CRITICALITY TESTING NEEDS FOR A SMALL FAST-SPECTRUM REACTOR DESIGN FOR SPACE POWER APPLICATION. S.M. Bragg-Sitton[1], J.D. Bess[1], D. Poston[2] and S. Bailey[3], [1]Idaho National Laboratory, MS 3860, Idaho Falls, ID 83415, Shannon.M.Bragg-Sitton@inl.gov, [2]Los Alamos National Laboratory, [3]Bailey Engineering and Management.

Introduction: Researchers on the Fission Surface Power (FSP) team were tasked with reviewing possible criticality testing needs to support development of a FSP reactor design that could be employed on Lunar, Martian or asteroid surfaces. Reactor physics testing can provide significant information to aid in development of technologies associated with small, fast spectrum reactors. Several studies have been conducted in recent years to assess the data and analyses required to design and build a FSP reactor with high confidence in system performance [1-4].

This paper summarizes previous critical tests and physics measurements that are potentially applicable to the current reactor design, summarizes recent studies of potential nuclear testing needs for space reactor development with specific reference to the current baseline FSP reactor design, and provides an overview of a suite of tests (separate effects, sub-critical or critical) that could fill gaps in the information database to improve the accuracy of physics modeling efforts as the FSP design is refined.

Importance of Nuclear Testing to FSP Design Evolution: The overall purpose of testing and incorporation of validated test data in computational design is to develop technologies that will allow for a system design in which researchers are sufficiently confident, regarding design margins and value uncertainty for both nominal operation and postulated accident scenarios. Review of data from previous test programs can elucidate gaps in the database, or identify parameters for which the uncertainty in the data is sufficiently large as to cause unacceptable uncertainty in the overall FSP design. Testing and analysis early in the system design stage can provide identification of technology development needs and clarify technology development paths for future design optimization.

Although design optimization has not yet been performed for the FSP reactor concept, some generalities can be stated for small, compact reactors intended for space applications. First, the system is characterized by a relatively small size and mass, such that it can be transported to its intended location using existing launch vehicles. Second, the reactor must be designed to meet all ground handling and launch safety requirements. Third, concept development should be kept within a reasonable, "affordable" cost. The latter requirement drives designers to the selection of a low-risk approach, which guides the selection of materials, components, and operating temperatures and takes into account historical applications and existing databases of operating characteristics.

FSP Reference Concept: The initial FSP concept definition report identifies key requirements for the reactor module and balance of plant [5]. The preliminary reference concept includes a liquid-metal cooled, fast-spectrum reactor with Stirling power conversion and water-based heat rejection. The conceptual reactor module uses highly enriched UO_2 fuel pins in a hexagonal core matrix; primary heat transfer from the core to the Stirling power convertors would be provided via a pumped NaK (sodium-potassium eutectic) liquid metal cooling loop. Reactivity control is accomplished via external Be / B_4C control drums, taking advantage of the high neutron leakage and resulting high external beryllium reflector worth. Cost and development risk are reduced by adopting stainless steel for all core structure, coolant piping, and the reflector shell.

Applicable Critical Experiments Data: Numerous reactor physics and criticality tests have been conducted to measure physics parameters, determine critical configurations, validate codes, etc. for simple configurations, highly flexible configurations, and for detailed reactor core designs. A review of the historical datasets was conducted, with a specific focus on those conducted for previous space reactor programs, fast spectrum reactors, and simple configurations incorporating materials relevant to the FSP design.

Small fast spectrum reactors, such as the FSP, can be designed to have very high reflector worth to maximize safety in accident scenarios. Hence, the loss of a reflector in a postulated accident would cause the system to be subcritical, even if it was replaced with water or wet sand. The database of available criticality tests does not fully address reactor designs with very high reflector worth. However, this generalization is somewhat difficult to ascertain directly from the criticality benchmark reports (vs. benchmarks for measured reactor physics parameters) [6]. The reflector worth in each of these datasets is determined from a series of direct difference calculations using the model input decks included in the appendices for each benchmark report. This calculation has been performed for the tested SP-100 reactor configurations (ZPPR-20C), but could also be completed for other benchmarked experiments.

In the current FSP concept, the radial and axial reflectors represent approximately 40% and 5% of the total system reactivity worth, respectively. A highly-reflected, compact fast reactor is expected to exhibit two unique aspects relative to larger terrestrial fast reactors. (1) The reflector has a significant impact on dynamic performance. In some cases, the temperature coefficient of reactivity feedback for the radial reflector is higher than that of the fuel, and the thermal time constant for the reflector is significantly longer than that of other core components. Hence, the reflector temperature and expansion effects must be modeled individually. (2) Core neutrons leak into the reflector, and are then reflected back into the core, such that "reflected neutrons" have a much longer lifespan than in-core neutrons. This delayed neutron group is referred to as "geometric delayed neutrons." Additionally, these neutrons have higher "worth" than in-core neutrons due to moderation as the neutrons travel through the reflector and back into the core [5]. The impact of the geometric delayed neutron group can be seen in calculation results, which show flux peaking in the outer ring of fuel elements due to reflected neutrons [7].

As the reflector thickness increases, the impact of the reflected neutrons on interactions in the fueled region of the core also increases, resulting in greater bias in the corresponding eigenvalue calculations. The increased bias is partially due to uncertainties in the physics interactions governing production of the neutrons from the reflector region, but may also be due to geometric effects and travel time of neutrons in the reflector region and back into the fueled region of the core. The largest uncertainty in the FSP design derives from the neutron interaction cross sections for ^{9}Be, where the design is most substantially impacted by the elastic scatter cross section for ^{9}Be, including the angular distribution as a function of energy. Although improvement in the physics uncertainties will improve the overall quality of the calculation bias, improved physics data will not provide further clarification of the geometry effects, nor will it account for the effects of manufacturing uncertainties (e.g. dimensions, composition). Hence, a cold critical experiment may still be required for an FSP-like configuration to support design optimization and/or on the FSP flight system.

Current Test Options: Reactor physics and qualification testing can include "separate effects testing" to ascertain parameters corresponding to individual materials, subcritical testing, and/or critical testing of simple configurations or more detailed configurations that more closely resemble a full reactor core and reflector design. Tests planned in support of FSP development should consider flexible configurations that allow analysis of design options to aid in FSP design optimization.

Cross section measurement and evaluation. The largest contributors to the uncertainty in the FSP design have been attributed to the uncertainties associated with individual interaction cross sections for ^{235}U and ^{9}Be. While the *total* cross section for a specific element may be fairly well known, cross sections for specific interactions may have significantly larger error bars. Interactions of interest for cross section refinement include ^{235}U(n,γ) and various neutron interactions in ^{9}Be (e.g. (n,n), (n,2n), (n,α)) in either Be metal or BeO, along with the associated covariance data.

The National Nuclear Data Center (NNDC) collects, evaluates, and disseminates nuclear physics data. Analysis of the n+^{9}Be system that will eventually result in updated cross sections for all the reactions, including new elastic scattering angular distributions, is currently being conducted. Once available, analyses will be performed to determine the impact of the updated ^{9}Be cross sections on the FSP design uncertainty.

Subcritical and critical testing. As noted in previous studies, it is expected that subcritical and critical testing will be required for postulated accident scenarios (e.g. water immersion or wet sand burial). If tested in a facility authorized only for subcritical assembly testing, then subcritical configurations could possibly be tested more readily and at lower cost than critical configurations, although the bias and uncertainty in the results will be notably increased without a corresponding critical baseline. Both subcritical and critical experiments can be used to evaluate the effect of modifying conceptual reactor designs during the technology development and design evolution stage of a program. Hence, selection of a test facility and test configuration that allows for test of an easily modified configuration (vs. a near-final flight design) would be beneficial during the technology development phase of the program.

Conclusions: The FSP program is currently proceeding with nonnuclear hardware development and testing in support of FSP technology development. No decision has yet been made with regard to nuclear testing to support design optimization; the current study provides a basis for understanding what tests might be needed, what benefits might be derived from those tests and possible detriments of not conducting them, and what facilities and materials are available to conduct a suite of tests to support FSP reactor qualification.

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