ENHANCEMENT OF MOX-FUEL RADIATION PROTECTION BY DOPING WITH ^{231}Pa AND ^{232}U

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PROLIFERATION RESISTANCE OF NUCLEAR MATERIALS (NM)

- Proliferation resistance of NM is one of the “key stone” of the nuclear technology development.

- Proliferation resistance of NM may be assured by imparting the inherent proliferation protection properties to NM.

INHERENT RADIATION BARRIER

One of the main inherent proliferation protection properties of NM is **inherent radiation barrier.**

PROBLEM:

Fresh nuclear fuel (just after reprocessing) is not self-protected (has the low inherent radiation barrier).

PROBLEM DEFINITION

- To investigate the measures to impart to MOX-fuel enhanced radiation barrier;
- To estimate achievable levels of MOX-fuel protection which are able to oppose against short-term actions of adversaries or terrorists;
- To study the possibilities of ^{231}Pa and ^{232}U as getter materials.

PARAMETERS OF RADIATION BARRIER

- Protection level L in terms of rate of equivalent dose (RED);
- Time of action T of the barrier at the protection level above L;
- Time-dependent non-uniformity of the proliferation protection level for specified time T.

USEFUL PROPERTIES OF ^{232}U-GETTER

- High-energy gamma-radiation of ^{232}U is emitted by its decay products, mainly by ^{208}Tl;

- Introduction of ^{232}U into fuel composition allows to improve neutron balance of chain fission reaction.

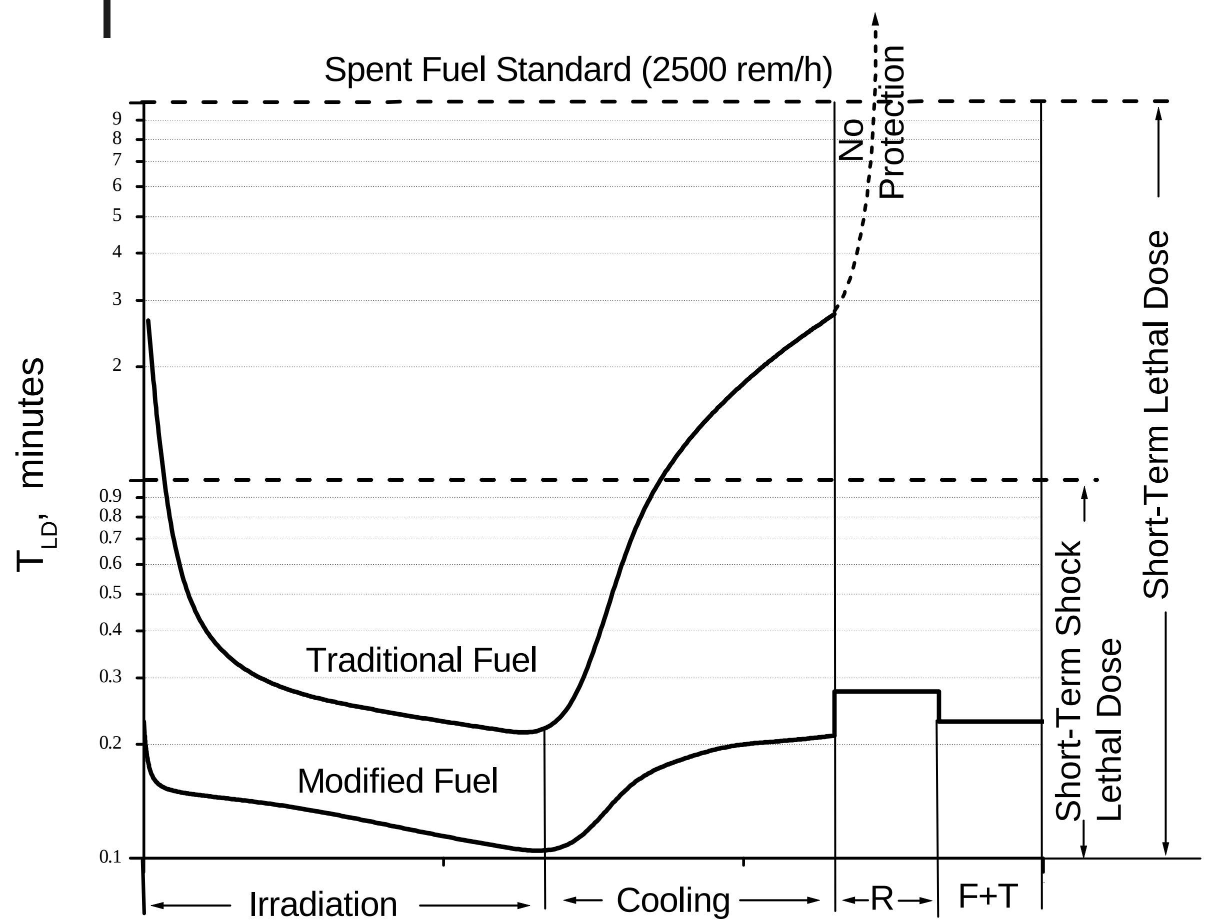
USEFUL PROPERTIES OF ^{231}Pa-GETTER

- Melting temperature of protactinium (1575^{0}C) is substantially higher than that of uranium (1134^{0}C) already used as a getter material in vibro-compacted MOX-fuel;
- Under neutron irradiation, ^{231}Pa is intensely converted into ^{232}U;
- ^{231}Pa, acting, in essence, like a burnable poison, reduces effectively an initial reactivity margin and reactivity swing.

MATHEMATICAL MODEL

- The proliferation resistance is evaluated for different stages of the closed NFC. Minimal value of MOX-fuel proliferation resistance at the most vulnerable stage of NFC was selected as a criterion for MOX-fuel proliferation self-protection.
- NFC of LWR under analysis is based on MOX-fuel containing weapon-grade plutonium.
- The proliferation resistance of NM is expressed in the terms of time T_{LD} till receiving the lethal dose LD (LD=500 rem).

AREAS OF MOX-FUEL PROLIFERATION SELF-PROTECTION

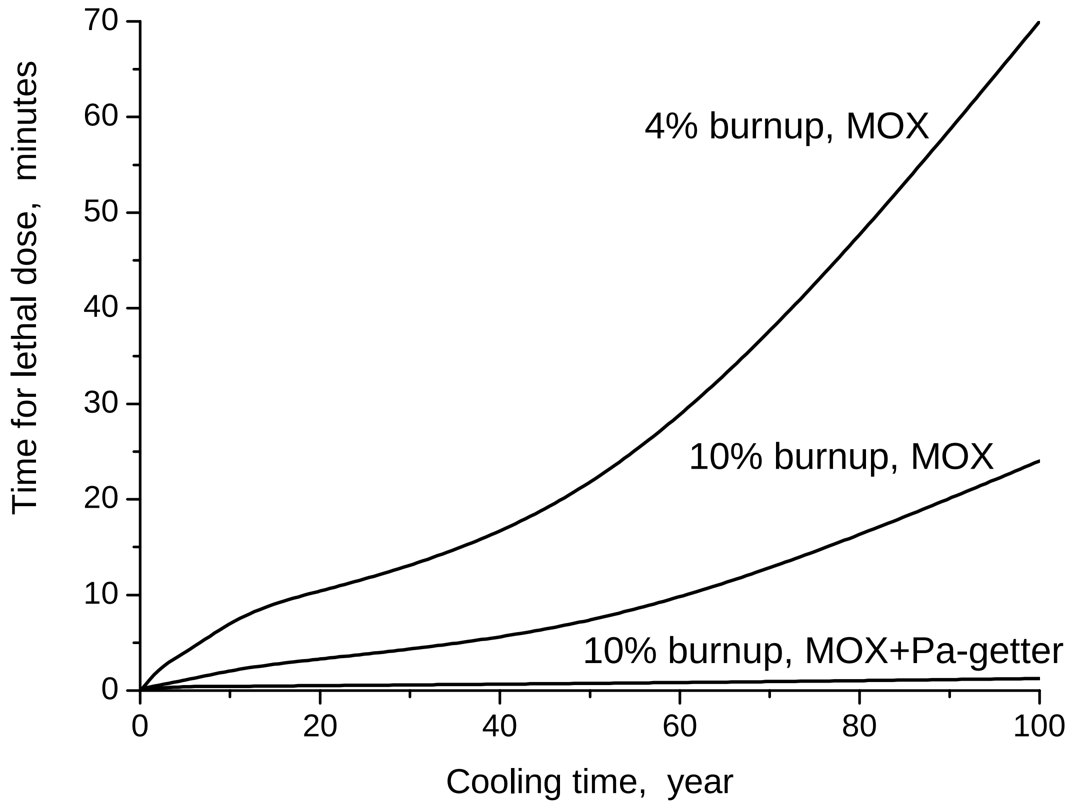


Time till receiving the lethal dose in the vicinity (30 cm) of MOX-FA at different stages of MOX-fuel management.

At the irradiation stage T_{LD} was evaluated after 3-month cooling time.

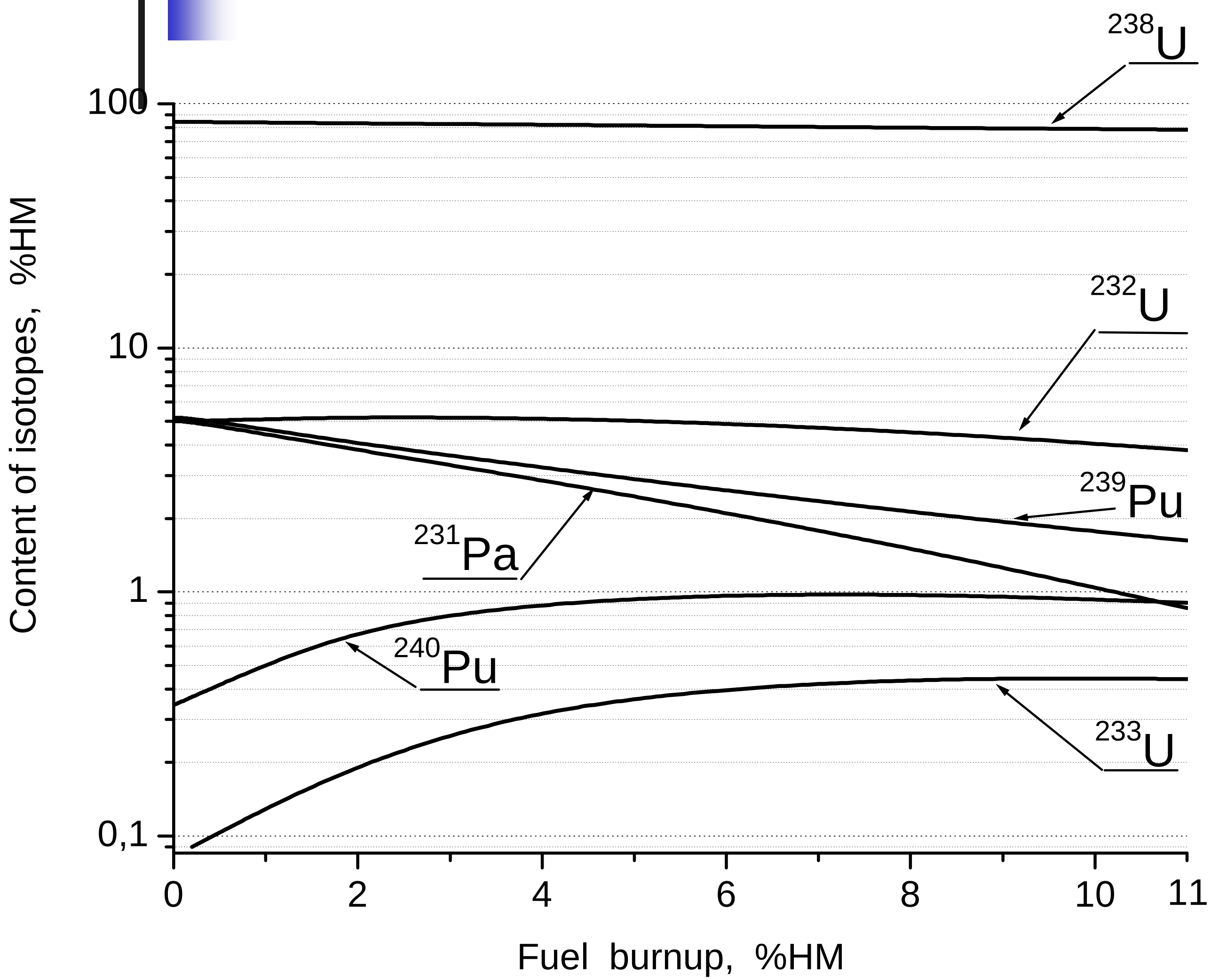
R – radiochemical reprocessing; F – fresh MOX-fuel fabrication; T – transportation of MOX-fuel to nuclear power plant.

PROLIFERATION PROTECTION OF SPENT FUEL



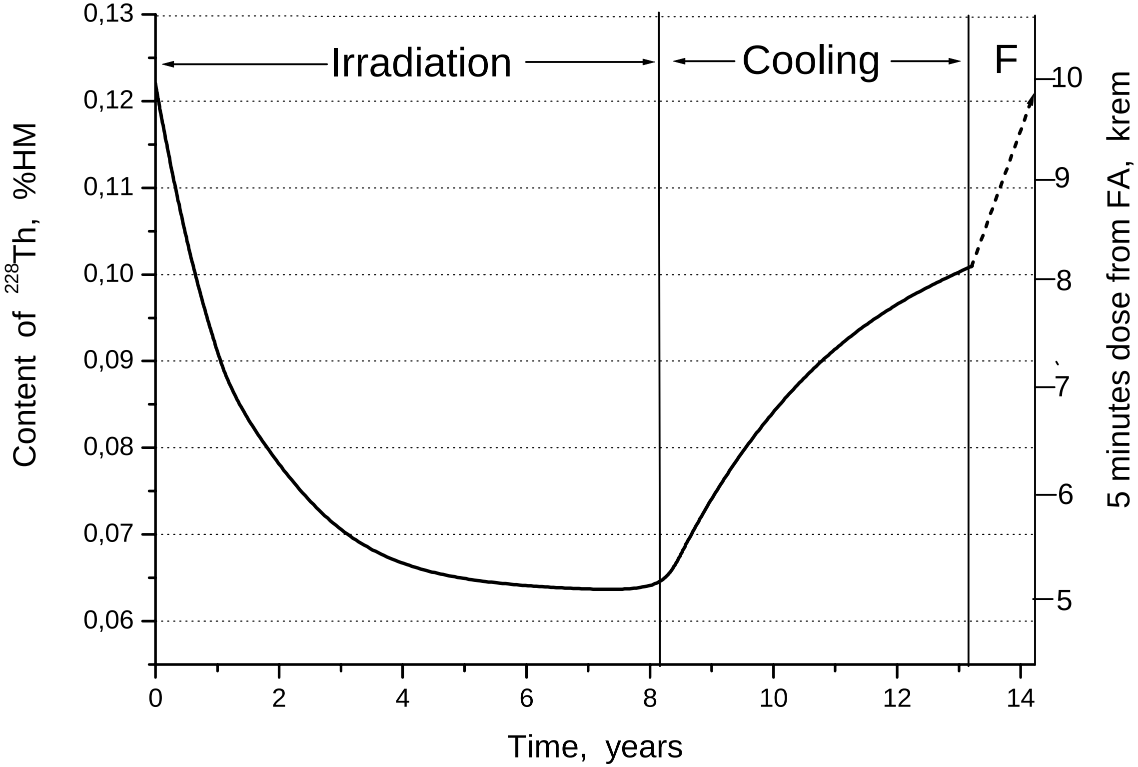
Introduction of Pa-getter into fresh fuel composition makes it possible to enhance significantly the proliferation protection of spent fuel.

MOX-FUEL COMPOSITION IN MODIFIED NUCLEAR FUEL CYCLE



- Protactinium undergoes high burn-up and transforms into ^{232}U;
- Content of ^{232}U, which defines, in the end, the inherent radiation barrier of fresh MOX-fuel, varies insignificantly.

CONTENT OF ^{228}Th AND CORRESPONDING γ-DOSES FROM FUEL ASSEMBLY



- Concentration of ^{228}Th defines the radiation barrier level at any specified time moment;
- ^{228}Th significantly burns up under neutron irradiation in LWR. However, by the end of 5-year cooling time, ^{228}Th concentration restores up to the equilibrium level defined by content of ^{232}U in MOX-fuel;
- Content of ^{228}Th in fresh fuel (after re-fabrication) corresponds to shock 5-minute lethal dose.

CONCLUSIONS

1. Neutron-physical properties of ^{231}Pa and ^{232}U make these isotopes promising for application as getter materials because they can protect fresh MOX-fuel against unauthorized proliferation and keep neutron multiplying properties of LWR core till high fuel burn-up.
2. Introduction of ^{232}U, ^{231}Pa getter in different amounts into MOX-fuel composition allows not only reach the proliferation resistance within wide range but to increase the fuel burn-up for the value more than 10%HA as well.
3. In the extreme cases, significant introduction of (^{232}U, ^{231}Pa) getter (up to 10% HM) provides the inherent radiation barrier of fresh MOX-fuel at the level high enough to oppose successfully the forcible seizure actions.

CONCLUSIONS

4. The inherent radiation barrier of MOX-fuel seems to be a reliable proliferation protection tool because:
   - it acts on the whole fuel mass;
   - fine separation of plutonium and ^{232}U requires application of sophisticated radiochemical technologies.
5. The technology developed for fabrication of vibro-compacted fuel containing getter materials, being essentially remote technology, allows to handle with highly radioactive NM and creates a base of principle for practical implementation of the proliferation protected NFC.