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Lead Containing Pb-208: New Reflector for Improving Safety of Fast Neutron Reactors

Summary / Objectives:

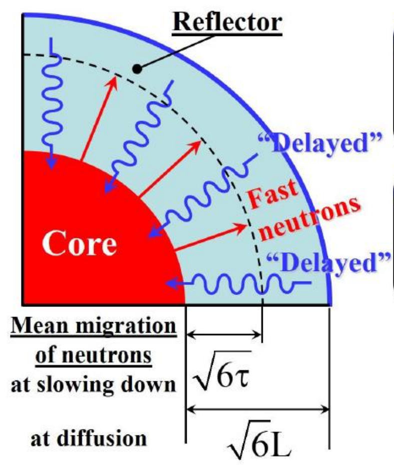
This webinar considers improvement of fast reactor safety through slowing-down power runaway. The idea is surrounding the core by the neutron reflector made of lead-208, a material of heavy atomic weight and extremely low neutron absorption. The power runaways can be slowed down because of a long way for leakage neutrons to come back from distant layers of neutron reflector to the core. It is demonstrated that mean prompt neutron lifetime can be elongated roughly by three orders of magnitude with appropriate slowing-down the reactor power runaway.

Meet the Presenter:

Dr. Evgeny Kulikov earned his PhD at the National Research Nuclear University MEPhI in Moscow in 2010 and is currently the associate professor at the Institute of Nuclear Physics and Engineering. His areas of professional interests include improving fuel burn-up, nuclear fuel cycle, non-proliferation, and fast reactor safety. Currently, his scientific research is supported by the Russian Science Foundation. He lectures on theoretical aspects of nuclear reactors and conducts laboratory works on experimental reactor physics. He is serving on the Gen IV International Forum Education and Training Task Force.

Idea of slow down chain reaction:

This idea is safety improvement by slowing down chain reaction. These requirements to slow down chain reaction are a neutron age as large as possible and a diffusion length larger than square root of neutron age. The idea to slow down chain reaction is a fast neutrons go deeply into reflector and return to the core with essential time delay.



1. "Penetrate deeply into reflector" Neutron age τ ($E_{fis} \rightarrow E_{th}$) as large as possible
2. "High probability to return to the core" Diffusion length L larger than $\sqrt{\tau}$

Reactor	Thermal	Fast
Λ	~ ms	~ µs
β	0.65%	0.36%

Safety improvement by slowing down chain reaction

- How we can slow down chain reaction
  - fast neutrons from the core should penetrate deeply into reflector
  - they should have high probability to return to the core as a result of diffusion (in some way "delayed" neutrons)

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Characteristics of Chain Reaction Rate:

The reflector need to a large atomic mass for a large neutron age, a small absorption cross-section for a large diffusion lengths and a small absorption cross-section for a long lifetime of a thermal neutron. The lead 208 is a good choice for a material of reflector.

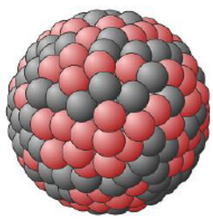
1. **Neutron age** $\tau(E) \sim A \int_{E_1}^{E_2} \frac{1}{\Sigma_s^2} \cdot \frac{dE}{E}$ $\quad$ $\tau \uparrow A \uparrow$

$\sqrt{6\tau}$ – **mean migration of neutrons at slowing down**

2. **Diffusion length** $L \sim \frac{1}{\sqrt{\Sigma_a^{th} \cdot \Sigma_s^{th}}}$ $\quad$ $L \uparrow \Sigma_a^{th} \downarrow$

$\sqrt{6L}$ – **mean migration of neutrons at diffusion**

3. **Lifetime of thermal neutrons** $T_{th} \sim \frac{1}{\Sigma_a^{th}}$ $\quad$ $T_{th} \uparrow \Sigma_a^{th} \downarrow$



^{208}Pb

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Reflector Properties:

The neutron age and diffusion length of lead 208 are very large. The length of thermal neutron lifetime is very important for safety. The thermal neutron lifetime of lead 208 reflector is longer than in any other material.

Material	$\sqrt{6\tau}$ (cm)	$\sqrt{6L}$ (cm)	Slowing down probability (2 MeV → 0.025 eV)	Lifetime of thermal neutrons (ms)
^{208}Pb	213	843 !	0.993	597 !
Pb_{nat}	213	33	0.304	0.9
Na	227	43	0.297	0.3
Bi	223	96	0.160	4.7
C	49	138	0.998	13

Moderator Properties:

The logarithmic energy decrement is describes average energy loss per a collision. it is not dependent on energy and it depends only on atomic mass. The lead 208 is a low logarithmic energy decrement and low moderating ability. But, the absorption cross-section of lead 208 is very small. As such Moderating ratio of lead 208 is a better than light water or barium oxides or graphite.

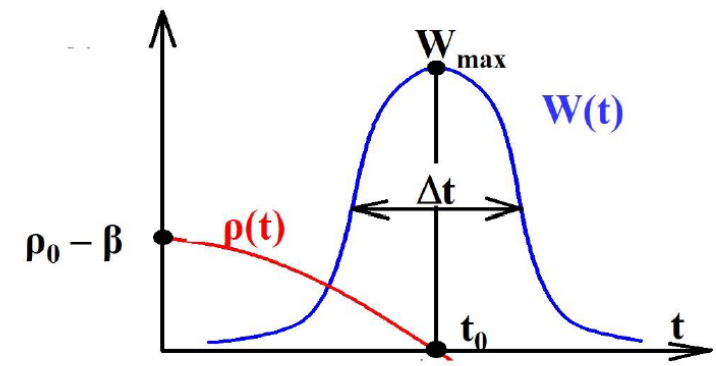
Material	Logarithmic energy decrement ξ	Moderating ability $\xi \cdot \Sigma_s$ (cm^{-1})	Moderating ratio $\xi \cdot \Sigma_s / \Sigma_a$
H_2O	0.95	1.39	70
D_2O	0.57	0.18	4590
BeO	0.17	0.12	247
C	0.16	0.063	242
Pb_{nat}	0.01	0.004	0.61
^{208}Pb	0.01	0.004	477

^{208}Pb is an effective moderator

Overview of Neutron Flash model (p0 > B):

According to the neutron flash model, if a interpret reactivity exceeds delayed neutron fraction is the state of prompt super criticality. And, the doppler effect has enough time to action and duration of neutron flash is proportional to a neutron life to lifetime. while energy yields is in dependence on neutron lifetime.

- this is the state of prompt super-criticality
- heat does not have time to reach the coolant
- only Doppler effect has enough time to act
- duration of neutron flash $\Delta t \sim \Lambda$ neutron lifetime
- energy yield of neutron flash $Q \sim W_{max} \cdot \Delta t \neq f(\Lambda)$



Reactor Power and Fuel Temperature at the Neutron Flash:

The case of natural leads a neutron lifetime is about one microseconds and the case of lead 208 an about one millisecond. In the reactor power, a peak power is thousand times lower and thousand times slower than natural leads. There is enough time for the heat to be transferred from fuel to coolant. In the fuel temperature, a peak temperature is lower and thousand times slower than natural leads.