

PROTACTINIUM PRESENTS A CHALLENGE FOR SAFEGUARDING THORIUM REACTORS

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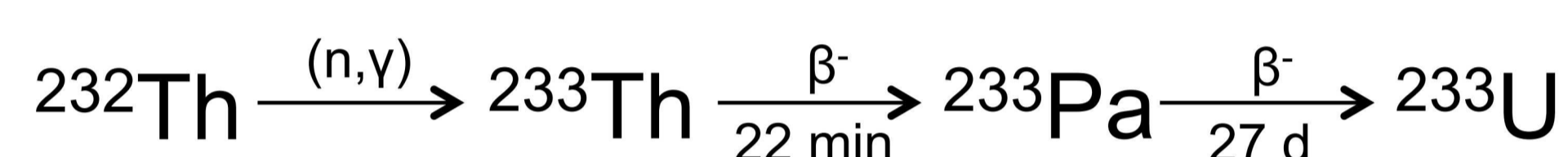
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ABSTRACT

- Despite their potential for enhanced proliferation resistance, thorium reactors will present unique safeguards challenges.
- ^{233}U generated in thorium reactors is an attractive material to potential proliferators.
- Proliferation risks of thorium reactors depend on the quantity of ^{232}U generated in the spent fuel.
- Chemical reprocessing will change the quantity of ^{232}U in the final ^{233}U .
- Intentional or inadvertent isolation of ^{233}Pa results in the production of isotopically pure ^{233}U .

BACKGROUND

- Commercial nuclear power from thorium has been pursued around the world since the 1960s, but safeguards concepts are underdeveloped [1].
- Natural thorium has no fissile isotopes, but ^{233}U is generated as follows:



- ^{233}U has a low critical mass and low spontaneous fission rate, and the IAEA has defined a significant quantity as 8 kg (similar to ^{239}Pu).
- ^{232}U is generated through a series of neutron reactions (Figure 1).
- The intense radiation from the daughters of ^{232}U is widely credited with increasing the proliferation resistance of ^{233}U from thorium reactors [2].

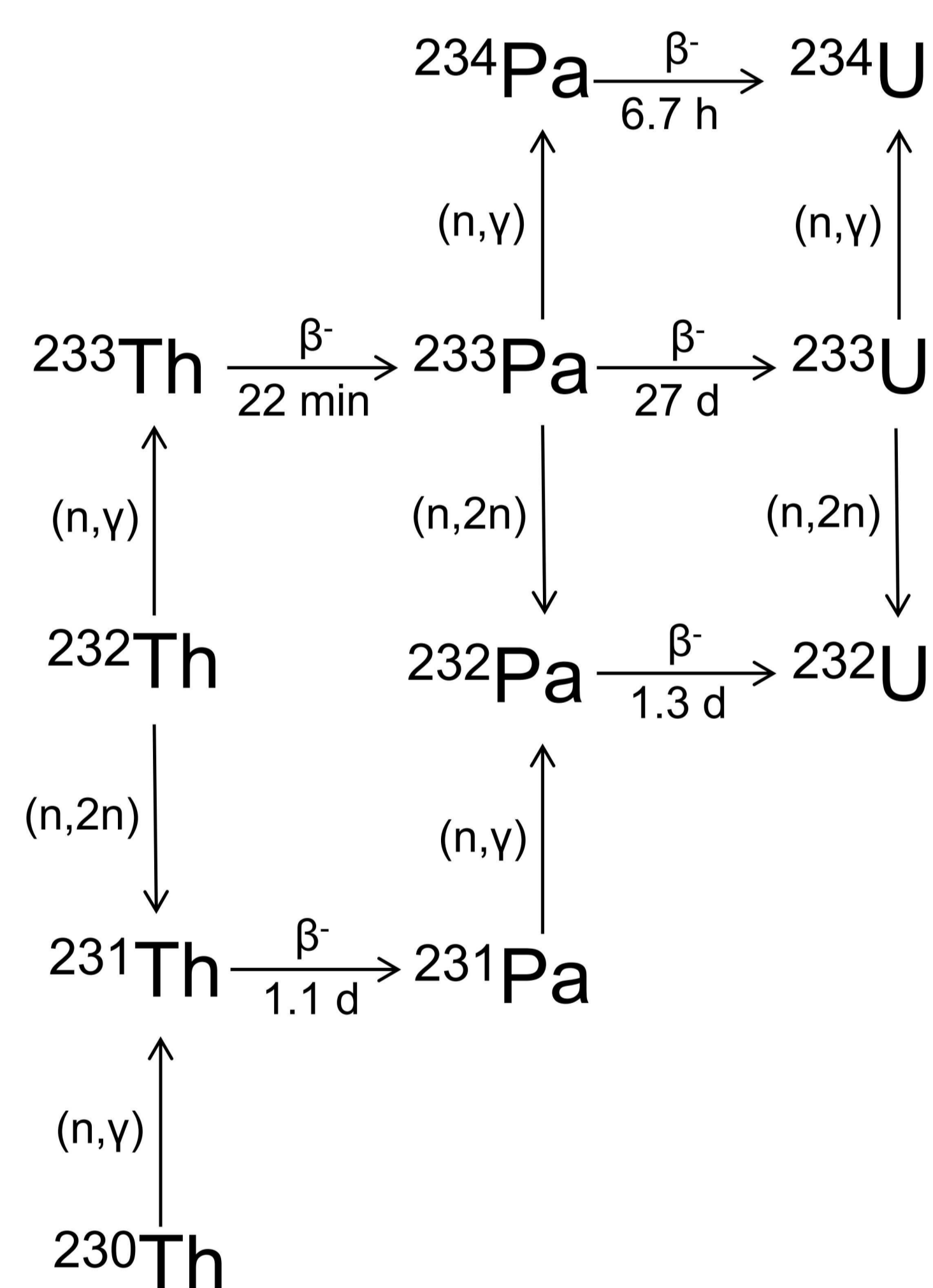


Figure 1. Formation of various isotopes during neutron irradiation of ^{232}Th .

THE PROTACTINIUM PROBLEM

^{232}Pa , ^{233}Pa , and ^{234}Pa produced from neutron irradiation of ^{232}Th β^- decay to ^{232}U , ^{233}U , and ^{234}U , respectively. If ^{233}Pa can be chemically isolated, then it will decay to pure ^{233}U over the course of approximately one year. However, chemical separation of protactinium from irradiated thorium results in the separation of all protactinium isotopes together.

Table 1. Radioactive decay of Pa isotopes

Isotope	Radioactive Half-life
^{232}Pa	1.3 days
^{233}Pa	27 days
^{234}Pa	6.7 hours

The different half-lives of protactinium isotopes results in time-varying isotopic composition of protactinium. Over time, ^{233}Pa will constitute a greater percentage of the total as ^{232}Pa and ^{234}Pa decay (Figure 2).

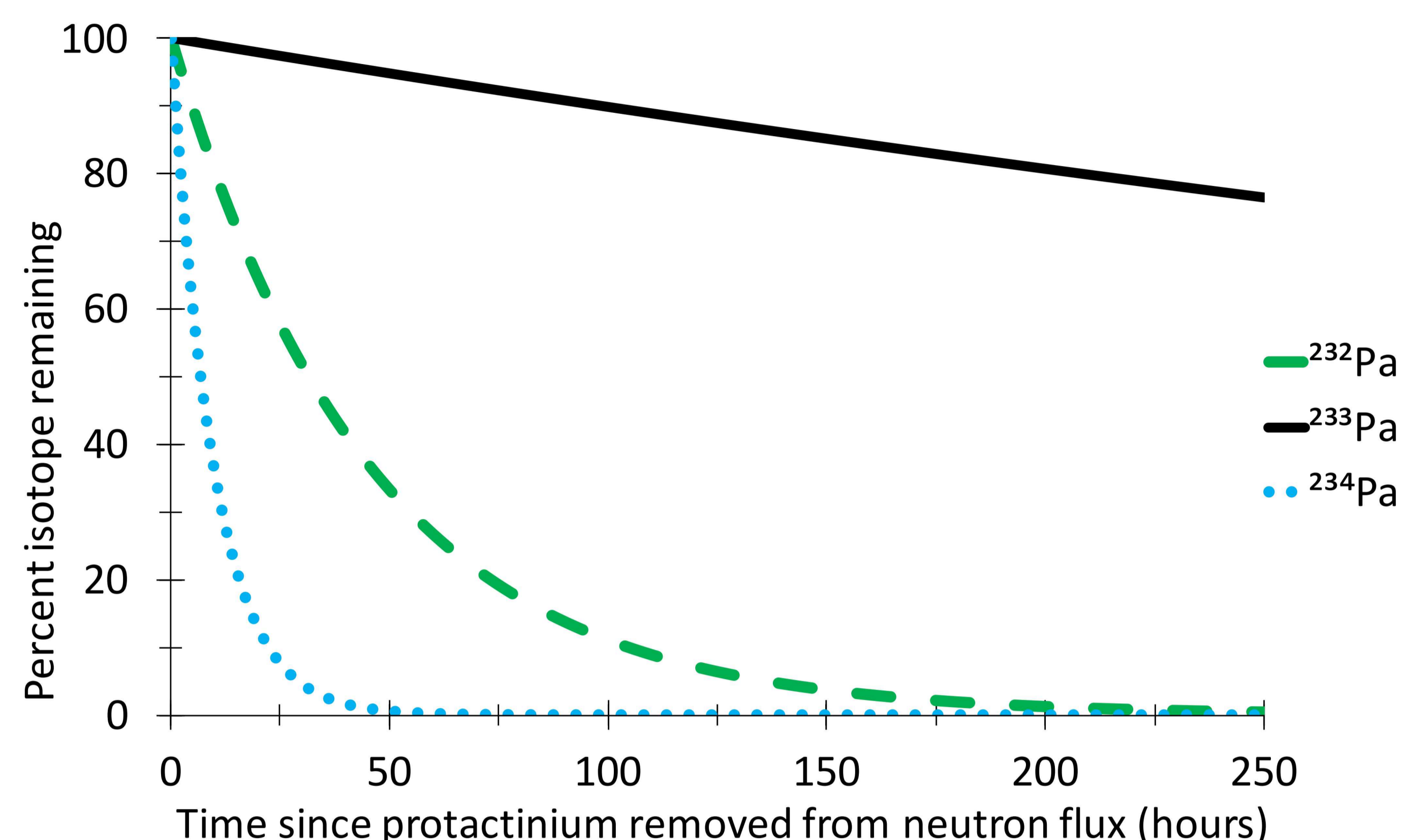


Figure 2. Radioactive decay curves for ^{232}Pa , ^{233}Pa , and ^{234}Pa .

PROTACTINIUM SEPARATION SCENARIOS

THE CHEMISTRY OF PROTACTINIUM

Differences in chemical bonding and stable oxidation states of thorium, protactinium, and uranium facilitate their chemical separation. Protactinium possesses distinct chemistry, is notoriously difficult to handle, and is the least studied of the early actinides [3], which poses challenges for developing safeguards approaches. There are two scenarios where rapid extraction of protactinium may be feasible.

AQUEOUS REPROCESSING OF ThO_2 FROM HEAVY WATER REACTORS (HWR)

- Online refueling allows rapid removal of low-burnup fuel or blanket material without powering down the reactor.
- Low-burnup blanket material could be reprocessed immediately.
- THOREX reprocessing may separate protactinium from uranium [2, 4].

ONLINE REPROCESSING OF THORIUM MOLTEN SALT FUELS

- Molten salts are LiF or LiF and BeF_2 containing ThF_4 , UF_4 and PaF_4 .
- ^{233}Pa is a neutron absorber and limits ^{233}U breeding and fuel lifetime.
- Protactinium can be isolated by liquid bismuth reductive extraction combined with fluorination to remove volatile UF_6 [5].

CONCLUSION

Once protactinium is separated from uranium, the isotopic purity ^{233}U that it produces can be controlled. Safeguards By Design (SBD) challenges for thorium HWRs are similar to safeguarding low-burnup ^{238}U blankets from HWRs. SBD for commercial THOREX and PUREX reprocessing may also be similar. However, THOREX chemistry may result in the inadvertent isolation of ^{233}Pa . Online reprocessing of molten salt reactors contains numerous SBD challenges, including material accountability for bulk material at a continuous flow facility, in a high gamma background and under conditions of extreme heat and radiation.

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