBM code of a multi-group, one dimensional diffusion equation) to determine the critical dimensions of spheres containing the fuel-water mixtures of interest. These systems were considered to be reflected by 30 cm of water. This is equivalent to an infinite water reflector.

The neutron cross sections for the S_4 calculations were dependent on the atomic ratio of U^{235} to H and the ratio of the summation of the macroscopic 2200 meters/sec. cross sections of the 1/v absorbers to the atomic hydrogen density.⁽²⁾

Material bucklings were calculated for various lattices of fuel in water from the critical sphere radii using 8 cm as the water-reflected cylinders containing fuel rods and water. The cross sectional area of each critical mass per unit length of cylinder. When plotted as a function of water-to-fuel volume ratio, the critical mass per unit length goes through a minimum.⁽³⁾

Critical infinite slab thicknesses are also calculated from material bucklings. For every fuel concentration there is a critical infinite slab thickness. The critical slab thickness multiplied by its corresponding concentration is the critical mass per unit area. When plotted as a function of concentration (water-to-fuel volume ratio) the critical mass per unit area goes through a minimum.

The maximum safe mass per unit area (based on optimum water moderation for minimum mass per unit area) may be used to evaluate nuclear safety of arrays. This method gives more and more conservative results the longer the fuel rods. Existing solid angle criteria⁽⁴⁾ may also be used to determine minimum distances between safe groupings of fuel. The application of the solid angle criteria requires a minimum edge-to-edge separation between safe groupings independent of the k_{eff} of a single grouping.

V. DISCUSSION OF RESULTS

The maximum safe batch size (45 per cent of calculated critical) for hydrided fuel rods having an $N_H = 6.5 \times 10^{22}$ atoms/cm³ is shown in Figure 1 as a function of water-to-fuel volume ratio for several fuel rod diameters. These data are for water-moderated and water-reflected fuel rods placed in spherical geometry. The dotted curve is a plot of the maximum safe

FIGURE 1

MAXIMUM SAFE BATCH SIZE vs WATER-TO-FUEL VOLUME RATIO
(45 PERCENT OF CRITICAL)
(SPHERICAL GEOMETRY)

FUEL ROD DIAMETER (INCHES)

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batch sizes as a function of water-to-fuel volume ratio for 0.5 inch diameter rods having an $N_H = 6.0 \times 10^{22}$ atoms/cm³. It is seen that the maximum safe batch size for the 0.5 inch diameter rods having the greater N_H is less than for those having the lower N_H . The difference, primarily due to the difference in hydrogen density in the fuel, becomes smaller and smaller as the water-to-fuel moderator ratio increases. At the larger water-to-fuel moderator ratios the difference in hydrogen density due to the fuel becomes negligible when compared to that in the overall water-to-fuel volume ratio. For the larger rod diameters it may be expected that the difference in maximum safe batch sizes between hydrided fuel rods having the same difference in hydrogen density will be greater. This is due to the lower water-to-fuel volume ratios for which the minimum critical masses occur for the larger rod diameter fuels.

The maximum safe batch sizes as a function of fuel rod diameter are taken from these minima and plotted in Figure 2, Curve A. Curve B is a similar plot for unhydrided rods based on results of an earlier study.⁽¹⁾ The homogeneous case was calculated in the course of the present study. Curve C for unhydrided rods is taken from Curve B so that the maximum safe batch sizes for the unhydrided rods can more directly be compared (on same scale) with those for the hydrided rods at the same fuel rod diameter. The difference between the maximum safe batch sizes becomes increasingly greater as the fuel rod diameter increases. The effect of the hydriding is much greater for the larger diameter fuel rods because of the more intimate contact between fuel and hydrogen in the hydrided rods than from the hydrogen from the water in water-flooded rod assemblies. It is interesting to note that the maximum safe batch sizes of homogeneous mixtures of water and hydrided fuel (zero rod diameter) is about 10 per cent greater than that for aqueous solutions of UO_2F_2 (350 gm U^{235}). The maximum safe batch size for homogeneous mixtures of water and unhydrided fuel (zero rod diameter) is about 13 per cent greater than that for the hydrided fuel and about 25 per cent greater than that for aqueous solutions of UO_2F_2 . There are several variables that cause this difference. Chief among these are the following:⁽¹⁾ differences in atomic ratio of H/ U^{235} at which the minimum critical masses occur and (2) differences in relationships between the H/ U^{235} atomic ratio and fuel concentration expressed in gm U^{235} /cm³ for the three systems.

Maximum safe batch sizes larger than those indicated for homogeneous mixtures should only be used when the fuel rod length is at least six inches. Since Figure 2 is based on spherical assemblies, use of this curve will give increasingly conservative results for very long fuel rods. A 1.25 inches diameter alloy fuel rod (unhydrided) contains about .158 Kgm U^{235} /ft length of rod. From Figure 2 the maximum safe batch size for 1.25 inches diameter fuel of this type is 1.90 Kgm contained U^{235} . Fuel rods of this diameter whose combined length is longer than 12.0 feet contain more U^{235} than allowable (based on spherical geometry). In the extreme case a single rod would be limited to 12.0 feet. A single rod of this diameter that is infinitely long can not be made critical. The maximum safe diameter for a more reactive fuel (highly enriched, unalloyed uranium metal) is 2.5 inches.⁽⁵⁾

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It is interesting to compare the maximum safe batch sizes of this zirconium fuel with those of unalloyed highly enriched uranium fuels as a function of fuel piece size. Criticality conditions for highly enriched uranium fuel pieces as a function of fuel material size and water moderation have been determined experimentally.⁽⁶⁾ The fuel piece sizes used were, one inch and one-half inch cubes and one-eighth inch diameter by 12 inches long rods. The minimum critical masses obtained for each fuel piece size at optimum water moderation and reflection were plotted as a function of equivalent fuel piece sphere diameter. Earlier data was already available for the critical mass of a single sphere reflected by water. The cube sizes were converted to spheres having the same masses. The one-eighth inch diameter rods were assumed to be equivalent in reactivity to spheres having the same diameter. A more appropriate conversion, at least for this diameter fuel rod, appears to be by equating the geometric buckling for spheres and cylinders. Using this method, spherical pieces of 0.163 inch diameter are equivalent to the 0.125 inch diameter rods. This change results in better agreement between the curve drawn and all the experimental points.⁽⁶⁾ Based on this data the maximum safe batch size (45 per cent of critical) at optimum water moderation and reflection is plotted in Figure 3, as a function of fuel piece sphere diameter (Curve A). The dotted portion of this curve in the upper range is in an area where there is no experimental data. The curve is extended in the opposite direction as a dotted line to safe masses based on homogeneous solution data. The upper curve (Curve B) is drawn dotted as an estimate of the critical masses of cylindrical rods as a function of rod diameter. The point for one-eighth inch diameter rods is given because it is an experimental point. That portion of this curve for fuel rods having diameters larger than this is based on the spherical data curve using the geometric buckling conversion.

The curve is extended in the opposite direction as a dotted line to safe masses based on homogeneous solution data. Until it can be shown that this buckling conversion method is valid over the entire range of fuel sphere and cylinder diameters, it must be considered as non-conservative to use this upper curve. However, it appears to be safe to use the sphere curve for cylindrical fuel rods having the same diameter as that of the sphere, particularly for diameters less than two inches. The much greater masses allowable for unalloyed fuel rods than for alloyed ones (Figure 2) emphasizes the importance of fuel composition in evaluating nuclear safety parameters. The unalloyed fuel, although it has a much larger U^{235} concentration than the alloyed fuel, has a smaller safe batch size only for finely divided fuel homogeneously mixed with water. Similarly, it is not safe to use the data in Figure 2 for highly enriched uranium-zirconium alloys having a uranium content less than 10 percent used in the present study. Only for the homogeneous cases will the maximum safe batch always be less than that for alloy fuels containing smaller percentages of U^{235} .

Where the criteria as given by Figure 2 become overly restrictive, the mass per unit length principle⁽³⁾ may be applied. The maximum safe mass per unit length (45 percent of calculated critical) for infinitely long rods is plotted in Figure 4 as a function of water-to-fuel volume ratio for several hydrided fuel rod diameters. The minima from these

MAXIMUM SAFE BATCH SIZE (Kgm U^{235})

FIGURE 4
MAXIMUM SAFE MASS PER UNIT ROD LENGTH vs WATER-TO-FUEL VOLUME RATIO (HYDRIDED RODS)

ROD DIAMETER (INCHES)

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curves are plotted as a function of fuel rod diameter in Figure 5. The data for unhydrided rods are based on the earlier study.⁽¹⁾ Curve A is for hydrided rods and the dotted Curve B is for unhydrided rods. Curve C, for unhydrided rods, is drawn to the same scale as Curve A so that a comparison between the maximum safe parameters for hydrided and unhydrided rods, is drawn to the same scale as Curve A so that a comparison between the maximum safe parameters for hydrided and unhydrided rods can be more readily made. From Figure 5 it is seen that the maximum safe mass/unit length for the 1.25 inches diameter unhydrided rods is 1.15 kgm U^{235} /ft length of rod. Since the U^{235} concentration for rods of this composition and diameter has a density of 0.158 kgm U^{235} /ft length of rod, the maximum safe number of rods, independent of length is seven.

For short rods the use of Figure 2 will give less restrictive results. Consider fuel rods 12 inches long and having the same diameter and composition as in the example used. Where there is no control of spacing between rods or the degree of water flooding, the maximum safe number of rods is based on Figure 2. The use of Figure 5 would allow only the handling of seven such rods under the same conditions. The application of Figures 2 and 5 to the handling of fuel lengths is obvious.

In the earlier report⁽¹⁾ it was shown that the minimum critical slab thickness and cylinder diameter for containers of the unhydrided fuel occurs at a particular water-to-fuel volume ratio depending on the fuel rod diameter. For the hydrided fuel rods these critical parameters occur when there is no water intermixed with rods. The critical dimensions for containers holding the hydrided rods are 4.8 inches diameter for cylinders and 0.96 inches for the infinite-slab thickness. Using the criteria for safe geometries presented in the Nuclear Safety Guide⁽⁵⁾ as a basis, the safe geometries may be considered as 4.0 inches diameter for cylinders and 0.75 inch thickness for slabs.

The maximum safe mass per unit area of floor space (based on infinite slabs as discussed under Methods of Analysis) is shown in Figure 6 as a function of water-to-fuel volume ratio for several hydrided-fuel rod diameters. The minima from these curves are plotted in Figure 7 as a function of fuel rod diameter. These values are 45 per cent of critical at optimum water moderation and reflection. Based on Figure 7, any safe batch size for the hydrided fuel rods given in Figure 2 may be placed in a single plane infinite array with a minimum edge-to-edge separation between batches of 20 inches. This is independent of spacing between fuel pieces within a single batch or the degree of water-flooding.

For two and three dimensional arrays other criteria must be used. The data presented in Table I may be used as criteria for the safe storage in a two dimensional array, of all safe batches presented in this report.

FIGURE 6

MAXIMUM SAFE MASS PER UNIT AREA vs WATER-TO-FUEL VOLUME RATIO (HYDRIDED RODS)

MAXIMUM SAFE MASS/UNIT AREA ($K_{gm} U^{2.35} / Ft^2$)

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TABLE IMinimum Safe Spacing For Two Dimensional Arrays

Container Height (inches) (5 inches Dia. Cylinder)	Edge-to-Edge Spacing (Feet)	
	<u>In Line Array</u>	<u>Infinite Array-Square Spacing</u>
30	1.25	1.5
48	1.5	2.0
00	2.5	4.5

These safe spacings are based on interaction criteria presented in the Shipping Guide.⁽⁴⁾ Using the same solid angle criteria presented in the referenced report safe separations between two-and three-row groups of cylinders, have been calculated with the center-to-center distance between rows the same as that between cylinders within a row. Two rows of cylinders (five cylinders per row) are safe with a minimum center-to-center separation of 12 inches, 17 inches, and 31 inches when the cylinder diameters are 4 inches, 5 inches and 6 inches, respectively. Each cylinder not safe by geometry should contain no more than the maximum safe batch size as given in Figures 2 or 5. For the same diameter cylinders in three rows (five cylinders per row) the minimum center-to-center spacing should be 16 inches, 26 inches, and 49 inches, respectively. The above criteria are safe for fixed arrays as in birdcages, pieces of equipment held in position to the floor or wall of a room, etc. No allowance is made for the transportation of fuel between units within the array. If the safe distances are doubled, it is safe to transport a single safe batch between any units of the array.

For a three dimensional array the number of safe storage units in a single array is a function of fuel mass per container, fuel distribution within a container, container size, and spacing between containers. Criteria for safe storage in three dimensional arrays have been formulated.⁽⁷⁾ Based on these criteria it is safe to store 70 safe batches provided each batch is held within a cross sectional area of 29 square inches, has a maximum height of 15 inches, and is centered in a birdcage or its equivalent that is at least 30 inches on a side. Based on the maximum allowable solid angle criteria for a given k_{eff} 125 safe containers are allowable in a three dimensional array when the storage unit has a maximum cross sectional area of 29 square inches, has a maximum height of 15 inches, and is centered in a birdcage 30 inches on a side. When the cross sectional area of the fuel holding container is equal to that of a seven inches diameter cylinder, the maximum safe number of units is reduced to seven.

In any fuel handling or fabrication facilities where a number of different fuels may be handled with the same equipment, it is very important to take into account the possibilities of several fuel types being in a given room at the same time. It is therefore essential to establish work stations (i.e., melting, hydriding, etc.) where only a

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single type fuel may be handled at a given time. The maximum safe batch sizes at each such station must be clearly posted. This will make it possible for the Criticality Safeguards Coordinator to establish maximum allowable masses for a given room. The number of work stations in a room times the allowable mass of fuel per station is equal to the total fuel allowable in the room. This is especially simplified when only a single batch is allowed per station. Unless there are fixed positions where safe batches are placed (i.e., birdcages, partitioned shelves, etc.), only a single safe batch should be allowed per station.

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