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THE DESIGN AND PROPOSED UTILIZATION OF THE SANDIA ANNULAR CORE RESEARCH REACTOR (ACRR)

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ABSTRACT

The Sandia ACRR became operational in 1978 and currently serves as the major in-pile fast reactor safety test facility for the U.S. Nuclear Regulatory Commission. The ACRR is an upgrade of the Annular Core Pulse Reactor (ACPR) with the installation of a new flexible control system and a core of uniquely designed $BeO-UO_2$ fuel elements for increasing the neutron fluence in the experiment cavity. The reactor is now capable of driving multi-pin advanced reactor test fuel into vapor with a pulse width of 5 msec. In the steady state mode, the reactor can simulate post accident decay heat at prototypic levels in fission heated debris beds up to 10 cm in diameter. A number of programmed operating modes including high power square waves, ramps and pulses can produce a multitude of power profiles in order to simulate the power histories in the various accident scenarios. The reactor capabilities and the reactor safety research test program are discussed in this paper.

INTRODUCTION

A major test reactor facility has recently become operational in the United States. The Annular Core Research Reactor (ACRR) is the result of a four year program to improve the performance of the Annular Core Pulse Reactor (ACPR) for advanced reactor safety programs and weapon radiation effects experiments. The U-ZrH fueled core of the ACPR was replaced with a core of uniquely designed $BeO-UO_2$ fuel elements. This paper described the design, performance characteristics, and reactor safety experiment capabilities of the ACRR.

OBJECTIVE OF THE ACRR PROJECT

The objective of the project was to improve the performance of the Annular Core Pulse Reactor (ACPR) for Nuclear Regulatory Commission and Department of Energy sponsored experiments. For reactor safety experiments, the ACRR permits simulation of higher decay heat powers for post-accident heat removal (PAHR) experiments and in the pulse mode provides more uniform energy deposition profiles in single and multiple fuel pins for transient overpower (TOP), loss-of-flow (LOF), and prompt-burst energetics (PBE) experiments.

The ACRR project was a modification of the existing ACPR facility and utilized the ACPR core geometry, grid structure, and reactor tank. The existing 22.8 cm diameter dry, experiment cavity at the center of the core structure was retained. A design goal was established to improve the cavity fluence by a factor of 2.6 to 3.1 for a single pulse with an initial period of about 2 msec. A steady-state flux improvement goal of 2.5 times the ACPR flux was chosen and it was decided that the core would continue to utilize natural convection cooling. An interim report on the early ACRR project was given in 1976 [1] and preliminary characterization of the $BeO-UO_2$ core was reported by Boldt, et al. [2] The calculated reactor parameters were reported by Pickard and Odom [3].

REACTOR DESCRIPTION

The core of the ACRR is water cooled and moderated and consists of 226 fuel elements arranged around the central hexagonal cavity. The fuel is BeO-21.5 weight percent UO_2 with a uranium enrichment of 35 percent. The fuel element diameter is 3.75 cm and the active fuel length is 52.2 cm. There are six fuel-followed control rods, two fuel-followed safety rods and three void-followed transient rods. The outer perimeter of the core is surrounded by a row of nickel elements with the same outer dimensions as the fuel elements. The nickel elements are required to reduce neutron generation time of the reactor and to control fission density peaking in outer fuel elements.

The control system provides flexibility in the rate and sequence of insertion for the 11 regulating rods and permits the capability to shape pulses for the simulation of reactor accident scenarios. The transient rods are used for pulse operation and are withdrawn as a bank or individually to produce a single large pulse or up to 3 smaller pulses. The control system was designed by Sandia Laboratories, fabricated by Gulf General Atomic and satisfies the redundant protect channel requirements of IEEE 279.

The bulk pool water temperature is controlled by a 2 MW heat rejection system which circulates the water through two 1 MW heat exchangers. The experiment cavity exhaust system is filtered by charcoal and HEPA filters to minimize the release of radioactive material in case of leakage from an experiment. The cavity can be sealed and pressure tested as a large volume containment, if required for the safety of an experiment. The height of the ceiling of the reactor building was raised 4.5 meters and a monorail crane was installed to aid in the handling of long experiments in the building.

A fuel motion detection system is installed in the reactor tank and can be partially removed when not needed for an experiment. The fuel motion detection system utilizes coded aperture imaging to produce high resolution pseudoholograms at a rate of 5/msec. When reconstructed, the holograms produce pictures of fuel movement taking place in the sodium coolant behind 2.5 cm of reactor and experiment containment. The radial, axial and temporal resolution of the system is respectively 1 mm, 5 mm and 200 μsec. The system is installed in the ACRR tank and its relation to the reactor core is shown in Figure 1. A collimator penetrates the core to the experiment cavity displacing 11 of the 200 fuel elements. The coded aperture and associated imaging electronics are located behind a massive bulk shield and are removed after each experiment. A complete description of this system as well as initial operating data is discussed by Kelley, et al. [4] at this conference.

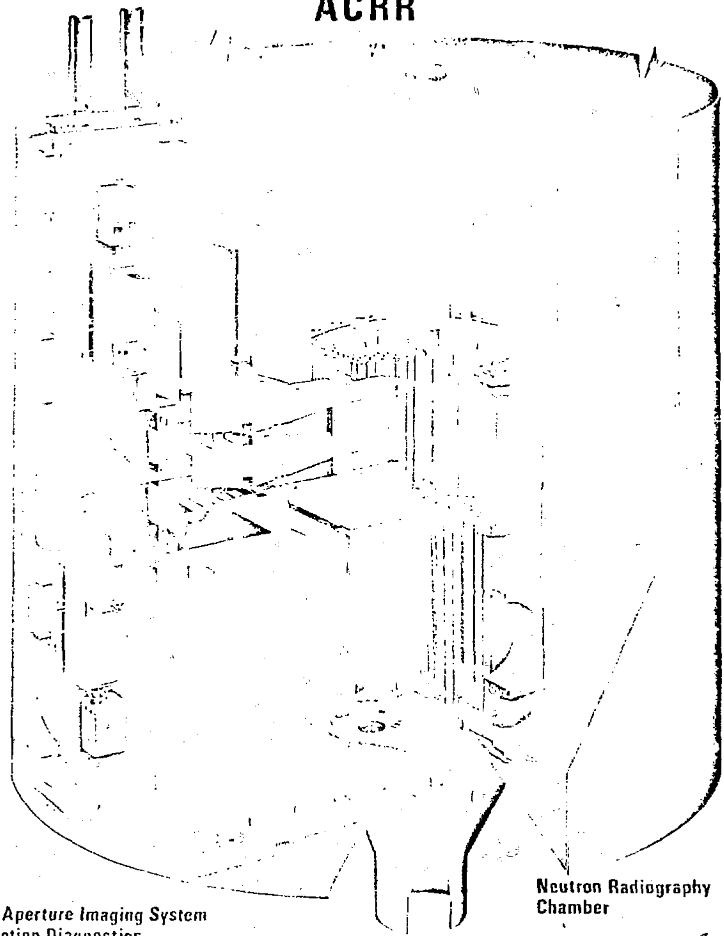
The BeO-UO_2 fuel element design is a unique feature of the ACRR and was developed to provide high energy deposition during a pulse, as well as modest temperatures during steady-state operation.

The BeO-UO_2 fuel development and testing program has been reported by Pickard, et al. [5] and Sasmor, et al. [6]. The BeO-UO_2 fuel pieces were formed by Lawrence Livermore Laboratory in a dual-slotted concentric annuli configuration to reduce thermal stresses and fracturing. The 0.64 cm thick fuel pieces were cold pressed and sintered to 99+% of theoretical density. The dual annulus fuel configuration was designed by finite element analysis techniques to minimize fracturing of the fuel pieces by the thermal gradients that exist during the pulse mode of operation.

The BeO-UO_2 fuel pieces are contained in niobium cups inside the stainless steel clad. There are five cups which fit together inside a fuel element. The cups have a wall thickness of 0.038 cm and were formed by deep drawing of 0.05 cm thick niobium. The cups serve several important functions in the fuel element: (1) The niobium forms a refractory liner (melting point = 2470°C) between the fuel and clad since the peak design fuel temperature (1400°C) approaches the clad melting point; (2) there are ridges formed in the cup to maintain heat transfer gaps between the fuel and cup and cup and clad; and, (3) if the fuel does fracture with long-term use, the pieces will remain within each cup and restrained

Annular Core Research Reactor Facility

ACRR



from collecting at the bottom of the fuel element where ratcheting and clad swelling might occur. The fuel element is filled with two atmospheres of helium to provide an inert environment for the fuel and to promote steady-state heat transfer.

PERFORMANCE CHARACTERISTICS

The current cavity fluence in the ACRR is 3.5 times the pulse fluence that was available in the ACPR. The current nominal operating characteristics are given in Table 1 for both pulse and steady-state operation. The reactivity insertion of $2.95 is the current maximum worth of the transient rod bank. Since the fuel element design is based on a maximum fuel temperature rise of 1400°C for pulse operation, and the peak temperature rise currently available is ~1100°C with a yield of 330 MW-sec, it is possible to increase the reactor yield further. The design temperature for steady-state operation is 1200°C. Operation at 2 MW results in peak temperatures of 960°C, and higher power operation is anticipated. Extrapolation of pulse data to a fuel temperature rise of 1400°C indicates a yield of 470 MW-sec; a 40% increase over current operation. Fuel tests are being conducted with $BeO-UO_2$ samples in the ACRR to provide a more extensive data base for fuel performance at 1400°C peak temperature. Assuming acceptable fuel performance at 1400°C, the transient rod bank worth will be increased to provide an insertion of $3.50 for a maximum single pulse. Pulsed operation to this level will provide a fluence increase of a factor of 4.2 over the old ACPR. Extrapolation of steady-state data indicates that 1200°C would be reached at 3 MW.

ADVANCED REACTOR SAFETY EXPERIMENT CAPABILITIES

The ACRR provides the capability to perform phenomenological experiments covering a broad range of safety issues in accident energetics and post accident containment. The current ACRR program and scope is summarized in Table 2.

In the steady-state mode, self-heated debris beds of UO_2 particulate can be produced with bed powers of up to the maximum post accident decay power. With this capability, the entire range of bed powers and depths pertinent to safety related post accident cooling studies are being examined. Parameters under study include fragmentation and bed formation, settling, bed parameters for incipient and fully developed dryout, self-leveling tendencies, impurity effects, effects of subcooling, and the effect of bottom cooling. In these tests relatively uniform fission-density profiles are achieved in beds up to 10 cm in diameter. More important, however, is the very uniform radial temperature profiles achieved across the bed. The enhanced steady state flux also permits greater flexibility in experiment containment design which permits molten pool studies to higher temperatures without undo sacrifice in fission densities.

TABLE I

Annular Core Research Reactor
Performance Characteristics

Pulse Operation	Nominal Current Operating Parameters
Reactivity Insertion	\$2.95
Fuel Temperature Rise	$1100^{\circ}C$
Pulse Width (FWHM)	6.7 ms
Reactor Period	1.65 ms
Energy Release	330 MJ
Peak Power	29,500 MW
Cavity Fluence (> 10 keV)	4.4×10^{15} neutrons/cm^2
Cavity Fluence (all energies)	7.5×10^{15} neutrons/cm^2
Peak Neutron Flux	3.5×10^{17} neutrons/cm^2-s
Steady-State Operation	
Power	2000 kW
Fuel Temperature	$960^{\circ}C$
Cavity Flux (> 10 keV)	2.4×10^{13} neutrons/cm^2-s
Cavity Flux (all energies)	4.1×10^{13} neutrons/cm^2-s

TABLE II

ACRR Experiment Program Areas

Area	Scope/Focus	Reactor Capabilities
1. FBE/EOS/FCI	Pressure sources and work potential on reactor containment are being determined under accident conditions.	Up to 10,000 J/g in single pin 20% fuel 5 msec FWHM single pulse capabilities. 1 to 19 bundle capability.
2. Fuel Dynamics	Experiments under simulated LOF and TOP conditions to determine fuel failure modes, location and subsequent fuel motion into the channel and upper core structure.	Various square wave, ramp and pulse heating modes; single pellet up to 19 pins.
3. Transition Phase	Phenomenological experiments utilizing fission heated source to determine plugging and freezing potential of fuel in upper core structure.	Steady state and quasi steady state (sq. wave) heating modes for boiling pool. Pulse modes for streaming and plugging experiments.
4. Debris Bed (PAHR)	Coolability of internal heated debris beds of UO_2-steel particulate in sodium are examined over bed powers of interest.	Capability of heating deep beds of ≈ 10 cm diameter to 4% power in steady state operation.
5. Molten Pool (PAHR)	The transition to and the behavior of internal heated molten UO_2 pools are examined.	As for debris bed, but limited by safety requirements of containing the pool.

The current capabilities in accident energetics allow experimental and complementary analytical investigations of the energetics of fuel-clad-coolant system subjected to energy deposition conditions associated with super-prompt critical excursions. In the past the emphasis has been on capsule tests of single pin UO_2 and UC fuels with and without sodium. Supporting experiments to determine the equation-of-state of these fuels are carried out under different heating conditions. Future tests will include multipin geometries, irradiated fuel and flowing sodium as well as separate effects studies of fuel-coolant interactions and the hydrodynamics and thermodynamics of the expanding HCDA core vapor bubble.

In early fuel dynamics tests disruption of preirradiated mixed oxide fuel is being observed visually under simulated LOF heating conditions. These studies provide data on the time and mode of fuel failure and initial motion as well as the role played by the fission products in the fuel disruption process. Shown in Figure 2 is a plot of the integral of reactor power vs. time for a certain LOF scenario. Also superimposed on the same figure is the resultant test fuel pin radial temperature profile at 6.5 sec into the test. As can be seen, good simulation of LOF conditions can be produced using this square wave operating mode.

Future experiments will involve single and multiple pin geometries with flowing sodium and will utilize the fuel motion detection system. LOF, TOP, and TUCOP heating conditions will be produced. Typical programmed reactor power histories for these tests are shown in Figure 3.

Average energy depositions of up to 10,500 J/g can be obtained in single 20% UO_2 test pins and up to 4500 J/g in the central pin of a 7 pin bundle. Calculations indicate that a 19 pin graded bundle (central pin-50%) can be driven in excess of 2500 J/g. The energy deposition profiles associated with such experiments range from a peak to average ratio of 1.15 to 1.4 depending on the experiment configuration. Temperature gradients associated with these tests can be reduced significantly by the use of programmed power modes.

CONCLUSIONS

The Annular Core Research Reactor provides a highly flexible test facility for a variety of reactor safety research and weapon radiation effects experiments. The development of the $BeO-UO_2$ fuel represents a significant step in pulse reactor technology. The large volumetric enthalpy of the fuel provides high energy deposition with modest temperature rise. The reactor control system provides a wide variety of operational modes between single pulse and steady state operation.

ACKNOWLEDGMENTS

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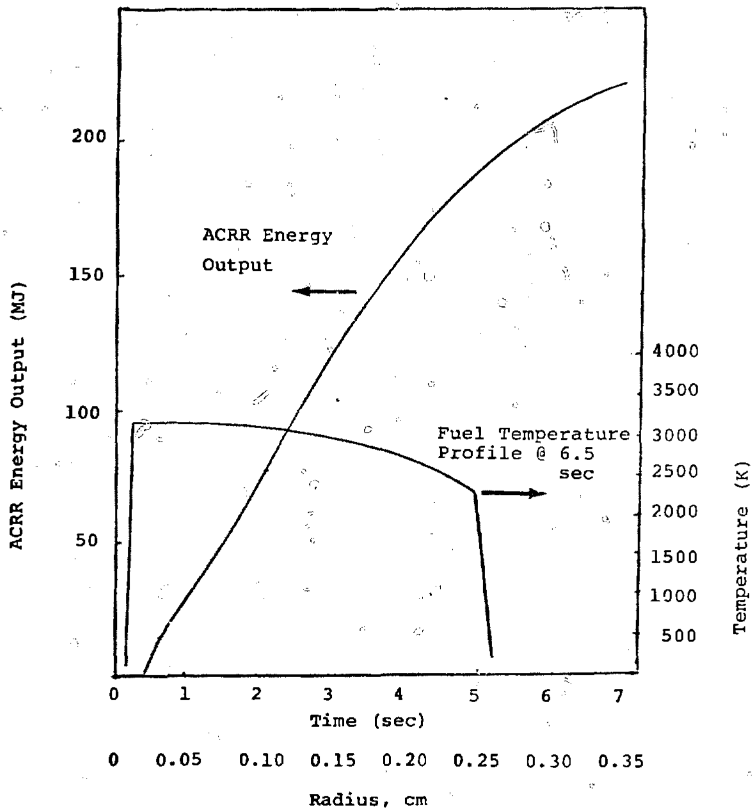
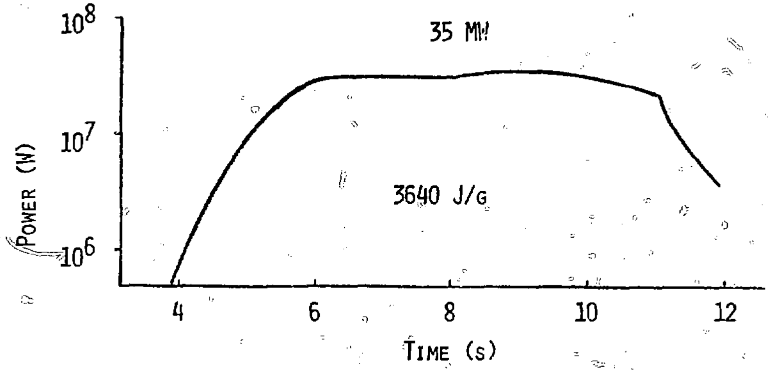


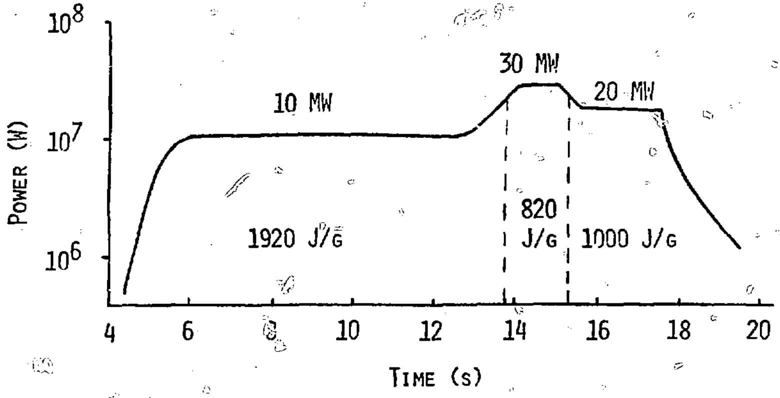
Figure 2 - ACRR Energy Output vs time.
Fuel temperature Profile at 6.5 sec.

CALCULATED SHAPED PULSES

SQUARE WAVE (TOP SIMULATION)



LOF SIMULATION



CALCULATED SHAPED PULSES

PBE SIMULATION