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Progress Report on Activities for the Core Conversion in Jamaica

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ABSTRACT

With the current core configuration, the SLOWPOKE in Jamaica has another 14 years of operation, at which time a large beryllium annulus can be added extending the core life-time by an additional 15 years. However, in keeping with the spirit of the global threat reduction initiative and Reduced Enrichment for Research and Test Reactors (RERTR) program, the core of the SLOWPOKE will be converted from HEU to LEU. Although progress has been slow there have been several key developments during the last year, particularly in the area of regulatory oversight, including the expected licensing requirements for defueling, commissioning and operation of the reactor. This paper reports on the current status of SLOWPOKE-2, the selected fuel and the proposed action plan for the next two years. Provided that the fuel fabrication process can be completed in the estimated 18 months, the core conversion process should be accomplished by the end of 2014.

1. Introduction

During the last 28 years International Centre for Environmental and Nuclear Sciences (ICENS) has been successfully operating a 20kw SLOWPOKE research reactor which was obtained from Atomic Energy of Canada Limited (AECL). The reactor is fueled with ~ 1 kilogram of U.S.-origin highly enriched uranium (HEU) provided through a Project and Supply Agreement with the IAEA. The Jamaican SLOWPOKE is one of only seven ever built and is the only one outside of Canada. Presently there are still five operating, three of which utilize HEU fuel and two LEU. The reactor achieved its first criticality in March 1984 and normally operates at an average power of 10 kW for approximately 1300 hours per year. It has now operated for a total 101 MWh out of a calculated lifetime of 190 MWh or 52% of the current core configuration. This reactor is highly utilized especially for environmental, health-related studies and mineral exploration in Jamaica. ICENS has also cooperated with the IAEA to establish a research reactor coalition reactor in Colombia and Mexico to increase regional access to research reactor services and nuclear-related education and training. With the current core configuration the SLOWPOKE in Jamaica has another 14 - 18 years dependent upon operational conditions, at which time a large beryllium annulus can be added extending the core life-time by an additional 15 years. However, in keeping with the spirit the global threat reduction initiative and the growing international consensus to eliminate civil uses of HEU, a formal request was made in 2009 via the IAEA to the GTRI and the Reduced Enrichment for Research and Test Reactors (RERTR) program to convert the reactor in Jamaica to LEU fuel and to ship the spent fuel to the U.S. This paper reports on the current status of SLOWPOKE-2, the selected fuel and the proposed action plan for the next two years. Provided that the fuel fabrication process can be completed in the estimated 18 months, the core conversion process should be accomplished by the end of 2014.

2. SLOWPOKE

2.1 HEU Core

The reactor core consists of an assembly of 296 fuel pins containing a total of 817 g of 93.5% enriched ^{235}U as co-extruded alloy containing 28% by weight of U in Al. A 100 mm thick pure beryllium annulus encases the fuel cage, which is a cylinder of size 23 cm by 25 cm. The annulus acts as a side reflector for neutrons and a 50 mm thick beryllium disc forms the bottom reflector. The top reflectors consist of semicircular plates of beryllium each only a few millimeters thick. There are five (5) small inner irradiation sites within the beryllium annulus, however only four are available for use at our facility as site # 2 presently houses a flux detector installed as a replacement for the originally installed flux detector which malfunctioned in 1988. In addition there are two (2) large sites outside of the beryllium and an in-pool irradiation system [1]. The SLOWPOKE neutron flux is uniformly distributed about the axis of the core and extends a short distance outside the reactor container, Fig 1. The maximum operational in-core flux is 1×10^{12} n cm^{-2} s^{-1}, the site-specific flux variation is less than ± 3%, and the flux as measured in the large outer site is approximately 51% of the nominal flux. The epithermal and fast components of the reactor neutron spectrum account for approximately 5 % and 23% respectively of the total inner site flux. The fast component of neutron spectrum of SLOWPOKE is composed of both fission neutrons and those generated by (γ, n) reaction from the Be reflector.

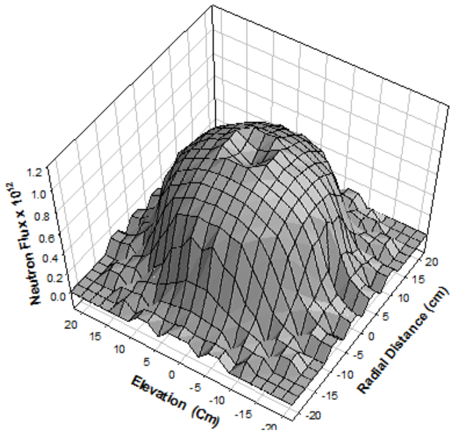
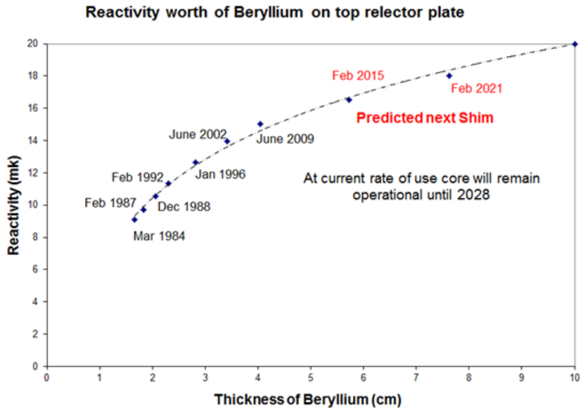
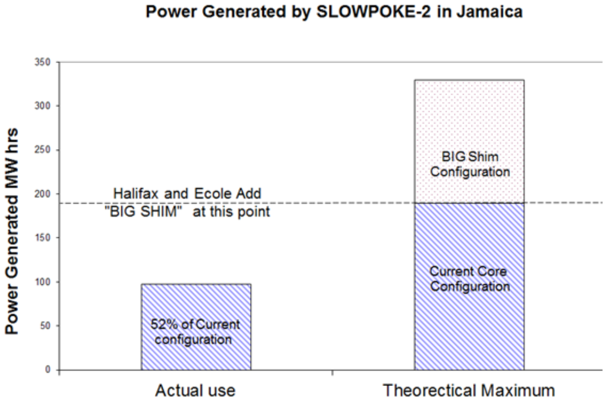


Figure 1 Thermal flux distribution for Slowpoke 2

2.2 Estimated Fuel burn up and Reactivity Adjustments

During the operation of the reactor ^{235}U is consumed at a rate of ~0.46g/kW.yr [2], or a reactivity loss of ~ 0.08 mk.yr. Fission product poisons account for an additional loss of about 0.64 mk.yr, ~94% of this is due to the stable fission product isotope ^{149}Sm, and total reactivity loss is estimated at 0.72 mk.yr. The reactor core is a lifetime core, and burn-up is corrected for by the addition of beryllium reflectors on top of the fuel cage, thus negating the need for on-site spent fuel storage.

Figure 2a. History of Shim Adjustments	**Figure bb. Power Generated by SLOWPOKE**
	

Given the current core configuration and rate of usage, the core will last another 16 years, at which time an additional beryllium annulus can be, Fig 2a &b.

2.3 Estimated Fission Product Activity

The fission product activity of the used fuel, is a function of the reactor flux hours, and has in the past been estimated using an AECL calculation based on a SLOWPOKE reactor which was operated for 5 years at a neutron flux of 1×10^{11} $n.cm^{-2}s^{-1}$ (2kW), then 10 hours at a neutron flux of 1×10^{12} $n.cm^{-2}s^{-1}$ (20 kW) [3]. The calculated activity 30 days after shutdown was 23 TBq. Based on a maximum usage for the Jamaica SLOWPOKE of 4 hours per day 5 days per week at an average flux of 4.95×10^{12} $n.cm^{-2}s^{-1}$ (average over the last 29 years), the 5 years average continuous flux will be 0.57×10^{11} $n.cm^{-2}s^{-1}$ (1.1 kW). Based on a maximum usage for the next 5 years, the expected activity of the core 30 days after shutdown should not exceed 13 TBq. Previous experience (Montreal) has shown this calculation to be reasonably accurate (~18 TBq) [4], and that a one month cooling period is sufficient before the conversion process takes place. These estimates will be verified with new models developed in conjunction with Argonne National Laboratories.

2.4 LEU Fuel Composition

In order to minimize the effects of the fuel change from HEU to LEU the overall reactor geometry was essentially retained for an LEU fueled reactor, with only the fuel cage and fuel elements altered [5]. This similarity simplifies the core conversion as the beryllium annulus and other auxiliary systems can be reused without modification. The AECL developed LEU fuel was fabricated from zircaloy-4 clad uranium oxide pellets and contained 1100g of 235U (total mass of U ~5600g) with an enrichment of 19.9%, as the LEU fuel requires ~ 20% more U-235 to achieve the same reactivity as the HEU core. The core itself is 220 mm in diameter and 227 mm in height. Existing LEU cores at Royal Military College (operational since 1988) and École Polytechnique de Montréal (converted in 1997) achieved criticality with a total of 198 fuel pins in the fuel cage, each pin being 5.26 mm in diameter and 234 mm in length [6]. The inherent safety of the HEU core is provided by a large negative temperature coefficient [7] which is also true for the LEU core and ensures that power excursions are self-limiting [5]. Based upon the operational success of the AECL manufactured LEU cores, the SLOWPOKE at ICENS will utilize fuel of identical composition and dimensions. The Y-12 National Security Complex, a branch of the US Department of Energy (DOE) has been selected as the manufacturer of the fuel. The recently signed Non-Disclosure Agreements (NDA) between AECL, Argonne National Laboratory (ANL) and ICENS will permit the exchange of information on key issues such as the isotopic concentration of the UO_2 ceramic powder, the conditions of the sintering and specifications for fuel element fabrication among many other details necessary for manufacture. The characteristics of the LEU core have been well documented and modeled [6, 7 & 8]; however, neutronic and thermal-hydraulic models of the reactor will be developed to support the conversion safety analyses in cooperation with the ANL.

2.5 Facility Upgrades

In June of 2011, an independent facility review was carried out for the ICENS SLOWPOKE with the objective of evaluating the adequacy of the reactor site and facilities to support the LEU conversion planning and preparation activities. The resulting report [10] identified no major issues to prevent or delay proceeding with the conversion project. It recommended, among other things, that the planned replacement of the analog control system with a digital one, be carried out prior to the core conversion. The system being presently reviewed is a Commercial Off-The-Shelf (COTS) digital control and instrumentation system developed specifically for the SLOWPOKE-II reactor. The SLOWPOKE Integrated Reactor Control and Instrumentation System (SIRCIS) was commissioned at the Royal Military College (RMC) reactor in June 2001. Discussions have begun with the manufacturer to resolve long term maintenance and sole source issues. As part of the approval process, an independent review of the safety analyses report provided by the vendor for SIRCIS will be carried out, and the ICENS approved SAR for SIRCIS will then be submitted to the Oversight Committee for their approval of the console upgrade.

2.6 Core Replacement and approach to critical

In all likelihood the core will be removed in accordance with procedures developed at Montreal [4, 10]. The local regulatory body will be approached to license the AECL owned F-257 transportation flask. The spent fuel flask removal process was reviewed with the UWI campus maintenance supervisor. It was determined that a mobile lifter, which was available on campus, would be the most appropriate method to lift the F-257 transportation flask (~4000 lbs) in and out of the reactor pool. The lifting equipment would need to be disassembled into three sections to enter the counting room and the reactor room and need to be reassembled in the reactor room. The floor ramp outside the counting room will require some reinforcement or replacement, to support the loaded transport dolly when exiting the room [9]. A simulated load dry run of the spent fuel flask removal procedures will be performed, well in advance of the actual removal, to ensure equipment availability, assembly issues, maneuverability and procedures are satisfactory.

For all SLOWPOKES to date the approach to first criticality has involved adding fuel pins to the core according to a prearranged schedule using a peening process. During fuel loading, the subcritical multiplication of neutrons are from an Ac:Be source placed in irradiation site 1, in the annular beryllium reflector [11]. For the HEU core at ICENS the fuel loading took 15 cycles. The clear advantage of this methodology is that it has been successfully utilized with seven HEU and two LEU cores. One alternative to this process is to have the fuel cage shipped partially loaded, thereby reducing the number of cycles for the approach to critical, while minimizing the risk of damage to the fuel pins during peening. Ultimately the feasibility of alternative approaches will depend upon how closely our predictions for the core loading match past data for the LEU cores.

3. Radiation Safety Authority

In January of 2011, the Government of Jamaica (GOJ), via Cabinet Decision # 01/11, designated the Ministry of Industry and Commerce as the parent ministry for the Radiation Safety Authority (RSA) under the auspices of the Bureau of Standards Jamaica (BSJ), Fig 3. The RSA using the general theme of "Radiation Safety Infrastructure" has enacted the Jamaica action plan (2012 – 14) with the following actions:

- With the assistance of the IAEA the draft law compliant with the international Basic Safety Standards and related IAEA publications such as GS-R1 Requirements, the Code of Conduct on the Safety and Security of Radioactive Sources and Guidance on Import and Export, is scheduled for completion in March 2013.
- Stakeholder forum to be convened for consultation on and review of draft law (September 2012)
- Establish time-lines for actions leading to enactment of legislation (Coming out of stakeholder consultation)

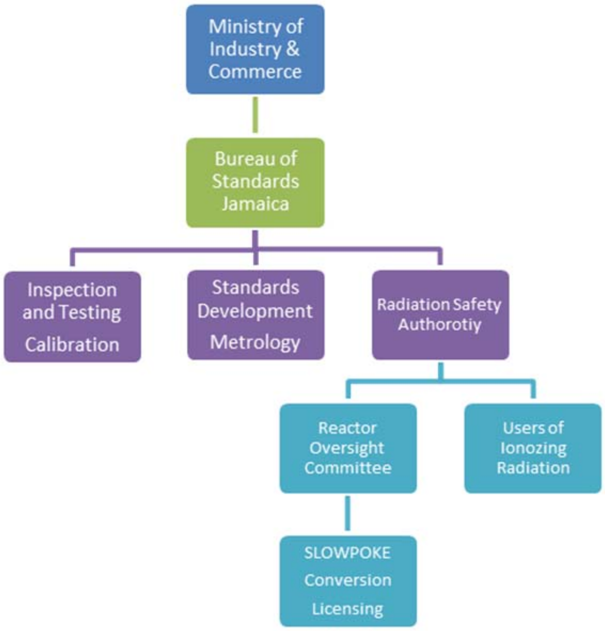


Figure 3. Position of RSA within the Ministry

3.1 Regulatory Oversight

One of the first activities of the newly appointed Radiation Safety Authority was the establishment of an independent reactor oversight committee to act as the de facto nuclear regulator. This committee will review all operational aspects of the research reactor at ICENS and will ensure that the upcoming conversion of the SLOWPOKE–II reactor from HEU to LEU is conducted in accordance with all guidelines stipulated by the IAEA. The committee has thus far adopted the IAEA safety requirements document NS-R-4 "Safety of Research Reactors" as its reference document and are currently finalizing the list of documents that will be required for the conversion process.

Activity	2011		2012				2013				2014	
Legislation & Regulatory Oversight	Cabinet Decision # 01/11 of 10 January 2011 Bureau of standards Jamaica to house RSA	Reactor Oversight Committee established in RSA	Draft Law prepared	Identification of appropriate regulations to give effect to the proposed law	Stakeholder forum to be convened for consultation on and review of draft law	IAEA agreement on regulations	Draft Guidance Documents and Codes of Conduct	BSJ will establish a national nuclear/radiation security and safety committee			Cabinet to issue drafting instructions for the regulations according to priority listing Conversion and Operating license issued	
Documentation		Statement of Work defined		Report on adequacy of reactor site and facilities Tripartite NDA Signed (AECL-ANL-ICENS) PSA signed by Jamaican Government	Report on safety and licensing documentation requirements	Completed conversion SAR reviewed by ANL staff for PSA presented December 2012 Board of Governors Meeting.	Submit documents for regulatory approval of operations /maintenance procedures for LEU fuel	Provide project quality assurance manual and other project manuals as agreed upon by ICENS and ANL staff		Submit documents for regulatory approval of conversion and operation of LEU core		
Meetings	RRFM	RERTR	RRFM	NNSA/DOE ICENS/RSA		RERTR Meeting on Conversion Related Activities (AECL-ANL-ICENS)	RRFM	Determine available equipment or drawings for equipment to be manufactured. Issue contracts for defueling, refueling, commissioning, health physics etc. (AECL/ANL/ICENS/Subcontractors)		RERTR		
AECL							Finalization of AECL involvement and use of equipment (contracts drawn)					
Facilities Upgrade							Submit documents for regulatory approval		Control System Upgrade	Safety & Utilization related upgrades		
Core Modeling							HEU-LEU cores (ANL & ICENS)					
Fuel Fabrication						Fuel and fuel cage to be fabricated by Y12 as per specifications from AECL 19.9% enrichment.						
Transportation							Arrangements to be made with Savannah River Acceptance Program team and AECL for use of F257 flask (re-license)				LEU fuel delivered	HEU removed F257 flask
Installation							Dry run of the defueling fuelling procedures as well spent fuel flask removal procedures				Fuel cage to be loaded following classical approach to critical.	

Figure1. Timeline of conversion activities

3.2 Timeline of Activities for core conversion

The areas lightly shaded have already taken place, while those in darker shading are ongoing. All other scheduled activities have not yet started, Table 1. There are still several key issues that must be resolved; these include a signed agreement with AECL for work to be contracted to them and the use of specialized equipment for the core conversion. Additionally we will need to renew the competent authority certification from the US Department of Transport for the F-257 flask which expired on September 30th 2012.

4. Conclusion

The conversion of the Jamaica SLOWPOKE core from HEU to LEU has funding provided by the DOE. The work will be undertaken by AECL staff, external contractors and ICENS staff. The fuel and fuel cage will be manufactured by the DOE Y-12 facility. The issues of independent regulatory oversight in the Jamaican jurisdiction are being addressed and we are awaiting final drafting instructions for the regulations to be issued by the Government. The new National Oversight Committee, which initially has limited knowledge in the nuclear field, will be assisted by the IAEA in the review of safety analysis reports and other relevant documents.

The signing of the NDA between AECL, ANL and ICENS is a welcomed first step; however, contractual arrangements still need to be entered into regarding the participation of AECL staff, and the use and logistics of transporting specialized conversion equipment to and from Jamaica. It is envisaged that the process from shutdown to commissioning can be completed within six weeks, provided that the fuel fabrication process can be completed in the estimated 18 months. If all goes well the core conversion should be accomplished by the end of 2014.

In March 2014 the ICENS Jamaica SLOWPOKE will be celebrating its 30th year of operation. It is planned to celebrate this milestone with a number of events that recognize and highlight the output and efforts of the staff over the years, in carrying out research and developing competences in the field of nuclear science. It is hoped that the new core will herald an era of renewed effort and work in promoting the peaceful uses of nuclear technology, with ICENS as a catalytic core for interdisciplinary programmes for the next 30 years.

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