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CRITICALITY SAFETY STUDIES OF A PROPOSED URANIUM-ZIRCONIUM ALLOY FUEL FABRICATION FACILITY

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Oak Ridge, Tennessee USA 37831-8223

Presented at the
American Nuclear Society
1990 Annual Meeting
Nashville, Tennessee USA

June 5, 1990

Prepared for the
Nuclear Criticality Safety Department
Oak Ridge Y-12 Plant
Oak Ridge, Tennessee USA 37831-8223
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U. S. DEPARTMENT OF ENERGY
under contract DE-AC05-84-OR21400

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DEPARTMENT OF ENERGY

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The purpose of this project is to provide criticality limits and guidance for the initial planning phase of a new facility for the production of a new metal alloy fuel material for the Hanford N Reactor. The proposed fuel material composition is a uranium-zirconium alloy consisting of approximately 90.7 weight percent zirconium and 9.3 weight percent uranium. While the anticipated enrichments range from 55 to 70 weight percent ^{235}U, this analysis considers only 100 weight percent ^{235}U for simplicity and conservatism. The fuel material would be produced in the form of a solid, as-cast double billet using an arc melter process. Two finished billets result from one as-cast double billet.

The production process poses several criticality safety concerns that require evaluation. These concerns include non-homogeneous alloy formation in the arc melter, as-cast billet storage, and finished billet storage. All analyses were performed using the KENO V.a module of the SCALE computer code system with the 27 group, ENDF-IV based cross section library.[1] All calculations were performed on the IBM 3033 computer at Oak Ridge National Laboratory.

One important phase of the project was to calculate some applicable critical experiments to provide justification for the use of the k-eff safety limit chosen for this project since previous benchmark quality work with high volume ratio zirconium systems is lacking in the open literature. The best data available is some work performed as part of the SNAP reactor program in the early sixties.[2,3] This data was chosen because its enrichment is similar to that proposed for the Hanford reactor and because it uses uranium-zirconium hydride fuel.

Extensive experimental work was performed with a critical assembly designated as SCA-4C (SNAP Critical Assembly) whose core was a close packed triangular array containing 37 elements. The assembly was initially loaded with 37 lucite dummy rods. Phase I experiments indicated criticality was achieved with 32 fuel rods and an excess reactivity of approximately 62.0 cents. Phase II experiments indicated criticality was achieved with 31 fuel rods and an excess reactivity of approximately 11.7 cents. The results of a sensitivity analysis shown in Table 1 for variations in the calculational model indicate that the model is reasonable and KENO V.a handles large concentrations of zirconium quite well.

Three cases concerning non-homogeneous alloy formation have been examined: all uranium as right circular cylinder at the center of the as-cast billet, all uranium as a circular slab at the bottom of the as-cast billet, and all uranium as a sleeve around the zirconium in the as-cast billet. The maximum k-eff for each case occurs when the units are placed in a 3x3x1 array with full density water moderation and reflection. In each case the maximum k-eff is larger than the somewhat arbitrarily chosen safety limit of 0.90 which indicates a need for engineered physical controls.

The as-cast billets were evaluated in a 9x1x1 array with concrete reflection on two sides, representing a floor and a wall, and full density water reflection on the other four sides. The maximum k-eff was found by varying the volume fraction of the interstitial water and the pitch of the billets. The as-cast billets are safe under normal conditions (i.e. k-eff < 0.9) but an adequate safety margin does not exist under certain accident conditions such as placing an additional billet next to the center of the array (k-eff = 0.954 +/- 0.004). Thus, engineered physical controls would be necessary for safe storage of these billets.

The finished billets were examined using a fixed pitch with concrete reflection on three sides, corresponding to a floor and two walls in a corner, and full density water reflection on the other three sides. The maximum k-eff was found by varying the volume fraction of the interstitial water moderator. The billets were placed in two different arrays: a 16x15x1 array and a 12x10x2 array. The maximum k-eff value for both arrays occurs at a volume fraction of 0.10. The single layer array has a maximum k-eff of 0.758(0.005) while the double layer has a maximum value of 0.972(0.005).

In general, all phases of material storage present a criticality concern and must therefore be controlled. Non-homogeneous alloy formation could present serious problems if the billets are placed in storage arrays with the possibility of water moderation; therefore, proper arc melter operation must be assured at all times. As-cast billets cannot be stored without engineered physical controls.

Finished billets may be stored in a single layer array. If multi-layer storage is desired, some form of additional engineered physical control must be employed. The benchmark results indicate that the chosen safety limit of 0.90 could possibly be relaxed to 0.95; however, some additional work should be done to verify this new limit.

1. L.M. Petrie and N.F. Landers, "KENO-Va, An Improved Monte Carlo Criticality Program with Supergrouping", NUREG/CR-0200, ORNL/NUREG/CSD-2, vol. 2, sect. F11, Oak Ridge National Laboratory(1985).

2. A.R. Dyers, W.A. Flynn, and J.P. Hawley, "SNAP 10A Reactor Nuclear Analysis", NAA-SR-9754, North American Aviation, Inc., January 1965.

3. D.W. Clifford, "Final Report on the SNAP 10A Prototype Critical Assembly Studies", NAA-SR-8613, North American Aviation, Inc., April 1964.

Criticality Safety Studies of a Proposed U-Zr Alloy Fuel Fabrication Facility

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Overview

- Introduction
- Fuel Design
- Fuel Material Fabrication Flowpath
- As-Cast Billet Storage
- Benchmark Comparison
- Summary of Other Studies
- Conclusions
- Future Work

Purpose

- To provide criticality limits and guidance for initial planning phase of a new fuel production facility

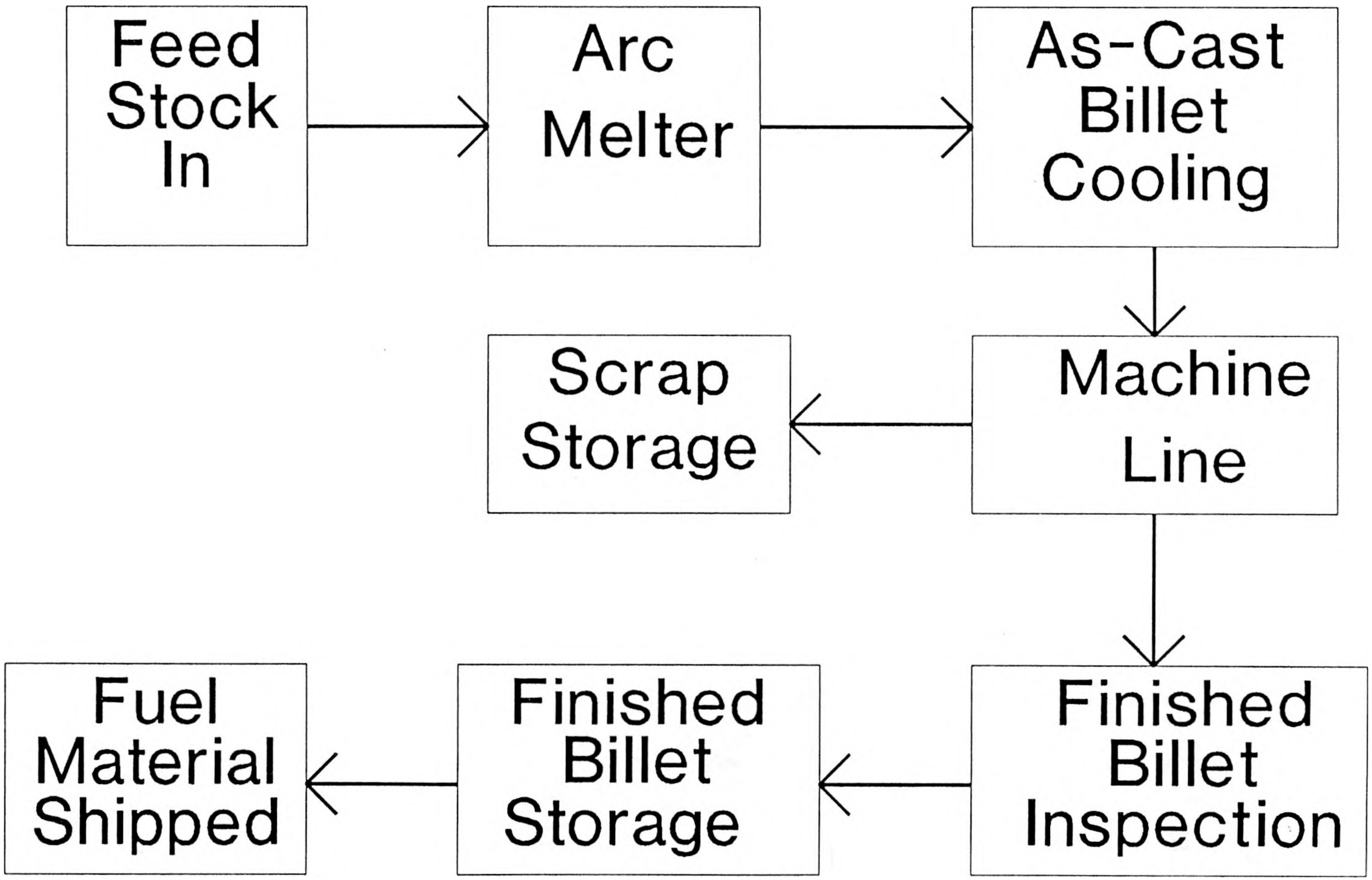
Background

- The restart of Hanford's N Reactor with a new metal fuel design is being examined
- This work pertains to the criticality safety analysis of the new production facility to be located at the Oak Ridge Y-12 Plant

Proposed Fuel Design

- Uranium-Zirconium Alloy
- Alloy: 90.7 weight percent zirconium and 9.3 weight percent uranium
- Possible enrichments range from 55 to 94 weight percent 235-U

Production Facility Flowpath



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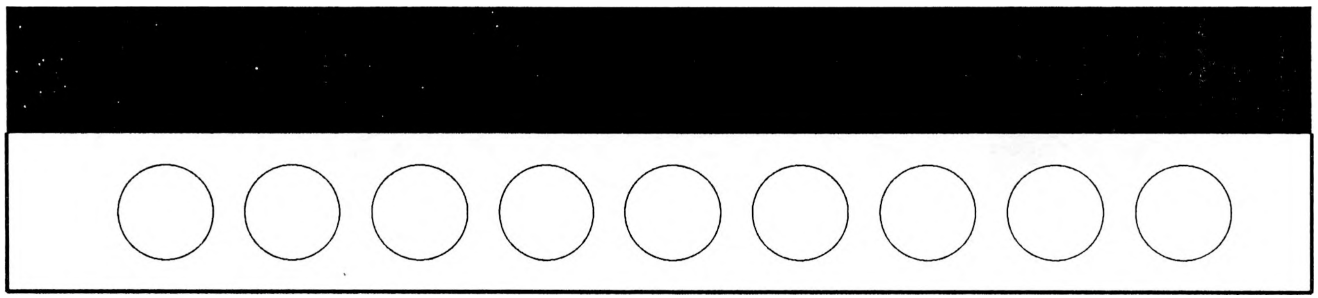
As-Cast Billet Storage Array



FULL DENSITY WATER MODERATION AND REFLECTION

Maximum k-effective
0.888(0.005)

■ Concrete

□ Water

○ Billet

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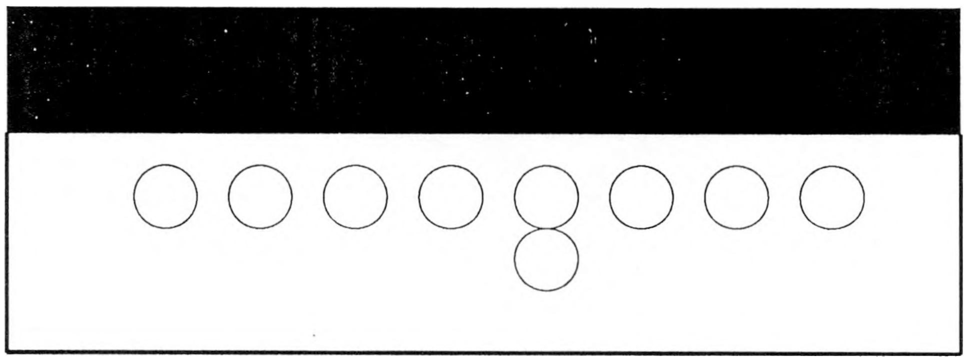
As-Cast Billet Storage Evaluation



FULL DENSITY WATER MODERATION AND REFLECTION

k-eff=0.954(0.005)

Concrete

Water

Billet

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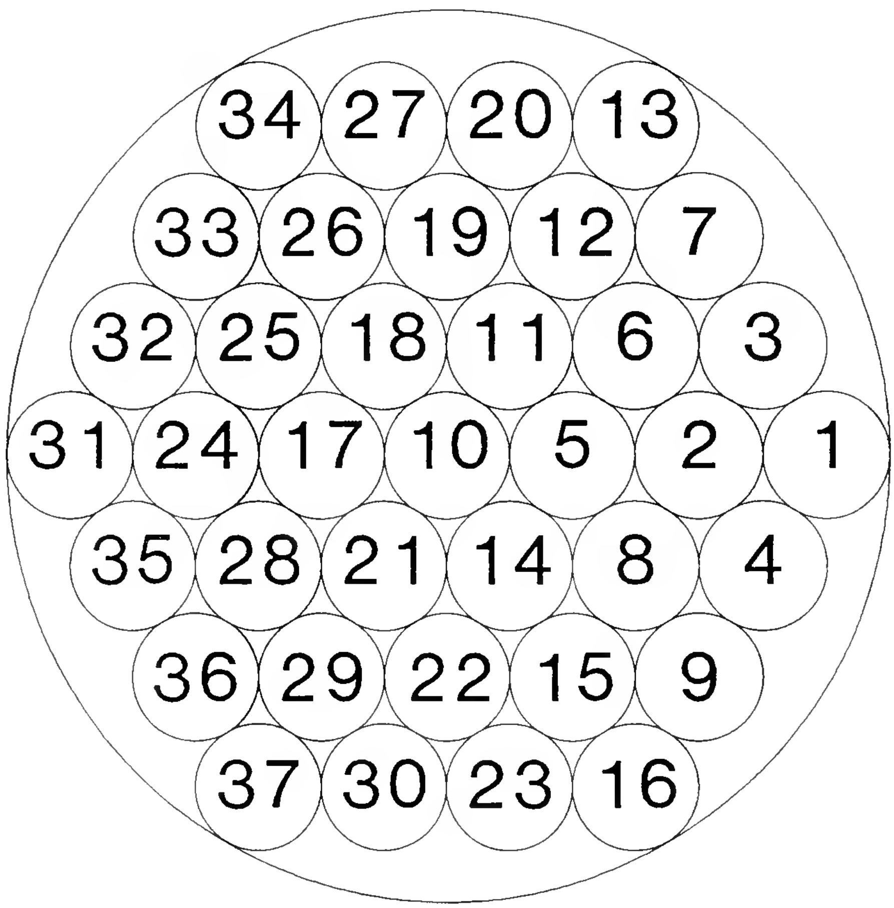
Benchmark
Comparison

- Try to calculate applicable critical experiments using same computational tools and cross section libraries used for storage analyses

SCA-4C Core Layout

Core Barrel=9 inches ID



Fuel Pin Diameter=1.25 inches

Active Fuel Height = 12.25 inches

Table 1: SCA-4C Benchmark Results

Case	Number of Fuel Rods	k-effective (± 1 SD)	Percent Change *
I	32	1.039(0.005)	–
I	31	1.031(0.005)	–
II	32	1.043(0.006)	0.4
II	31	1.033(0.006)	0.2
III	32	1.018(0.005)	2.0
III	31	1.003(0.006)	2.7
IV	32	1.051(0.006)	1.2
IV	31	1.050(0.005)	1.8
V	32	0.985(0.006)	5.2
V	31	0.978(0.005)	5.1

* Relative to the Base Case

I Base Case (Low Density Poison)
II No Poison
III High Density Poison
IV Steel Reflector Top and Bottom
V No Internal Beryllium Reflectors

Finished Billet Summary

- Constant Pitch
- Full density water reflection
- Vary water density to find max k-eff
- Both peaks at VF=0.10
- Single layer array safe k-eff=0.758(0.005)
- Double layer array unsafe k-eff=0.972(0.005)

Stratification Summary

- Three configurations examined
  - All U as right cylinder at center of billet
  - All U as cylindrical slab at bottom of billet
  - All U as sleeve on outside of billet
- Maximum k-eff for each case indicated a need for administrative quality control to insure proper arc melter operation

Scrap Material Study

- Metal shavings are generated during the machining process
- Uranium and zirconium are pyrophoric as shavings
- Water storage is required
- Mass Limits
  - 25 kg per 55 gallon drum
  - 15 kg per 30 gallon drum

Conclusions

- Benchmark Comparison Indicates KENO V.a models problem very well
- Proper arc melter operation must be assured
- As-cast billet storage requires engineered physical constraints
- Finished billet storage
  - Single layer safe
  - Double layer requires additional engineered physical constraints

Conclusions
(continued)

- Scrap Storage in 55 and 30 gallon drums is safe when mass limits are not exceeded
- Additional engineered physical constraints are necessary for scrap storage if double batching is to be considered
- In general, all phases of material storage pose some sort of criticality safety concern

Future Work

- Benchmark Comparison
  - Sampling of Samarium Trioxide regions
- Scrap Study
  - Short cylindrical pieces

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