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OPERATION OF THE SLOWPOKE-2 REACTOR IN JAMAICA

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ABSTRACT

Over the past sixteen years ICENS has operated a SLOWPOKE 2 nuclear reactor almost exclusively for the purpose of neutron activation analysis. During this period we have adopted a strategy of minimum irradiation times while optimizing our output in an effort to increase the lifetime of the reactor core and to maintaining fuel integrity. An inter-comparison study with results obtained with a much larger reactor at IPEN has validated this approach. The parameters routinely monitored at ICENS are also discussed and the method used to predict the next shim adjustment.

INTRODUCTION

SLOWPOKE is an acronym for Safe Low Power C(K)ritical Experiment. The reactor was designed by Atomic Energy of Canada Ltd. SLOWPOKE is simple to operate and provides a relatively high and remarkably stable neutron flux over long periods of time.

The SLOWPOKE-2 reactor at the International Centre for Environmental and Nuclear Sciences (ICENS) is the only nuclear research reactor in the Caribbean. It is mainly used for Neutron Activation Analysis (NAA) [1], at this time the main sample types are soils, rocks, sediments, and increasingly, plant and animal tissues. The reactor achieved criticality for the first time in March 1984. The reactor normally operates at a power of 20 kW for approximately 5 hours per day, 5 days per week. It has now operated for a total 5.63×10^4 -kilowatt hours out of a calculated lifetime of 3.395×10^5 kWh or 16.5% of total lifetime. A detailed database has been kept of some of the essential measurable reactor parameters. The data collected has not only been used to ensure the safe use of the reactor but also to predict the schedule of preventative maintenance and assist in the efficient use of reactor time and eventually aid during the decommissioning of the reactor.

This paper outlines the performance and current status of the SLOWPOKE-2 in Jamaica.

The ICENS SLOWPOKE-2 Reactor

Reactor Core

The detailed specifications of the reactor are available [2]. The reactor core is illustrated in Figure 1. It consists of an assembly of 296 fuel pins containing a total of 817 g of 93% 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, known as shims, consist of semi circular plates of beryllium each only a few millimeters thick. Since no adjustments to the core are allowed, burn-up is corrected for by the increased neutron reflection provided by adding shims as required. The core assembly is immersed in an aluminum tank containing very pure water (deionised weekly to a resistivity of 4×10^7 ohm cm) which is both moderator and heat transfer medium. The tank is suspended in a pool 6.4 m deep containing water that is continuously deionised to a resistivity of 10^6 ohm cm. This provides for both heat transfer from the core water and for biological shielding.

There are five small inner irradiation sites within the beryllium annulus and four large sites outside of the beryllium. Additional irradiation sites are provided by the inpool irradiation carousel, which is position on the surface of the reactor vessel adjacent to the core, figure 1.

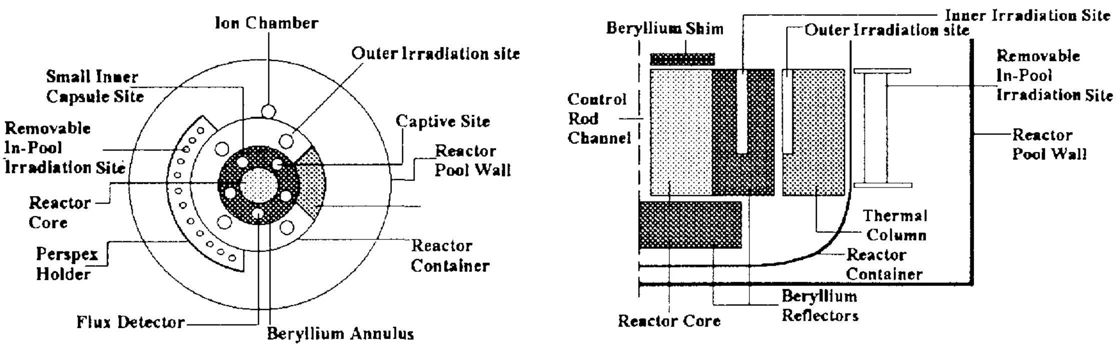

Figure 1. Schematics of the Slowpoke 2 eactor core showing in-core and in-pool irradiation sites.

The design and operating conditions of SLOWPOKE eliminate the need for the conventional complex instrumentation and electromechanical emergency shutdown systems. This high degree of intrinsic safety is achieved by a large negative temperature coefficient and by severe limitations on both the excess reactivity (maximum 0.40%) and the operating conditions. The large negative temperature coefficient ensures that power excursions are self-limiting [2]. Irradiation of more than 10 mg of ^{235}U or any other fissile material is prohibited, with this limit in place it is unlikely that operator intervention could increase the reactivity to the point of prompt criticality (0.788%). The power level is controlled by a single cadmium control rod via a feed back to a neutron detector located within the beryllium annulus. The neutron flux is measured by a Reuter-Stokes self-powered cadmium flux detector with a nominal sensitivity of 1×10^{-20} amps per unit flux.

Reactor core measurements

Core Stability

Under normal operating conditions the reactor core reaches its equilibrium temperature in approximately two hours as shown in Figure 2. The characteristics of the SLOWPOKE are not only stable over time, but are also very stable from reactor to reactor. In a recent inter comparison study [3] between ICENS, High Enriched Uranium (HEU), Ecole Polytechnic Low Enriched Uranium (LEU), and China Institute of Atomic Energy Minature Neutron Source (MNS) reactror; the relative thermal, epithermal and fast neutron fluxes were measured in the inner and outer irradiation sites of the reactors by the bare triple monitor method. The standard error of the thermal flux between the three cores was found to be 4.16%.

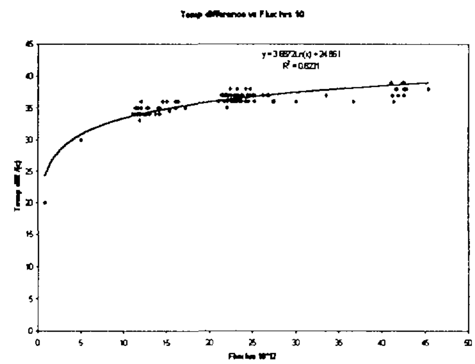

Figure 2. Increase in Temperature with time, Reactor at full power

One of the limits of this design, though also one of its important safety features is the inability to run for long periods of time as illustrated in figure 3. Fuel temperature and moderator density have time constants on the order of seconds; fission product poisons, hours; and fuel burn-up, weeks or months. Although the reactor has a negative temperature coefficient the increased loss of excess reactivity is due to the build up of poisons in the core.

Figure 3, shows that the run time of the core reactor is a function of the excess reactivity of the shims. The maximum running time just after a shim adjustment is approximately 13.5 hours. At the present level of excess reactivity the maximum run time is approximately 10.5 hours.

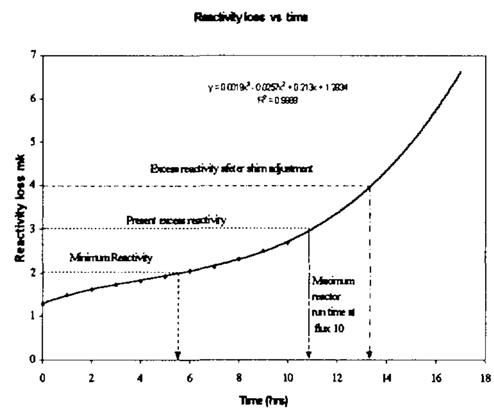

Figure 3. Reactivity with time, reactor operating at full power Data extrapolated from commissioning report [4]

Fuel burn up

The fuel burn up since the last shim is calculated from the change in the period measurement. Observing the control rod balance after a one-hour irradiation at maximum flux over the past four years also gives a measure of fuel burn up. The actual calculation of the excess reactivity was

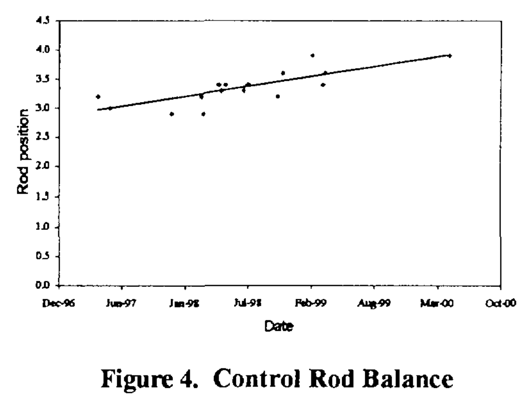

Figure 4. Control Rod Balance

performed using the rod calibration data from the commissioning report [4]. The results are shown in figure 4, and at 0.72 mk is in close agreement with the change in period measurement of 0.76 mk. (from 3.96 mk to 3.2 mk). The scatter shown in Figure 4 is most likely due to varying amounts of Xe-133 present from recent use of the reactor.

Shim Adjustment

Of the maximum 10 cm of shim possible only 2.84 cm have thus far been used, the last addition was made on 16th of January 1996 and increased the reactivity from 2.3 mk to 3.96 mk. This required an increase from 2.21 cm to 2.84 cm of beryllium.

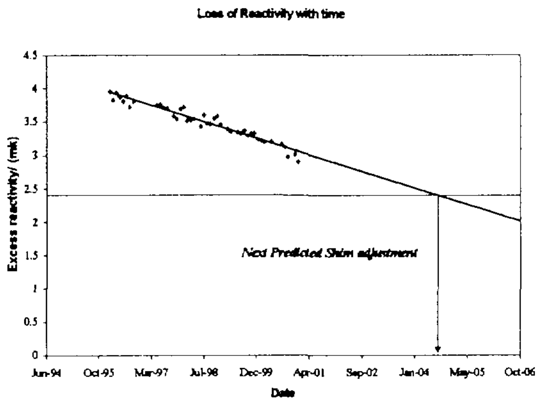

Figure 5. Shim prediction extrapolated from historical data

Reactor Core water Monitoring

Fuel integrity is vital to the continued operation of a reactor. A good indicator of the fuel integrity is the activity of the reactor container water. Under the current licensing agreement if the radiation monitor levels above the reactor vessel exceed 10 mR/h the reactor must be shut down. In addition, at the end of the lifetime of the reactor the integrity of the fuel elements will play a large role in determining exactly how the reactor is to be decommissioned. If the fuel is not intact the only containment vessel approved for the SLOWPOKE core, may not be sufficient thus adding greatly to the decommissioning cost.

Modeling the reactor dynamics related to delayed neutrons and xenon requires the inclusion of new state equations tracking the production of delayed neutron precursors, ^{131}iodine and ^{131}xenon. Shown below in figure 6 are the varying levels of four of the major reactor poisons. The lowest levels indicated represent weeks in which the reactor was run only in maintenance mode, approximately ten minutes at a flux of 1 x 10^{11} n cm^{-2} s^{-1} or 0.17 kWh. The highest level indicated was taken after the reactor had been run for 6 hours at maximum flux or 110 kWh. Each sample was taken approximately three days after shutdown.

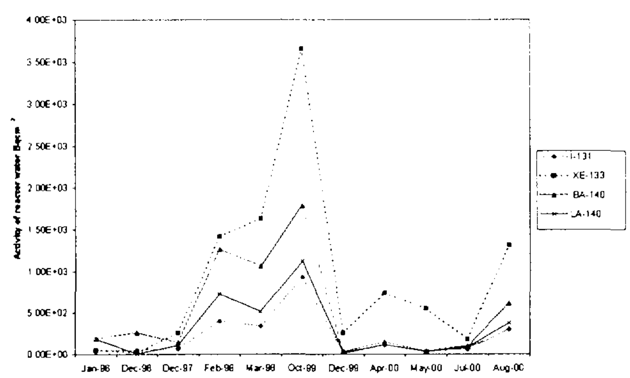

Figure 6. Major reactor poisons in reactor water after various times of operation

Neutron Activation Analysis

Although the maximum neutron flux of 10^{12} n cm^{-2} s^{-1} is low in comparison to that produced by larger reactors [5] the results produced are nevertheless comparable. In addition to the lower flux is the limitation of irradiation time. With the minimum acceptable excess reactivity at 2.3 mk, the reactor can run at full power for approximately 5 and a half-hours. However, an irradiation time of four hours has been found adequate for the present programmes and for optimising fuel burn-up [6]. An inter-comparison study was undertaken between ICENS using the SLOWPOKE 2 [7] and Instituto de Pesquisas Energeticas e Nucleares, IPEN-CNEN/SP, in Brazil, results shown in For the short-lived elements ICENS generally out performed the larger reactor at IPEN. The intermediate lived elements exhibit very similar detection limits [8]. As expected the long-lived elements are best analyzed in the larger reactor, with longer irradiation times and higher flux, induced activity is a function of half life [1].

Conclusion

At our current rate of fuel burn-up we can expect an additional twenty to twenty five years of service from our present core, at which time an extended life beryllium annulus, which has already been acquired, will be added to the bottom beryllium plate. The addition of this beryllium will further extend the life of the core by an additional fifteen years, giving a total of fifty years of service from one core.

The activity of the reactor water measured during maintenance has not shown signs of significant deterioration, indicating that the fuel sheaths are still in relatively good condition and, at present pose no threat to the continued operation of the facility.

The strategy of minimizing irradiation times to conserve reactor fuel has not significantly reduced our analytical capability. When possible samples are irradiated in-pool, thus utilizing the "free" neutrons. The addition of higher efficiency detectors could play a significant role; and might improve detection limits.

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