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Title: Attractiveness of Materials in Advanced Nuclear Fuel Cycles

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Attractiveness of Materials in Advanced Nuclear Fuel Cycles

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Presentation to the National Academy of Sciences Committee on Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors

Virtual Meeting

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What Is Material Attractiveness?

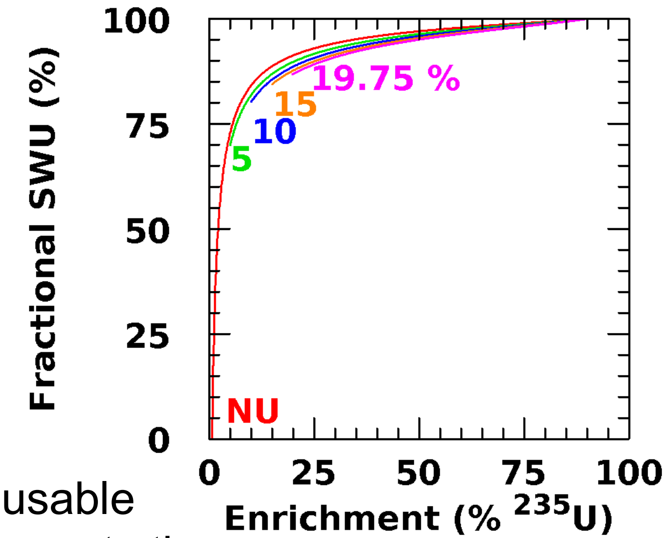
- Material Attractiveness (MA) is the relative utility of nuclear material for an adversary in constructing a nuclear device
- Factors that need to be taken into account are the time and potential difficulties with:
  - Acquiring material
  - Processing (purification and/or conversion) material
  - Fabricating a nuclear explosive device (NED)
  - Utilizing the NED
- Additionally, an adversary's capabilities must also be considered (Beauty is in the eye of the beholder)

Caveats

- More information is needed from advanced-reactor vendors, regulators, and policy authorities before I can fully analyze the risks inherent in any proposed fuel cycle incorporating advanced reactors
  - I do not have enough information on the design and operation of these reactors to determine some risks associated with the presence and/or generation of attractive materials. For example, fuel burnup can have a huge impact on the attractiveness of materials in spent fuel
  - I also need to know if a new fuel cycle or if modifications to an existing fuel cycle are required for these advanced reactors
    - Need for enrichment facilities
    - Need for reprocessing facilities

Would Large-Scale Deployment of HALEU Facilities Increase Proliferation and Terrorism Risk Relative to LEU?

- Yes, large-scale deployment of HALEU facilities would increase proliferation and terrorism risk relative to uranium enriched to ≤ 5% ^{235}U because:
  - Most of SWUs (70%) to go from NU to 90% ^{235}U are done by the time uranium is 5% ^{235}U[a]
    - USG has already assumed that risk
    - Canada has not assumed that risk
    - Going from 10 to 90% ^{235}U takes ⅓ less SWUs than it takes to go from 5 to 90% ^{235}U
    - Going from 15 to 90% ^{235}U takes ½ less SWUs than it takes to go from 5 to 90% ^{235}U
    - Don't make it easier for terrorist
  - Uranium enriched to ≤ 5% ^{235}U is not weapon usable
  - Every site with more than 4 kg of Pu or ^{233}U warrants the same security posture, *i.e.*, detection, pursuit, and recovery.
    - Why 4 kg? Because "*Hypothetically, a mass of 4 kilograms of plutonium or uranium-233 is sufficient for one nuclear explosive device.*"[b]



[a] Pekka Silvennoinen, Nuclear Fuel Cycle Optimization - Methods and Modelling Techniques.
[b] U.S. DEPARTMENT OF ENERGY, Restricted Declassification Decisions 1946 to the Present (RDD-8), U. S. DOE, Washington, D.C. 23 (January 2002)

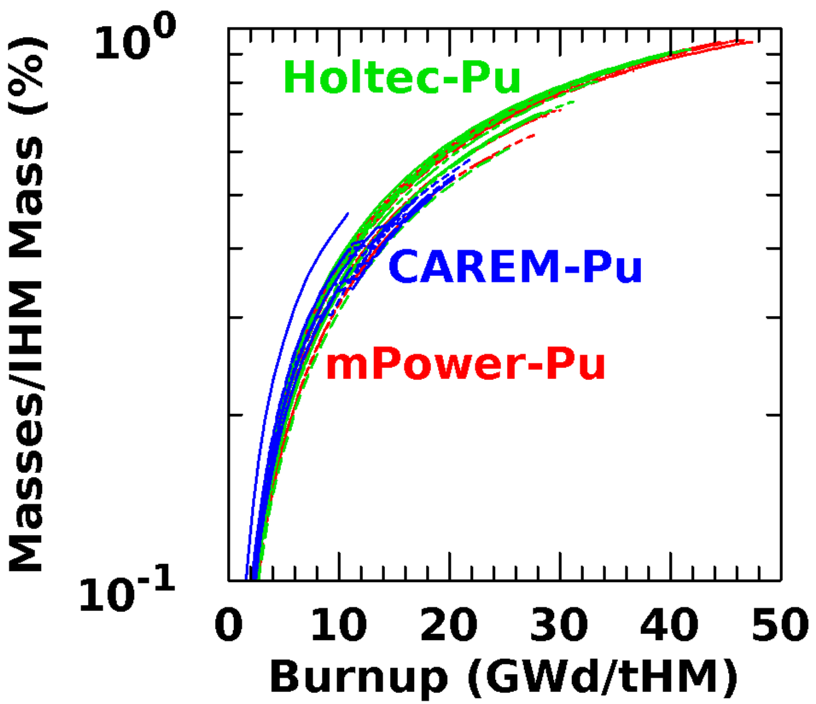
Characteristic of Some SMRs

- Below is a subset of SMRs I have examined previously that I believe are relevant to this discussion. An examination includes: 3-D, time-dependent burn simulations, decay calculations, bare critical mass calculations, and dose calculations
- The data given below represent a small portion of the data needed to do a proper risk assessment

Reactor Design	Coolant/ Moderator	Power (MWt)	Burnup (MWd/kg)	Enrich. (^{235}U %)	Fuel Type	Cycle Length (days)	Burn Cycles	FA Mass (kg)	IHM/FA (kg)	#FA	Fuel Height (m)	IHM (MT)
mPower	H_2O	530	37	≤ 4.95	UO_2	1400	1	391.6-403.6	285.5-294.3	69	2.51	19.7
Holtec SMR-160	H_2O	525	35	≤ 4.95	UO_2	1460	1	732.2	533.8	37 + 8(½)	4.27	21.9
CAREM	H_2O	100	10/20	≤3.9	UO_2	330	2(1)	90.6	60.8	61	1.4	3.71
AHWR300 Ref.	H_2O/D_2O	920	35	NA	$^{233}UO_2$/ PuO_2/ ThO_2	333	6(7)	162.8	116.6	452	3.5	52.7
AHWR300 LEU	H_2O/D_2O	920	64	19.75	UO_2/ ThO_2	354	10(11)	162.8	116.6	444	3.5	51.8
4S-10	Na	30	34.0	17/19	UZr	10478	1	879	513.6	18	2.5	9.24

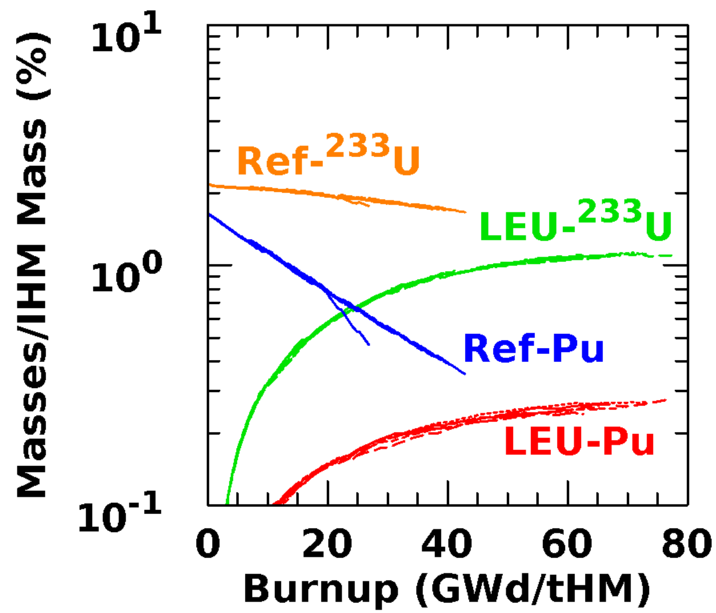
PWR SMRs Summary

- The mPower, Holtec SMR-160, and CAREM SMRs each demonstrate that SMRs do not need HALEU
- Each of these SMRs need the same safeguards and security posture as full-sized LWRs because of the amount of Pu discharged at the end of a burn cycle
  - mPower – 165 kg
  - Holtec – 177 kg
  - CAREM – 19 kg
- Remember, you only need 4 kg for an NED!



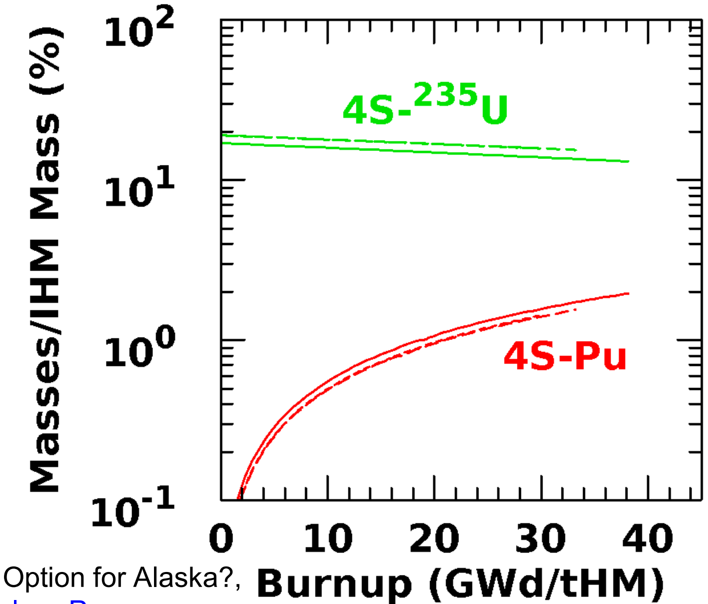
Thorium-Fuel-Cycle SMRs Summary

- India has proposed two SMRs based on the thorium fuel cycle
  - AHWR300-LEU is for export (UO_2/ThO_2 fuel)
  - AHWR300-Ref is for domestic use ($^{233}UO_2/PuO_2/ThO_2$ fuel)
- Each of these SMRs needs the same safeguards and security posture as full-sized LWRs because of the amount of ^{233}U and/or Pu at charge and/or discharge
  - LEU
    - 13 kg Pu and 48 kg ^{233}U at discharge
  - Ref
    - 123 kg Pu and 164 kg ^{233}U at charge
    - 40 kg Pu and 132 kg ^{233}U at discharge
  - Remember, you only need 4 kg for an NED!



Toshiba 4S-10 SMR Summary

- The 4S-10 was proposed for remote areas such as Galena, Alaska, without reactor operators, etc.
- This SMR needs the same safeguards and security posture as full-sized LWRs because of the amount of Pu discharged at the end of a 30-year burn cycle – 453 kg of SG-Pu
- Remember, you only need 4 kg for an NED!
- The 4S-10 does not consume all of its HALEU
  - Is it economical to reprocess the fuel for the HALEU and re-enrich it?



[a] Gwen Holdmann, Small-Scale Modular Nuclear Power: An Option for Alaska?, https://acep.uaf.edu/media/147559/Small-Scale-Modular-Nuclear-Power-an-option-for-Alaska-2011-ACEP-and-ISER.pdf, accessed 7/11/2021.

Summary

- Large-scale deployment of HALEU facilities would increase proliferation and terrorism risk relative to LEU (≤ 5% ^{235}U) – please don't make it easier for terrorist!
- Authoritative risk assessments require early and thorough reactor design data, operational data (burnup, shuffling algorithm, *etc*.), and the envisioned fuel cycle in which it will exist.
- Nuclear security postures depend on the threat (adversary), material attractiveness, and consequence
- Threat is a function of an adversary's capabilities
- Every SMR examined needs the same safeguards and security posture as full-sized LWRs