LONGER LIFE CORES FOR SLOWPOKE-2 REACTORS

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ABSTRACT

A method has been devised to increase the lifetime of SLOWPOKE-2 cores by increasing the initial fuel loading by about 7%. The method was implemented during the commissioning of the SLOWPOKE-2 (Kanata) reactor. Calculations indicate that the core lifetime will be doubled.

INTRODUCTION

SLOWPOKE-2 is a 20 kW pool-type research reactor(1). It produces a thermal neutron flux of 10^{12} $n.cm^{-2}.s^{-1}$ which is used mainly for neutron activation analysis and the production of short-lived isotopes. Because of its inherent safety characteristics it is licensed for unattended operation.

There are six operating SLOWPOKE-2 reactors in Canada, and one at the University of the West Indies in Jamaica. There is also one under construction at the Royal Military College in Kingston, Ontario, which will be the first SLOWPOKE reactor to have a low enrichment uranium core (2).

Six of the operating reactors have an effective life of one full-power-year, which corresponds to approximately ten calendar years at a typical university installation. A simple method has been devised to extend the core lifetime significantly for future cores by adding more fuel to the core initially.

SLOWPOKE-2: GENERAL DESCRIPTION

SLOWPOKE, an acronym for Safe Low Power Critical Experiment, is a pool-type reactor developed by Atomic Energy of Canada Limited as a neutron source for isotope production and neutron activation analysis. Low cost, inherent safety and simplicity of operation were primary considerations. The reactor provides a usable thermal neutron flux of 10^{12} $n.cm^{-2}.s^{-1}$ at approximately 20 kW thermal power. The prototype SLOWPOKE-1 was commissioned at the Chalk River Nuclear Laboratories in 1970. The first commercial unit, SLOWPOKE-2, was installed in 1971. These reactors are licensed to operate without conventional automatic shutdown devices and without an operator in attendance. The basic design specifications are shown in Table 1.

SLOWPOKE-2 has five sample sites in the beryllium radial reflector and five more sites in the water surrounding this reflector. Irradiation capsules are transferred to and from the reactor using a compressed gas system in tubes extending from the loading station to the sample site. Figure 1 shows the SLOWPOKE-2 reactor assembly.

TABLE 1: SLOWPOKE-2 DESIGN SPECIFICATIONS

REACTOR	
Pool Diameter	2.5 m
Pool Depth	6.1 m
Container Diameter	0.6 m
Container Height	5.3 m
Core Diameter	22.0 cm
Core Height	22.0 cm
Fission Power	20.0 kW

IRRADIATION FACILITIES

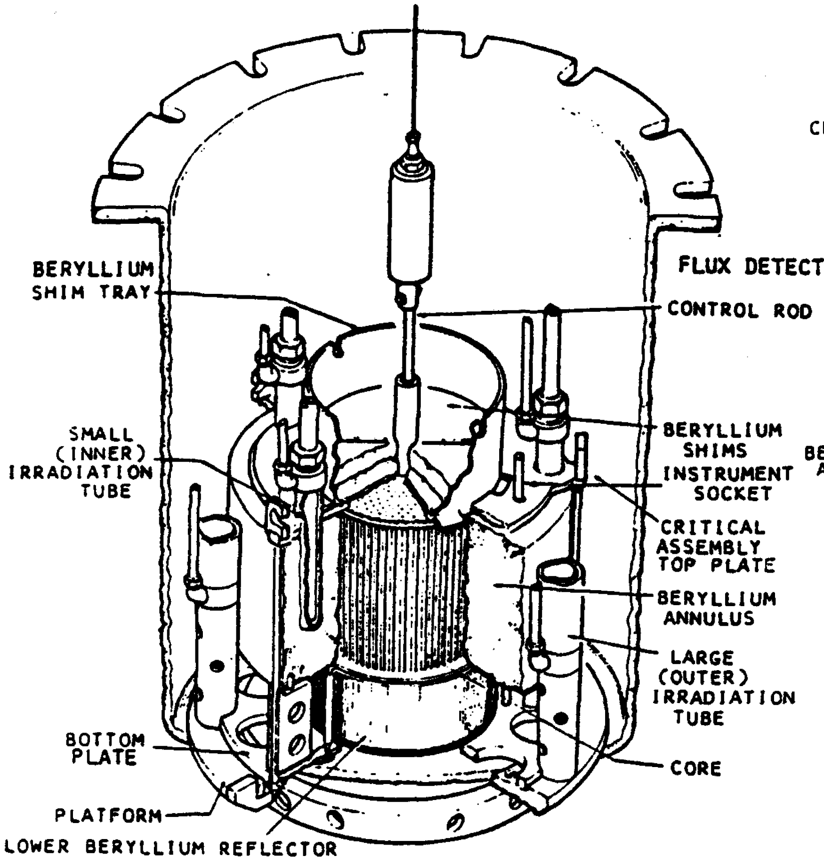
		INNER	OUTER
Thermal Flux	$n.cm^{-2}.s^{-1}$	10^{12}	5.8×10^{11}
Diameter	cm	1.6	2.9
Length	cm	5.4	5.4
Volume	cm^3	7	27

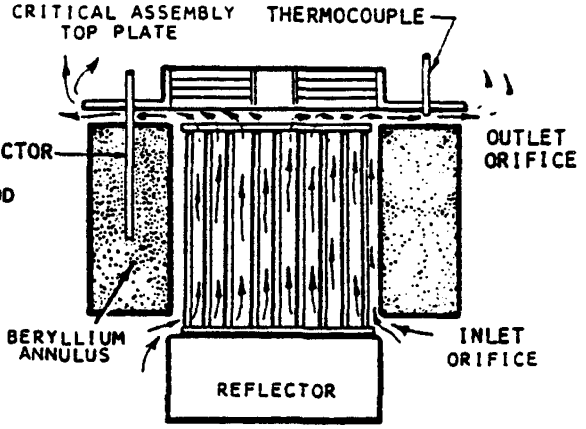
SLOWPOKE-2 cores contain about 820 g of U235 in the form of uranium-aluminum alloy, in which the uranium is enriched to 93 wt%. The core consists of approximately 300 aluminum-clad fuel elements. The cylindrical reactor core is surrounded by 10 cm thick beryllium reflectors on the side and bottom. Long term reactivity compensation is effected by adding thin beryllium plates to a shim tray on top of the core. The reactor core and beryllium reflectors are supported inside a cylindrical aluminum water tight reactor container suspended in the reactor pool, thereby providing double containment for the pool water.

The core is cooled by natural convection of the coolant-moderator water. Coolant heat passes through the wall of the container to the pool where it is removed by means of a cooling coil connected to the local water supply.

Inherent reactor safety is guaranteed by a combination of the negative temperature and void coefficients of the undermoderated core, a limited maximum excess reactivity of 0.0034 $\delta k/k$, administrative control of samples added, and restricted user access to the reactor core.

The core of the SLOWPOKE reactor is designed to have negative temperature and void coefficients of reactivity, so that heating or boiling of the coolant-moderator causes the reactivity to decrease. A consequence of this self-regulating characteristic is an upper limit on the equilibrium power equal to the heat removal capacity of the cooling system. A more important consequence of the negative temperature and void coefficients is the inherent protection against reactivity transients caused by loss-of-regulation. The reactor is designed so that the power and temperature transients, resulting from the most severe reactivity transients, are safely





COOLANT FLOW BY NATURAL CONVECTION

FIGURE 1: SLOWPOKE-2 CRITICAL ASSEMBLY

limited by the rapid increase in fuel and coolant-moderator temperatures and the production of sub-cooled voids.

Automatic control of the reactor is exercised by a single motor-driven cadmium absorber rod which moves along the central axis of the core through a hole in the top reflector. The control rod motor is activated by a signal from a self-powered neutron detector located in the beryllium side reflector. If the control system fails, the maximum credible reactivity insertion will result in a power transient limited to safe levels by the inherent negative feedback characteristics. If a fault develops in the automatic regulating system, the reactor can be shutdown manually by inserting cadmium filled capsules in one or more of the irradiation sites.

INCREASING CORE LIFETIME

The top beryllium reflector can have a thickness ranging between zero and 10 cm, and at the beginning of core life it is typically 1.7 cm thick. To compensate for fuel consumption, its thickness is increased by adding semi-circular beryllium plates manually. In typical use at a university, a plate is added about once per year.

The original approach-to-critical procedure required that fuel elements be loaded into the core until k-effective was about 0.995. The thickness of the top beryllium reflector was then increased in steps until k-effective would be 1.0034 with the central control absorber removed. The remaining beryllium for the top reflector was then added in the following years, so that after each adjustment k-effective was equal to or just less than 1.0034. The resulting core lifetime after the full 10 cm had been added, was approximately one full-power-year.

Reactor physics calculations showed that the core lifetime could be extended significantly if the first approach to critical were modified slightly so that fuel loading continued until k-effective was equal to or just less than 1.0034 with the control absorber removed. This leaves the total thickness of the top beryllium reflector to be added in later years to compensate for the reactivity lost to fuel burnup. This approach was used during the commissioning of the latest SLOWPOKE-2 reactor in June 1984 at the AECL Radiochemical Company's Kanata facility.

FUEL LOADING FOR SLOWPOKE-2 (KANATA) REACTOR

General

During commissioning of SLOWPOKE-2 reactors fuel loading proceeds by adding fuel to the core according to a prearranged schedule. During fuel loading, the subcritical multiplication of neutrons from an Ac:Be source placed in irradiation site #1 in the annular beryllium reflector is detected by two neutron sensitive ion chambers located outside but adjacent to the reactor (see Figure 2).

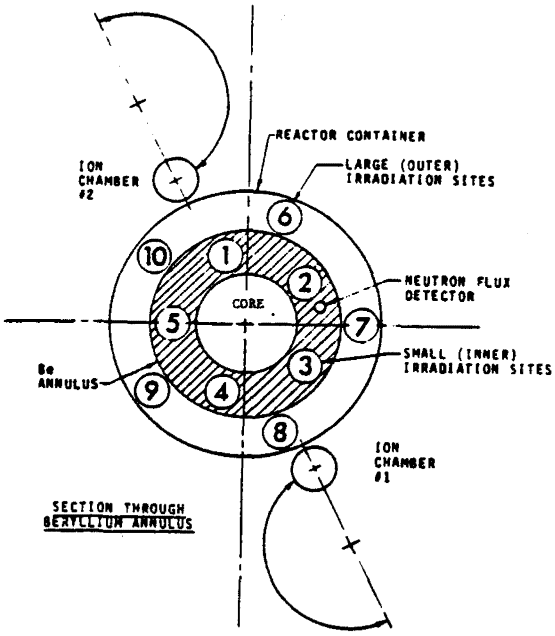


FIGURE 2:

CORE AND IRRADIATION TUBE LAYOUT

Graphs of inverse ion chamber signal ($1/\Phi_n$) and k-effective, versus number of fuel elements loaded are constructed using the relationship:

$$\text{k-effective} = 1 - \frac{KS}{\Phi_n} \qquad (1)$$

where S is the ion chamber signal for the Ac:Be source only (no fuel present), Φ_n is the ion chamber signal for total neutron flux produced with the Ac:Be source and the fuel elements present, and K is a factor dependent upon system geometry.

During commissioning a moveable absorber worth 5.3 mk is used to compensate for excess reactivity. It is located in irradiation site #5 in the beryllium reflector and is designated the commissioning rod.

Fuel loading continues until k-effective is approximately 0.995. In the past, beryllium plates were then added to the top beryllium reflector until k-effective was just less than or equal to 1.0034 as determined by a period measurement. However, at Kanata, fuel loading continued until k-effective was about 1.003. In this way essentially the full thickness of the beryllium reflector is available to compensate for burnup.

Preliminary Fuel Loading

At Kanata fuel loading progressed according to the fuel loading schedule until, with 297 fuel elements loaded, k-effective was estimated to be 0.9943. The approach-to-critical plot is shown in Figure 3. At this time fuel loading was temporarily suspended while the commissioning rod was calibrated and the neutron source was moved to a new position.

Repositioning of Neutron Source

Before adding more fuel elements, the Ac:Be neutron source was moved to an irradiation tube outside the reactor vessel, thereby reducing its effective source strength by a factor of 34. Subsequent sub-critical power levels were reduced by the same factor, so that the radiation fields experienced by the operators handling the core were minimized.

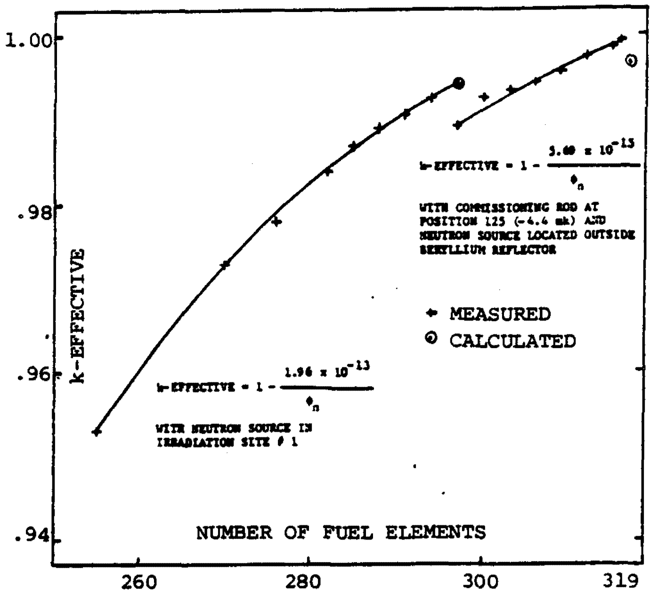


FIGURE 3:

APPROACH TO CRITICAL SLOWPOKE-2 (KANATA)

Final Fuel Loading

The commissioning rod was lowered to 85% of its full insertion and the system reactivity was thereby reduced from 0.9943 to 0.9899. Fuel elements were then added until the reactivity reached 0.999 with a total of 317 fuel elements in the core. Near the end of fuel loading, it was discovered that the three outer irradiation tubes were incorrectly installed in their sockets. When the error was corrected, the reactivity decreased by about 0.5 mk. The final core loading is shown in Figure 4. (The filled black circles in the figure indicate vacant sites.)

Addition of Beryllium Plate

With a loading of 317 elements, and the shim tray installed, the commissioning rod removed, and all irradiation tubes correctly in place, an additional 0.5 mk of reactivity was still required to give a potential excess reactivity of 3.4 mk. Since one more fuel element might have increased the reactivity beyond the allowable limit, one semi-circular beryllium plate (1.6 mm thick) was installed in the shim tray.

INCREASE IN CORE LIFETIME

The expected increase in core lifetime for the Kanata reactor relative to previous SLOWPOKE-2 reactors was calculated using the DSN option of the neutron transport code WIMS-CRNL (3). The midplane of the reactor core was modelled and axial leakage was taken into account by using an axial buckling. A 297-element core was used to represent the previous SLOWPOKE-2 reactor cores and a 317-element core represented the Kanata reactor core. The axial buckling corresponding to the beginning of core life (no top beryllium reflector) was obtained by finding the buckling which would make k-effective for the 297-element core equal to 0.9943 which was the value measured at Kanata for a 297-element core. The axial buckling corresponding to the end of core life (full top beryllium reflector) was set equal to the axial critical buckling for the 297-element core after one full-power year of burnup.

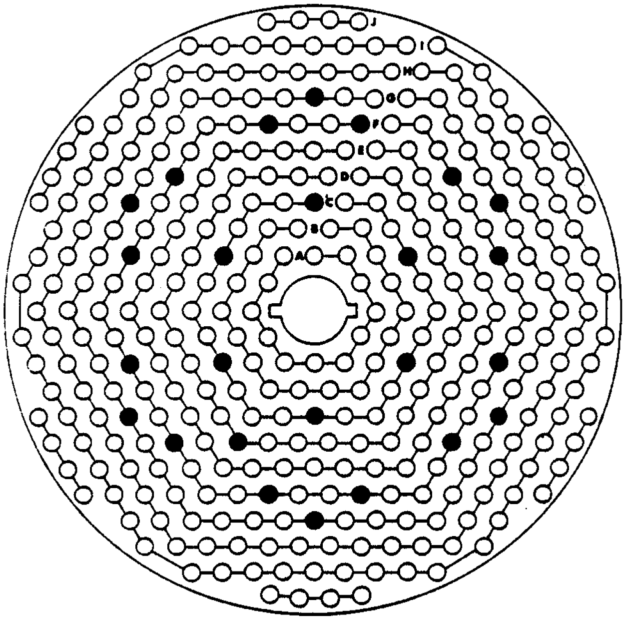


FIGURE 4:

FUEL ELEMENT LOCATIONS

When the initial axial buckling was used for the 317-element core a value of k-effective of 1.0011 was obtained. This is 2.6 mk lower than the measured value for the 317-element core. There are several possible experimental and calculational errors which could account for this discrepancy. One deficiency in the calculations is the use of a one-dimensional calculation which does not take into account azimuthal asymmetry.

Using WIMS, the 317-element core was then burnt up until the critical buckling was equal to that obtained for the 297-element core after one full-power year. This occurred after 2.0 full power years for the 317-element core.

The reactivity balances at the end-of-core life for both the 297- and 317-element cores are given in Table 2.

Table 2: REACTIVITY BALANCE

Effect	Reactivity Worth (mk)	
	297-element core	317-element core
Initial Be top reflector	9.1	0.4
Sm149	4.9	6.5
Burnup excluding Sm149	6.0	11.3
Total	20.0	18.2

The increase in core lifetime is mainly due to saving almost all the top beryllium reflector to compensate for burnup. However, Table 2 indicates that some of the increase is due to the samarium concentration approaching its equilibrium concentration. This is demonstrated by the fact that the reactivity associated with Sm149 increased by a factor of 1.3 while that associated with burnup (excluding Sm149) increased by a factor of 1.9.

The totals given in Table 2 should be equal to the reactivity worth of a 10 cm thick top beryllium reflector. For the 297-element core the total reactivity agrees well with the measured value of 20 mk. For the 317-element core the total is 1.8 mk less than the expected value.

Because the initial reactivity of the 317-element core is underpredicted and because the reactivity balance at the end of core life for the 317-element core does not account for the total reactivity worth of the beryllium reflector, it is expected that the present method of calculation underestimates the increase in core lifetime for the 317-element core. Thus, it is expected that the core lifetime will be increased by at least a factor of 2.0

CONCLUSION

A method has been outlined to increase the lifetime of SLOWPOKE-2 cores by increasing the amount of fuel loaded initially. This method was implemented during the commissioning of the SLOWPOKE-2 (Kanata) reactor. Calculations indicate that the 7% increase in fuel loaded will double the core lifetime.

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