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OPTIMIZING A THREE-ELEMENT CORE DESIGN FOR THE ADVANCED NEUTRON SOURCE REACTOR*

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Introduction

The source of neutrons in the proposed Advanced Neutron Source facility is a multipurpose research reactor providing 5 to 10 times the flux, for neutron beams, of the best existing facilities. The project team constrained the design with the "no new inventions rule," which states that the design should not rely on the development of new technology to meet the minimum design criteria (although R&D that can lead to further major improvements beyond the minimum requirements is encouraged).

The baseline design[1] for the reactor core, based on this objective and within this constraint, was an assembly of two annular fuel elements similar to those used in the high flux reactors at Oak Ridge and Grenoble, containing highly enriched (93%) uranium silicide particles. Subsequently, the Department of Energy commissioned a study of the impact on performance and on cost of using medium- or low-enriched uranium. In the course of that work, a three-element core design was studied as a means to provide extra volume to accommodate the additional uranium compound required when the fissionable ^{235}U has to be diluted with ^{238}U to reduce the enrichment.[2,3] This paper describes the design and optimization of that three-element core.

Design

Figure 1 compares the two- and three-element designs. Reference 1 describes the optimization studies carried out earlier in the course of selecting the reference core. There is an optimal size for these fuel elements because of the tradeoff among volume, power density, and rendement (the ratio of thermal neutron flux to reactor power).

As the fuel element length is increased, the coolant pressure drop across it increases, resulting in a lower pressure at the core outlet under any given conditions of inlet pressure and coolant velocity: accordingly, the greater the length, the lower the heat flux that can be accommodated without exceeding thermal safety limits (e.g., boiling) . Very short elements have a small volume and, therefore, cannot accept much power; very long elements have a large volume, but the lower outlet pressure (for any given inlet pressure and coolant velocity) limits the safe heat flux or the power density compared with a shorter core. Thus, there is a length, neither very short nor very long, that maximizes the safe reactor power.

The volume of the element can also be increased by increasing its radial thickness. However, the stiffness of the thin, aluminum-clad fuel plates (shaped into an involute curve between the inner and outer sideplates of the annuli) becomes less as their span is increased. The hydraulic forces from the cooling water cause deflections and stresses within the plates that become unsafe beyond a certain plate span; to compensate for this, the coolant velocity and, therefore, the safe heat flux and power density, would have to be reduced if the radial thickness of the element were increased beyond a certain limit.

Increasing the length also spreads out the source of neutrons and so reduces the rendement. The maximum useful thermal neutron flux (for neutron beam experiments we are concerned with the peak flux outside the core, in the reflector region that is accessible to beam tubes and guides) is the product of reactor power and rendement. This product will have a maximum at a certain length, which turns out to be less than the length that maximizes power.

Results

Trading off these various relationships leads to an optimum set of dimensions for the fuel elements. Maximizing the useful neutron flux without exceeding the incipient boiling power limit leads to an optimum volume of 67.6 L for a two-element core design and of 82.6 L for a three-element design (Fig. 2).

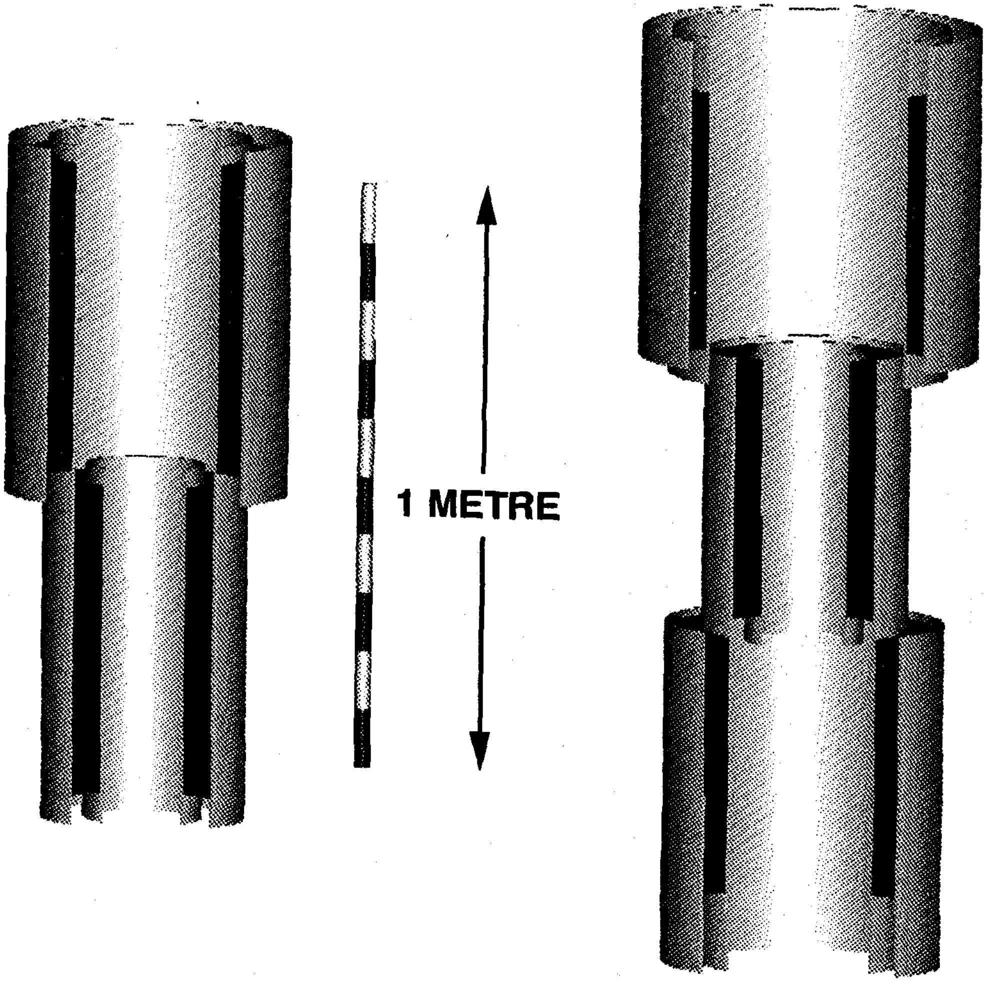
The optimum two-element design has a higher rendement and, therefore, a higher neutron flux at any given power level, than the three-element one by about 15% because of its smaller volume and surface area. On the other hand, the extra volume of the three-element core provides space for additional uranium, so it can operate with fuel of lower enrichment. In fact, if cores with the same lifetime (17 days) are compared, the three-element design has a higher flux when an enrichment of less than about 70% must be used (Fig. 3). Because of this added flexibility, the project has recommended adoption of the three-element, 82.6-L design.

References

1. G. L. Copeland et al., "Advanced Neutron Source Final Preconceptual Reference Core Design," ORNL/TM-11234, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., August 1989.

2. R. A. Bari et al., "Advanced Neutron Source Enrichment Study," draft preliminary report, Brookhaven Natl. Lab., December 1993.

3. E. E. Alston et al., "Fuel Density, Uranium Enrichment, and Performance Studies for the Advanced Neutron Source Reactor," ORNL/TM-12775, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., June 1994.



BASELINE TWO-ELEMENT CORE

82.6L , THREE-ELEMENT CORE

Figure 1

Maximum Safety Margin Between Operating Power and the Incipient Boiling Limit vs. Core Volume (3 element cores)

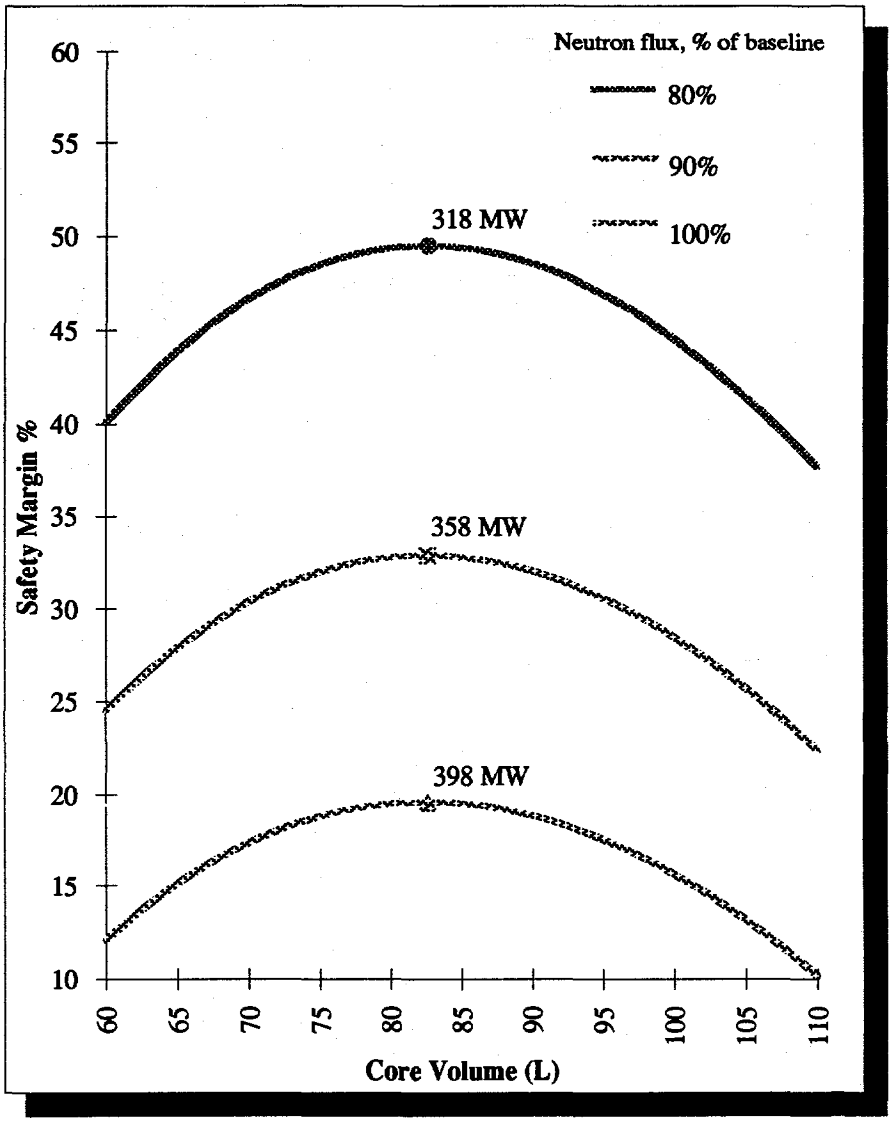


Figure 2

Compared with the baseline, the three element design has better performance below 70% enrichment but it has about 17% less flux with HEU (example shown is for 330 MW max. power, 17 day core life and 2.2 g U/cc in the fuel meat)

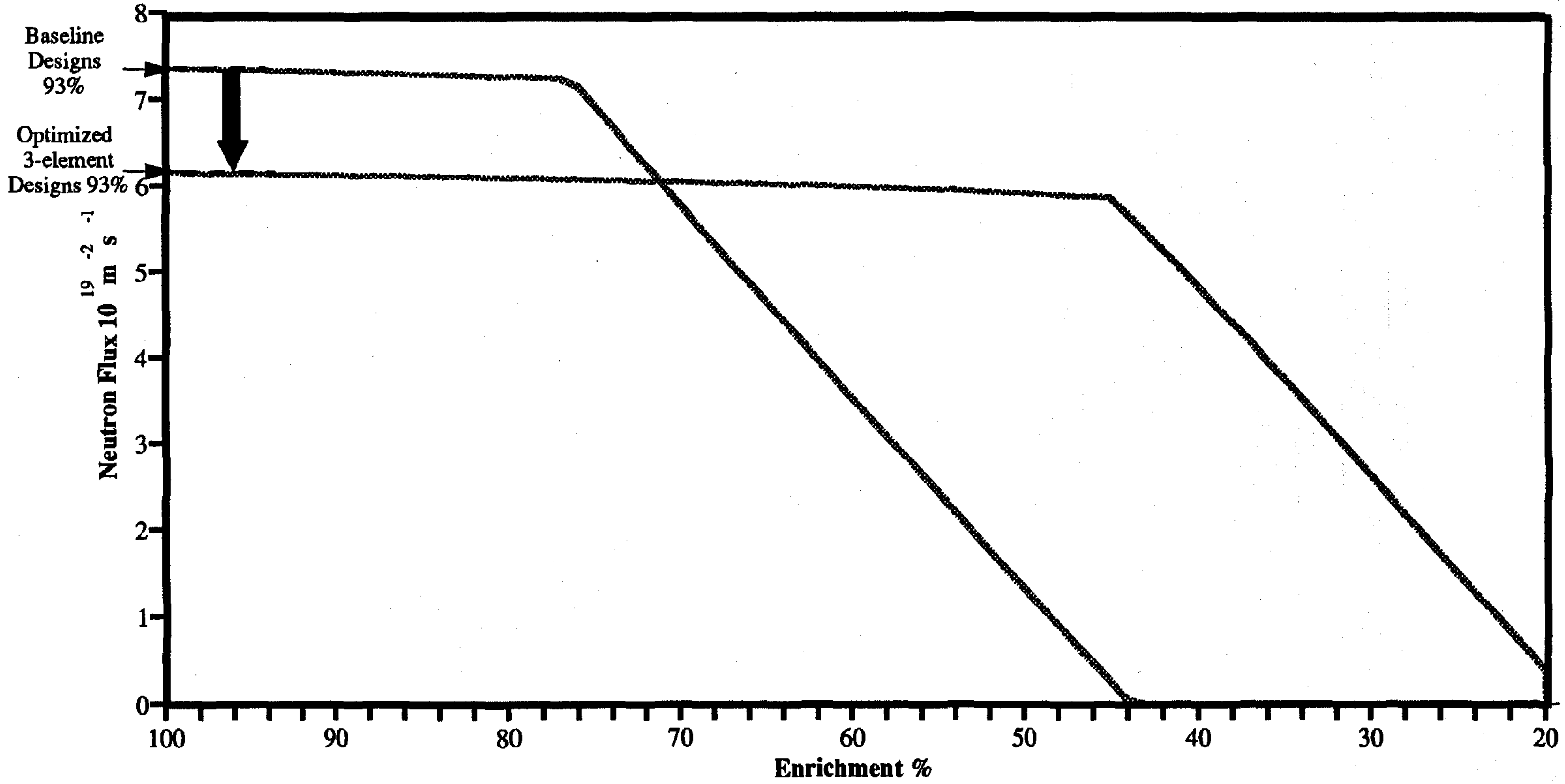


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Figure 3