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Reactor-Accelerator Coupled Experiments (RACE): A Feasibility Study at TAMU

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A series of accelerator driven system (ADS) experiments are being planned to conduct demonstration and benchmark studies involving a nuclear reactor in a subcritical condition coupled to an accelerator driven neutron source. These experiments are being planned to use various levels of criticality and various power levels allowing for kinetics evaluation with and without temperature feedback. The reactor fuel to be used in these experiments is TRIGA reactor fuel. These reactor fuels are inherently safe and the reactor systems involved have large coolant capacities to ensure safe operation. The cores to be considered will be fully-instrumented and will allow for detailed and accurate data on core power levels, temperatures, and neutron fluxes during the experiments. A feasibility study is currently in progress at Texas A&M University (TAMU) to determine the viability and capability of these experiments. Preliminary results of this feasibility study are given.

KEYWORDS: Accelerator Driven Systems, Transmutation, TRIGA Research Reactor Experiments

1. Introduction

An accelerator-driven system (ADS) consists of a lattice of fissile material in a subcritical configuration with the power of the system driven mainly by an intense accelerator source of neutrons. A variety of ADS designs have been studied in the past [1-5], and a number of accelerator-driven neutron sources have been designed and built over the years (including fusion sources using D-T fusion, spallation neutron sources using a proton beam, and photoneutron sources using an electron accelerator). However, an ADS system of significant power has never been built and operated. The knowledge base relating the operational characteristics of these systems is virtually non-existent.

Recently a series of experiments, named MUSE (Multiplication avec Source Externe), were performed to study the neutronics of ADS. These ground-breaking experiments were conducted at the CEA-Cadarache MASCURA facility. This included a subcritical configuration driven by first a ^{252}Cf source and later a commercial D-T source. These experiments measured a variety of parameters at low system powers including subcriticality measurements using the Modified Source Multiplication method and source importance. The MUSE experiments provide invaluable data on the physics of ADS; however, since the power levels in MUSE are very low, the systems operate without any significant reactivity feedback.

A new set of experiments, named the Reactor-Accelerator Coupled Experiments (RACE), are being planned in Texas that will provide operational data for ADS operated at significant power levels and with reactivity feedback. These experiments will involve coupling an accelerator-driven neutron source to a TRIGA reactor system in a subcritical configuration. The accelerator source will consist of an electron linear accelerator (LINAC) and a heavy

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metal target. The electrons from the accelerator produce Bremsstrahlung radiation in the target which in turn produces a source of neutrons via photonuclear reactions.

Both the University of Texas at Austin (UT) and TAMU operate 1-MW TRIGA research reactors. These reactor systems use TRIGA reactor fuel which has been shown to have exceptional safety characteristics even under the most extreme transients. The RACE experiments will couple the accelerator source to these TRIGA reactors to study the operational characteristics of these ADS. The source of neutrons is expected to have a strength on the order of 1×10^{13} n/s. These experiments are expected to allow for study of the following:

1) Behavior of an ADS at power levels between 1-20 kW and at various levels of subcriticality (ranging from k_{eff}=0.90 to k_{eff}=0.99)
2) Methods for level of subcriticality measurement at significant powers.
3) Reactivity control by various means including via neutron source importance variation.
4) Compensation of reactivity feedback with control rod adjustment or by altering the accelerator current.

The RACE project has four principle goals:

1) Produce an ADS demonstration with adjustable reactivity to demonstrate the ability to design, compute, and conduct ADS experiments and benchmark the ability to predict and analyze subcritical source-driven transients.
2) Provide ADS benchmark data for developing codes and methods for analyzing static and transient behavior.
3) Produce a teaching tool that can be used to educate the next generation of scientists and engineers in the operation and modeling of ADS and in advanced nuclear science.
4) Advance the state of knowledge of ADS transmutation

These experiments will involve a strategic partnership between five U.S. Universities: Idaho State University (ISU), the University of Nevada at Las Vegas (UNLV), the University of Michigan (UMich), UT, and TAMU. Each University provides state-of-the-art capabilities inherently necessary for successful completion of the experiments. ISU provides accelerator expertise, UNLV provides transmutation sciences skills, UMich provides transient calculational capability for subcritical systems, UT provides experimental science and instrumentation capability, and TAMU provides expertise in computational and analytical nuclear engineering and reactor experimentation. ISU has vast experience with electron acclerators and their use as an intense neutron source. ISU will design, construct, and evaluate an accelerator driven neutron source for use in all experiments.

This neutron source will first be coupled to a low power subcritical assembly at ISU for testing and evaluation purposes. The same source will then be used in static and transient experiments at UT using the existing Nuclear Engineering Teaching Laboratory (NETL) 1-MW TRIGA Mark II research reactor. The accelerator driven source will be placed into beam port #5 (BP#5) to allow for coupling to the reactor. The beam port configuration for the UT-NETL is shown in Fig. 1.

After completion of the experiments at UT, the accelerator driven source will be moved to the Nuclear Science Center (NSC) at TAMU. A subcritical assembly composed of spent fuel discharged from the TAMU NSC TRIGA reactor will be designed and built for location in the NSC pool. The accelerator driven source will be inserted into the reactor and used to evaluate static and transient effects with the source in several internal locations in the core and with adjustable reactivities up to k_{eff} of 0.98.

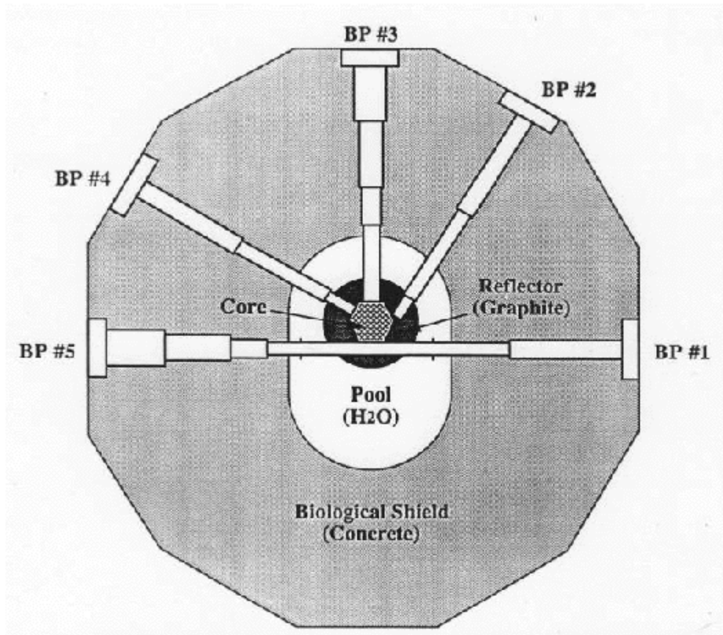

Fig. 1. Beam port configuration for UT-NETL TRIGA reactor.

A computational study has been initiated to determine the feasibility of these experiments and to estimate the instrumentation necessary for an effective series of experiments. This computational study first involved the analysis of the accelerator source design to determine the optimal source characteristics. This source was then used in simulations for the UT NETL reactor to determine the power levels attainable with the source placed in BP#5. The same source was then again used in a simulation involving spent fuel from the TAMU NSC TRIGA to determine the attainable power levels for a preliminary lattice design.

2. Initial Neutron Source Design

An accelerator driven neutron source consisting of a cylindrical lead target encased in a stainless steel container surrounded by a vacuum (Fig. 2) was simulated using MCNPX-2.5.d. A 40-MeV electron beam impacted normal to the target and along the axis of the cylinder. The electron beam had a diameter of 1.0 cm. The simulations consisted of a complete electron-photon-neutron simulation and tallied the neutron current exiting the outer surface of the target. Each simulation consisted of approximately 60,000 electrons.

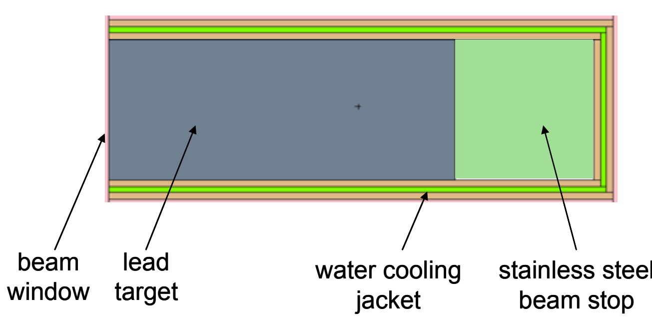

Fig. 2. Screen capture of MCNP geometry for accelerator driven neutron source.

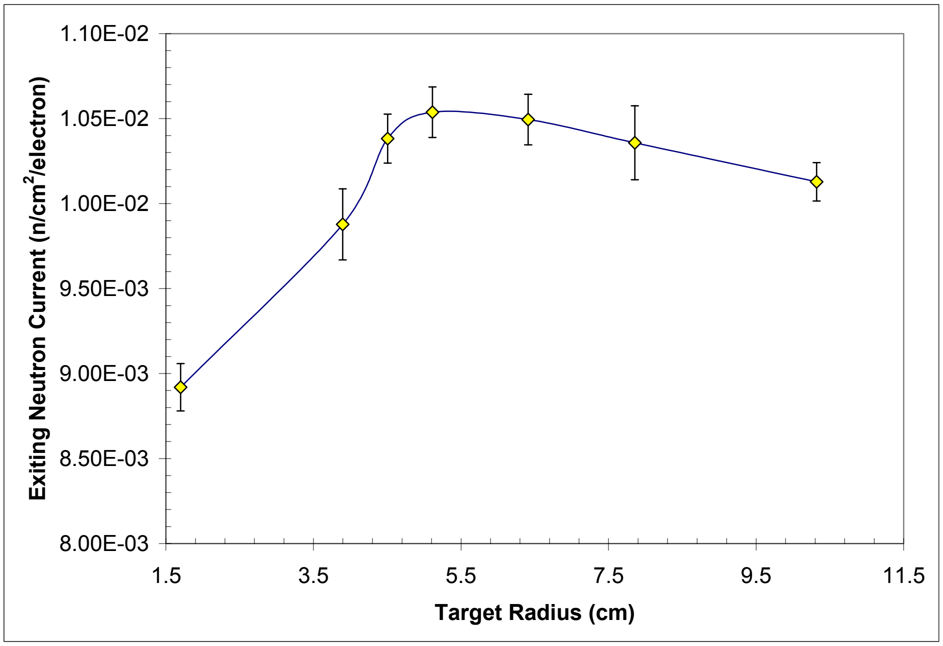

Fig. 3. MCNPX calculated neutron current exiting the lead target versus target radius.

The length and radius of this target was varied to determine the optimal target geometry. The radius was varied from a radius of ~1.5 cm to a radius of ~10.0 cm. The outgoing neutron current from the source versus target radius is shown in Fig. 3. As can be seen from Fig. 3, an optimal target radius exists at ~5.5 cm. The target length was varied from ~5 cm to ~40 cm. These simulations showed that there was no significant increase in exiting neutron current at target lengths greater than 25 cm. The dimensions of the target used in the simulations below was set at a length of 25.0 cm and a radius of 5.0 cm. These dimensions were near the optimal target dimensions and were sufficiently small to allow the target to easily fit into the space available in the reactors.

It should be noted that the choice of lead as a target material is only for the purpose of this feasibility and scoping study. Since lead has such a low melting point it may be advantageous to use a tungsten target instead of a lead target. Future evaluations will consider other target materials as well.

3. UT-NETL Simulations

The UT-NETL 1-MW TRIGA reactor was simulated in MCNPX-2.5.d with the target designed in Section 2 above inserted into BP#5 (Fig. 4). The core was modeled explicitly including each fuel rod, control rods, coolant, graphite reflector, and the pool water. Three separate simulations were performed with the control rods at different levels of insertion to place the system at different criticality levels. The system was simulated at k_{eff} of approximately 0.95, 0.98, and 0.99. These criticality levels were determined via criticality (kcode) simulations. Source driven simulations were then performed at each criticality condition and the heat generation in the fuel was tallied. The calculated heat generation rate in the fuel for a 40-MeV electron beam at a current of 100 μA and the target in BP#5 is shown in Table 1. It should be noted that this heat generation only includes heat from the neutrons. The photons from the source are not transported outside the lead target.

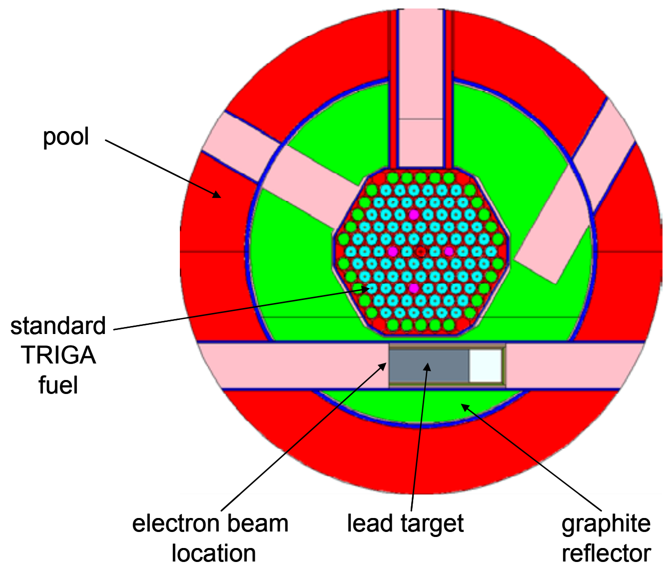

Fig. 4. Screen capture of MCNP geometry for UT-NETL experiment with accelerator source in beam port #5.

Table 1. Calculated Heat Generation Rates in the Fuel and k_{eff} for Each Experimental Arrangement.

Nuclear System	Source Location	k_{eff}	Heat Generation (kW)
UT-NETL	BP#5	0.9502±0.0007	1.16±0.11
UT-NETL	BP#5	0.9800±0.0004	1.47±0.15
UT-NETL	BP#5	0.9901±0.0004	2.44±0.29
TAMU-TTS	central source only	0.942±0.001	6.42±0.55

4. TAMU Simulations

The TRIGA reactor at TAMU has been in operation since 1961. Present at the facility is a complete core load of spent fuel. In the RACE experiments the target designed in Section 2 above will be paced in the existing TAMU NSC TRIGA to perform experiments similar to those for the UT NETL TRIGA; however, an additional experiment will also be performed using the spent fuel at TAMU. This spent fuel will be assembled into a subcritical lattice (within the existing NSC pool) with three internal accelerator driven target positions and three safety control rods (Fig. 5). The system will be designed such that it will remain subcritical with the control rods completely removed from the core. Thus, the control rods only serve as shutdown safety rods, but can also be used to operate the system at lower levels of subcriticality as well. This experiment will allow for evaluation of the ADS with the accelerator source in different locations in the core. The system will also serve as a teaching tool since its design maintains the system in a subcritical configuration and thus is more “student-friendly”. This design has been named the Texas Transmutation System (TTS).

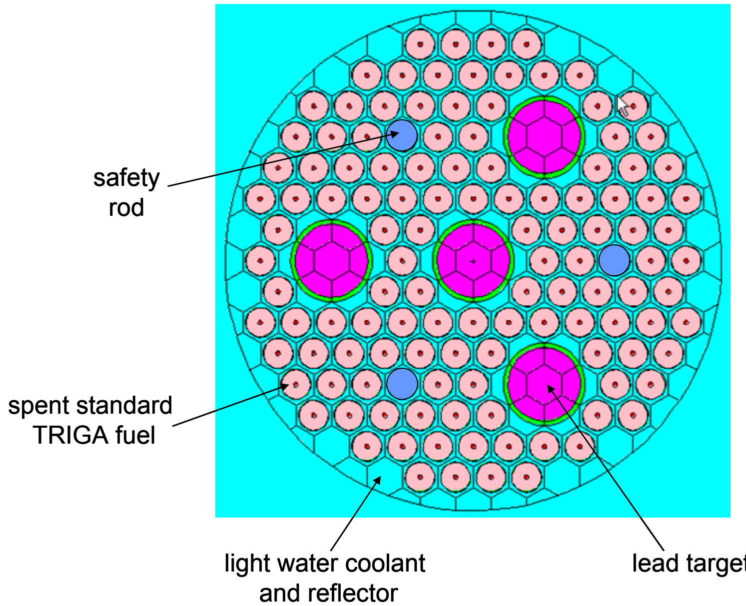

Fig. 5. Screen capture of MCNP geometry for TAMU-TTS experiment with four accelerator target positions available.

MCNPX simulations were performed to evaluate the initial TTS design. The system was modeled explicitly and a 40-MeV, 100-μA electron beam was impacted on the central target in the design. The heat generation rate in the fuel was then tallied. The results for this calculated heat generation rate is shown in Table 1. Again, it should be noted that this heat generation only includes heat from the neutrons. The photons from the source are not transported outside the lead target.

If successfully designed and constructed this ADS assembly will be used for static and transient studies. Following these studies, the TTS will remain in operation at TAMU as a training and teaching tool. This will allow for the training of the next generation of nuclear scientists and engineers in ADS technology.

5. Conclusion

Preliminary calculations were performed to evaluate the feasibility of the RACE experiments involving the TRIGA reactors at UT and TAMU. The initial parameter of interest in these studies is the heat generation in the core. Measureable temperature feedback effects in each core begin at powers of greater than 1 kW. Thus it was desireable to have a system between 1-10 kW. The results have shown that in all the cases studied the power level was greater than 1 kW. These studies have shown that the RACE experiments should be capable of providing significant experimental data to aid in the design and development of ADS technology as well as serve as a teaching tool to educate students on the role of ADS in their nuclear future.

Future analysis will be performed replacing the lead target with a tungsten target and in considering the energy deposition in the fuel due to the photons reacting directly in the fuel (primarily via photofission). Analysis will be conducted to determine the feasibility of placing the accelerator target in the central region of the UT-NETL reactor as well as in a beam port. This should allow for a significant increase in system power. Also, analysis for experiments using the existing TAMU NSC TRIGA core remains to be completed. The models developed in these studies will also be used to determine the instrumentation necessary for measuring the desired transient and static experimental data.

Acknowledgements

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