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A New Safety Principle for the SLOWPOKE Reactor

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ABSTRACT – Slowpoke-2 (LEU core) is a pool type nuclear reactor with a maximum thermal power of 20 kW. It uses a pelletized uranium oxide fuel (19.9% enrichment) and provides a useful high neutron flux in the order of 10^{12} $n.cm^{-2}s^{-1}$. The key safety features built into the reactor design are the strictly limited amount of excess reactivity and the negative reactivity feedback characteristics, which provides a demonstrably safe self-limiting power excursion response to large reactivity insertions. However, the limited amount of excess reactivity also limits the continuous prolong reactor operation at full power. With a 3.7 mk excess reactivity, the reactor can operate for about one day at the full power, 20 kW, before this excess activity is lost due to temperature effects and Xe poisoning.

A new safety concept is proposed in this paper to extend the continuous operation time to months by increasing the excess reactivity from 4 mk to 6 mk. This new concept has been demonstrated using a Matlab/simulink model of Slowpoke-2.

1. Introduction

The Slowpoke-2 reactor is a small pool-type nuclear reactor with a light water moderator. The reactor container is constructed in two parts, a lower and an upper section, with the critical assembly being contained in the lower section. The upper section is essentially an extension tube providing the depth of water necessary for effective radiation shielding and cooling to the core.

Both sections of the reactor container are 61 cm outside diameter. The lower section is 0.83 m deep, and the upper section is 4.44 m long [1]. The critical assembly is located in the lower section and consists of fuel core, beryllium reflector, and water reflector. Detail information of the reactor and pool can be found in reference [1] for LEU core.

The key safety features of

Both HEU and LEU cores have been installed in history. The current LEU core is composed 198 fuel pins
Background of Slowpoke-2 and the current issues with 20 kW Slowpoke
- Can’t run in continuous manner
- Limited application (only for research)

John’s proposal (200 kW) and possible applications for next generation Slowpoke
- Extend to isotope production
- Neutron beam

- Medical treatment

Safety principle of current Slowpoke and New proposal

- The current Slowpoke-2 has 4 mk excess reactivity. Based on the transient analysis and transient test, no sever consequence in case of loss of control.
- The new proposal is to have about 6 mk excess reactivity, which will enable the reactor to be operated in continuous manner, and with high power (200 kW). The safety of the reactor is provided by deploying one extra slow control rod which only can be withdrawn at a limited maximum speed, e.g. 1 cm /hr. This should limit the power peak and shutdown the reactor automatically in case of loss of control.

Computer Kinetic model and consideration (one paragraph)

- Based on D. Rozon's model
- On Matlab/simulink platform
- High level block diagram of the model

Detail description of the kinetic model (one or two paragraph)

- Point kinetic model for neutronic
- Layered thermal hydraulic model
- Major thermal hydraulic stage consideration

Verification results (multiple paragraph based on how many cases are simulated)

- Comparing to some basic case and exiting measurements

Safety case simulation based on the proposal (one paragraph)

- Loss-of-control accident simulation with two control rods

Simulation of continuous operation for weeks at 20 kW, 50 kW, 100 kW and 200 kW (one paragraph)

Conclusion (one paragraph)

Figure 1 – Illustration of the ZED-2 Facility.

3. Fission Chamber Calibration

Counts eThe reactor was operated at approximately 100 W for one hour with copper foils attached to the aluminum tube near the location of the fission counter, and copper wires attached to the fission chamber itself. Additional copper foils and wires were attached to a rotating reference wheel located at position O7W (symmetric with respect to the lattice). A cobalt wire on the wheel w

Figure 2 – Plan View of Core Lattice, Depicting location of Reference Wheel, Fission Chamber, and Ion Chamber.

4. Count Rate Measurements

The fission

Figure 3 – Subcritical Count Rates Detected as a Function of Moderator Height.

5. Reactivity Measurements

Several

Figure 3 – THIS FIGURE DOESN'T MATCH MIKE'S DATA, SUSPECT! I can't get at the information Mike used. Not sure which version (if either) is correct.

6. Core Alteration and Repeat Measurements

These m

6. Code Calculation Methodology

The resul

tten as

$$M = 1 + \sum_{i=1}^{N-2} \prod_{j=1}^{i} k_j + \prod_{j=1}^{N-1} k_j \cdot \left(\frac{1}{1-k_N}\right) \qquad (2)$$

7. Known Issues

It's noted that.

8. Conclusions

Experiments h.

9. References

[1] D. J. Winfield, "Safety Analysis Report for the Ecole olytechnique Slowpoke-2 Reactor", RC-1598 Rev 1, AECL, 1998 March

SLOWPOKE Reactor Safety and Control

- The Next Generation

Suggest "SLOWPOKE Reactor Safety and Control - The Next Generation" for the title, or "A New Safety Principle for the SLOWPOKE Reactor". I have no preference.

The Next Generation means higher power, greater excess reactivity and a new safety principle. Logical power steps would be 50kW, 100kW and 200kW, without forced cooling of the core or reactor vessel. This paper is limited to demonstrating the new safety principle using a computer kinetic model.

Transient tests at Chalk River in 1970 demonstrated that loss-of-control accidents approaching prompt-critical are safely limited by the negative reactivity coefficients. A rapid removal of the control rod resulted in a power peak of 180 kW and a temperature peak of 95 degrees C.

Describe present safety principles and the new safety principle - two paragraphs.

Our first goal is to design a computer kinetic model of SLOWPOKe 2. Then, increasing the excess reactivity from 4 mk to to 6 mk, demonstrate that the reactor can operate safely at 20 kW and xenon equilibrium continuously for days and weeks. The control range would be -1 mk to +6 mk, so the control absorbers would be worth 7 mk total. The core contains approximately 1 kg of U-235 in Low Enriched Uranium (LEU), and the total consumption at 20 kw would be 0.17 g U-235/week.

Our second goal is to license a two day demonstration of the new safety principle at an existing SLOWPOKE site.

I suggest drafting an outline with paragraph headings and bullets for circulation, as soon as possible.

From the beginning, inherent safety has been a cornerstone of the SLOWPOKE concept. Here are the original safety principles:

- *Maximum excess reactivity less than prompt critical by design.*
- *Negative temperature and void coefficients of reactivity.*
- *Double containment of the water-cooled core.*
- *Natural circulation through the core.*
- *Core sub-critical in water.*
- *Single motor-driven control rod; manual shutdown absorbers.*

Transient tests at Chalk River in 1970 demonstrated that loss-of-control accidents approaching prompt critical are safely limited by the negative reactivity coefficients. A rapid removal of the control rod injecting 6.8 mk of reactivity, resulted in a power peak of 180 kW and a temperature peak of 95 degrees C.

Operation at full power is limited to about 20 hours, before the reactivity loss from rising temperature and increasing xenon Xe-135 exceed the maximum allowable reactivity. To overcome this limitation, the following new safety principles are proposed:

- *Maximum excess reactivity greater than prompt critical, but* ***rate of reactivity addition limited by design.***
- *Reactivity worths of multiple motor-driven control absorbers each less than prompt critical by design.*
- *Removal times of motor-driven absorbers are designed to match the inherent negative rates of SLOWPOKE as follows:*

    Start-up and auto control – 20 seconds;
    Temperature effects – minutes;
    Xenon and samarium – hours, days;
    Fuel burn-up – days, weeks.

It is proposed that these new safety principles be demonstrated at an existing SLOWPOKE reactor site, using two slow speed absorbers, and one higher speed absorber. The loss-of-control accident, starting from shutdown, would be demonstrated by turning off the pool water cooling system and withdrawing all three absorbers at their maximum speeds.

Validating and licensing the new safety principles would be a first step towards up-rating the SLOWPOKE reactor to 100 kW, 500 kW and 2 MW. However, before proceeding on that path, there are two other SLOWPOKE applications that could be much more important in the near term: fixing the MAPLE reactors and the homogeneous SLOWPOKE reactor.

If each of the outer 12 fuel assemblies of the 10 MW MAPLE reactor were replaced by solid beryllium metal, the 7 central assemblies could be loaded with uranium/aluminum fuel elements using HEU alloy similar to that used in NRU targets for Mo-99 production. Operating the 7-channel core at 3.5 MW, and processing one fuel assembly every two days would produce almost as much Mo-99 per week as NRU. **In effect, a 7-channel SLOWPOKE-type core could replace the present 19 channel MAPLE core, without changing the hexagonal mechanical structure.**

Recent research at the Royal Military College indicates that the present 20 kW SLOWPOKE reactor could probably be converted to homogeneous operation using LEU sulphate solution, by replacing the present core inside the beryllium reflector with a small tank. **Three 20 kW reactors with daily extraction of Mo-99 from the whole core, and distribution to hospitals within two days, could meet the present Canadian demand of approximately 600 six-day Curies per week.**

Bio

PhD, Nuclear Physics, McGill, 1954
Reactor Physicist, Atomic Energy of Canada Ltd., 1954 – 1991
Researcher Emeritus, 1991 – 1994

Dr. Hilborn began his career in the nuclear industry in 1949, at the Port Radium uranium mine in the Northwest Territories. Joining AECL at Chalk River in 1954, he participated in reactor startups of NRU, NPD, WR-1, and the SGHW prototype at Harwell in England. Dr. Hilborn's most significant contribution was the SLOWPOKE reactor concept, which resulted in the SLOWPOKE research reactor, the SLOWPOKE Demonstration Reactor (SDR), and the SLOWPOKE Energy System (SES-10).

In 1964 he demonstrated the feasibility of the self-powered neutron detector for reactor in-core monitoring. It was patented in 1967. He was also co-founder of the manufacturer of those detectors, Reuter-Stokes Canada Ltd.

In 1974 Dr. Hilborn was awarded the Eadie Medal by the Royal Society of Canada, and the W.B. Lewis Medal by the Canadian Nuclear Association.

Dr. Hilborn retired in 1991, but continued his research work at Chalk River for several years, in the capacity of Researcher Emeritus.