CONF-790602-52

MASTER

Theoretical Evaluation of Ex-Vessel Monitoring for Initial Fuel Loading of a Liquid Metal Fast Breeder Reactor

J. T. Mihalczo, D. L. Selby, H. E. Knee
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

Transport theory calculations were used to determine the feasibility of monitoring the fuel loading to initial criticality of the Clinch River Breeder Reactor (CRBR) with a detector in a cavity outside the reactor vessel. Such monitoring of the CRBR with an ex-vessel detector will be different from monitoring of previous LMFBRs[1,2] where in-vessel detectors were used. The feasibility of ex-vessel monitoring will depend mainly on two criteria: (1) sensitivity -- will there be enough counts to obtain adequate counting statistics; and (2) interpretability -- will the count rate obtained during the initial fuel loading sequence be sufficient to determine the neutron multiplication or reactivity? Satisfying these criteria will assure that the reactor can be loaded safely to initial criticality.

The sensitivity criterion can be satisfied by inserting an additional neutron source (one much more intense than the inherent neutron source of the fuel subassemblies) into the core center and using ex-vessel detectors with high sensitivity, such as multiple BF_3 counters mounted in a graphite moderator block. These calculations were used to determine the intensity of the additional source required to produce adequate counting rates at the ex-vessel detectors.

---

*Research sponsored by the Division of Reactor Research and Technology, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

wDm

The interpretability of the ex-vessel detector count rates as the initial fuel loading sequence proceeds was assessed by comparing the calculated inverse neutron multiplication curves for the additional source present with those calculated without the additional source and a detector located in the center of the core.

The proposed initial fuel loading sequence is as follows: first, a neutron source will be inserted in the central subassembly of the core, which has been loaded with dummy subassemblies (no fuel pins) for hydraulic flow testing. Next, all control rods and the core and radial blanket subassemblies will be inserted. The fuel assemblies will be loaded from the core center to the outside rows, with an effort to equalize the reactivity change associated with fuel subassembly insertion in the latter part of the loading. This equalization will be accomplished by loading the outer rows symmetrically. The fuel and control rod locations for a 120° sector of the core and the fuel loading pattern are shown in the insert on Fig. 1. Loading all blanket subassemblies before loading the fuel subassemblies will result in an assembly that will be more easily understood, since only one variable (fissionable fuel) will be changing. Nevertheless, there will be changes in scattering materials, since fuel subassemblies will be replacing dummy subassemblies. The response of the ex-vessel detectors to insertion of the source and to addition of blanket subassemblies will be compared with the results of calculations before fuel is inserted. Symmetry of the loading sequence will assure that the responses of all three ex-vessel detectors to fuel additions will be the same. Thus, large differences in detector responses will indicate instrumentation malfunction.

The ENDF-B-IV cross-section file was processed with a modified version of the AMPX system[3] at ORNL to produce the 45-group cross-section set required in these calculations to accurately predict the neutron penetration through sodium and steel. Three-dimensional calculations were performed using the KENO IV Monte Carlo code[4] to determine energy- and region-dependent (one row of fuel or blanket per region) axial leakages, which were then used in two-dimensional S_4 calculations to correct for axial leakage effects.

Because of the complexity of these calculations, those for ex-vessel detector response were done in two parts. First, the discrete ordinates code DOT IV,[5] with an r,θ mockup of the central region through the fixed radial shield (60° sector, which includes core, radial blanket, and shield), was used to obtain an angular-dependent boundary source (the forward calculation). In the second step, the ^{10}B reaction-rate cross section was used as a source in an r,θ, DOT IV adjoint-source calculation to determine the importance to the detector response of all neutrons from the boundary source. The angular and spatially dependent flux from the forward calculation was combined with the angular and spatially dependent importance from the adjoint calculation to obtain the detector response. One adjoint calculation (∿10 hr of IBM-360-91 cpu time) was used for all configurations; one forward calculation (∿3 hr of cpu time) was required for each configuration.

Figure 1 shows (1) the inverse count rate for a fission chamber at the core center resulting from the neutron multiplication of the inherent source of neutrons from the fuel subassemblies and (2) the inverse count rate for an ex-vessel detector resulting from the neutron multiplication of the additional neutron source (2×10^{10} neutrons/s) at the core center. These inverse count rates are plotted as a function of the number of fuel subassemblies inserted (with the secondary and the row 4 primary control rods withdrawn). In addition to the dependence of the inverse count rate on neutron multiplication, the shape of the inverse count rate curve for the centrally located fission chamber depends on the effects of both the inherent source and the fuel being added around the detector. The shape of the ex-vessel detector curve results from the increase in the scattering materials between the additional neutron source and the ex-vessel detectors as fuel subassemblies are inserted. These calculations show that both types of monitoring of the initial loading provide meaningful extrapolations to the same delayed criticality condition. The reaction rates in an ex-vessel BF_3 detector were 35, 71, 320, 480, 1630, and 10,500 counts/s per gram of ^{10}B for full loadings of rows 1, 2, 3, 4, 5, and 6, respectively.

These calculations show that monitoring of the CRBR with an ex-vessel detector is feasible. This conclusion should be verified by initial loading experiments with mockups of the CRBR before the sensibility of ex-vessel monitoring is demonstrated. However, since such prototypic verification experiments may not be possible due to the size limitations of the critical experiment facilities, it might not be possible to mock up the detector core configuration experimentally. An in-core or in-vessel detector with remote signal transmission will be capable of monitoring the initial loading.[6] The initial loading can not be monitored with both a central in-core detector and an ex-vessel detector simultaneously, since the intense central source required for the ex-vessel detector would mask the response of the centrally located in-core detector to fuel loading changes. However, it would be possible to monitor the loading with a central source and a detector located at the outer edge of core or at other in-vessel locations.

REFERENCES

1. P. P. Clauzon, J. Boyer, J. Goundow, J. Martin, and J. Mougnoit, "Experimental Physics Results at the Startup of Phenix," *Int. Conf. Physics Fast Reactors, Tokyo, Oct. 16-23, 1972.*

2. Personal communication from D.C.G. Smith and R. C. Wheeler, Dounreay Experimental Reactor Establishment, 1974.

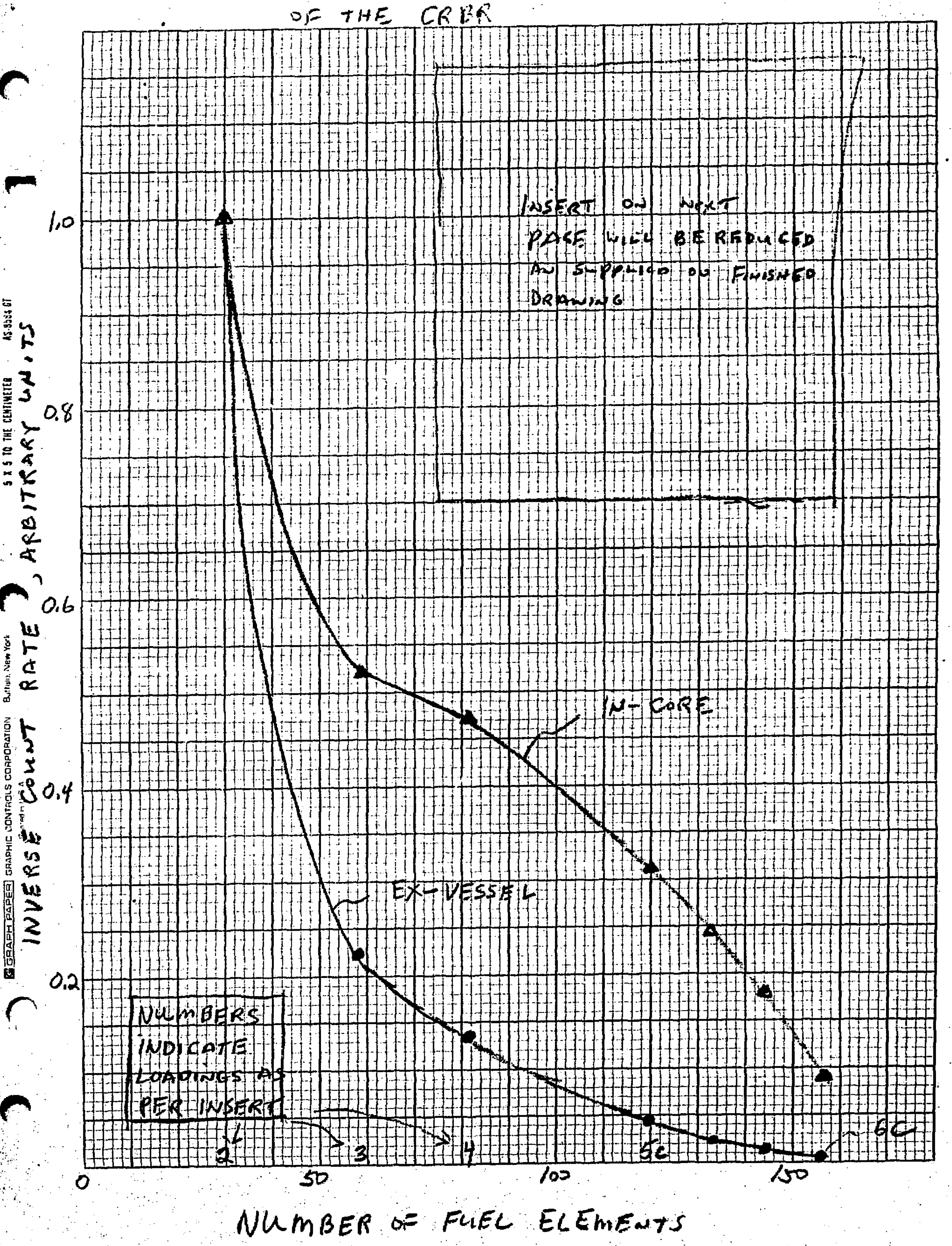
3. N. M. Green, J. L. Lucius, L. M. Petrie, W. E. Ford, III, J. C. White, and R. Q. Wright, *AMPX: A Modular Coded System for Generating Coupled Multi-Grouped Neutron-Gamma Libraries from ENDF/B*, ORNL-TM-3706 (1976).

4. L. M. Petrie and N. F. Cross, *KENO-IV: An Improved Monte Carlo Criticality Program*, ORNL-4938 (November 1975).

5. W. A. Rhoades, D. B. Simpson, R. L. Childs, and W. W. Engle, Jr., *The DOT-IV Two-Dimensional, Discrete-Ordinates Transport Code with Space-Dependent Mesh and Quadrature*, ORNL-5283 (1978).

6. Personal communication from J. T. De Lorenzo, ORNL, 1979.

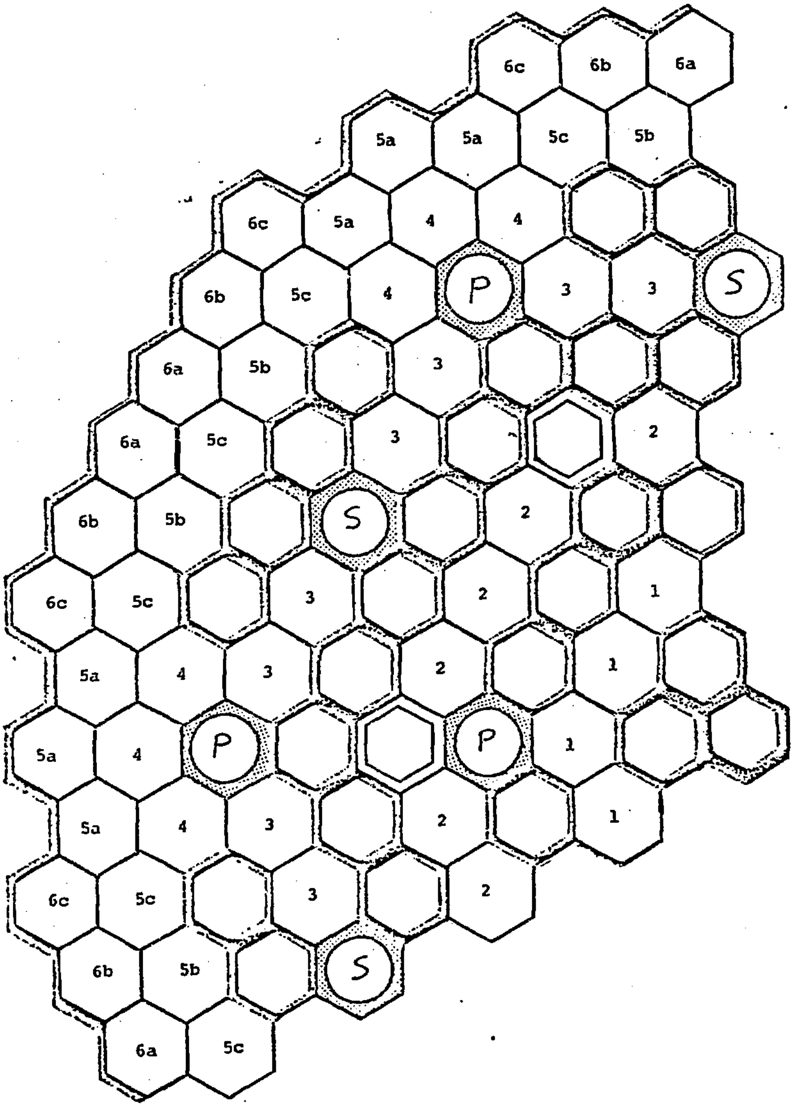
[illegible] — INVERSE COUNT RATE VS FUEL ASSEMBLIES LOADED FOR IN-CORE AND EX-VESSEL MONITIRING OF THE CRBR



INSERT ON NEXT PAGE WILL BE REDUCED AN SUPPLIED ON FINISHED DRAWING

INSERT FOR FIG 1

120° SECTOR OF CRBR CORE



P and S indicate primary and secondary control rod locations and black HEXAGONS INDICATE BLANKET ASSEMBLIES. NUMBERS INDICATE STEPS IN THE LOADING SEQUENCE.