ADVANCED TEST REACTOR (ATR) CONVERSION TO LOW ENRICHED URANIUM (LEU) FUEL

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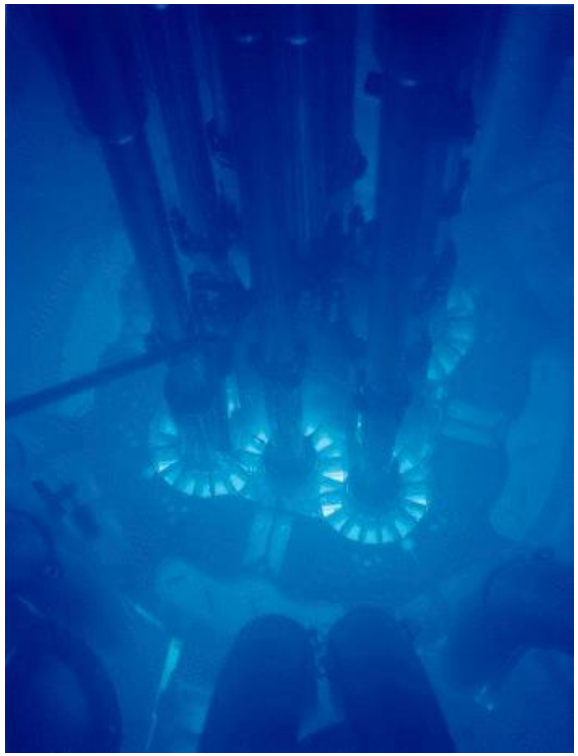

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USHPRR LEU Conversion

- The United States Department of Energy (DOE), National Nuclear Security Administration (NNSA), Office of Material Management and Minimization (MMM) is working to convert the remaining research reactors from 93% highly enriched uranium (HEU) fuel to 19.75% low-enriched uranium (LEU) fuel.
- These reactors include the following six U.S. high performance research reactors (USHPRRs):
  - Advanced Test Reactor (ATR) and the ATR Critical (ATRC) Facility at the Idaho National Laboratory (INL) near Idaho Falls, ID
  - University of Missouri Research Reactor (MURR) at Columbia, MO
  - Massachusetts Institute of Technology Reactor (MITR) at MIT in Cambridge, MA
  - High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) near Oak Ridge, TN
  - National Bureau of Standards Reactor (NBSR) at the National Institute of Standards and Technology (NIST) Center for Neutron Research (NCNR) in Gaithersburg, MA.

Advanced Test Reactor (ATR)

- The INL celebrated the 50th anniversary of the ATR criticality in July 2017.
- ATR is scheduled to continue operating through 2085 and possibly longer.
- ATR is schedule to convert from 93% HEU uranium aluminide (UAlx) fuel to 19.75% LEU uranium molybdenum (U-Mo) fuel in 2029.
- Less enrichment should be less expensive, use less U-235, etc.
- The driving force for LEU conversion of all reactors is non-proliferation.
- Technically, there are many challenges that need to be met before the conversion to LEU can be successful.
- Many of the perceived benefits for LEU fuel are actually misconceptions.

U-235 Enrichment

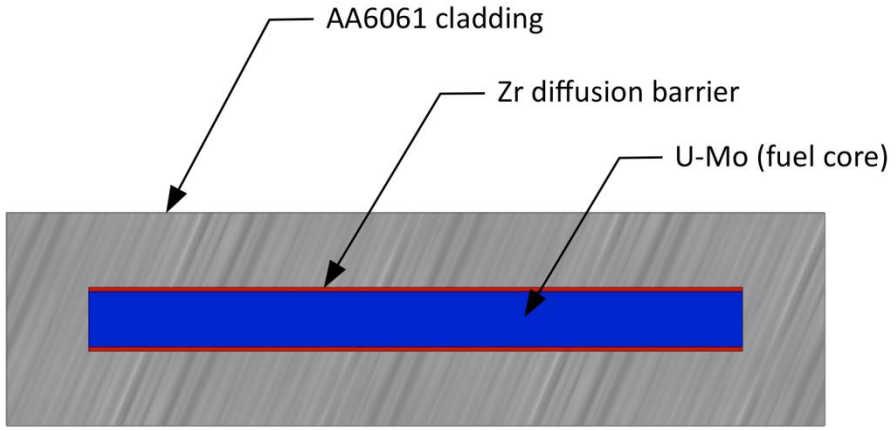
- U-235 enrichment to 19.75% instead of 93% is expected to cost less and save energy.
- The U.S. has not enriched uranium to 93% since the 1990's.
- The USHPRRs and the U.S. Navy's nuclear propulsion plants have been operating on 93% enriched U-235 stockpiled from the last enrichment campaign.
- The USHPRRs are able to use rejected uranium metal that contains impurities levels that are unacceptable for use in Naval nuclear propulsion plants.
- The U.S. does have commercial enrichment capabilities which enrich to ~5% for use in commercial power reactors.
- No one is enriching to 93%.
- No one is enriching to 20% for the USHPRRs, and the market is too small to be commercially viable.

DU for Downblending

- The current LEU conversion process is using the existing stockpile of depleted uranium (DU) for downblending with 93% enriched U-235 to form 19.75% enriched U-Mo fuel supply.
- The stockpile of 93% enriched U-235 and DU will both be exhausted about the same time the USHPRRs will be converting to LEU.
- This means that as early as 2025 the USHPRRs will need a new supply of 93% HEU or 19.75% LEU in order to continue operations.
- Ux Consulting Company, LLC (UxC) at UxC.com and World Information Service on Energy (WISE) Uranium Project at www.wise-uranium.org provide separative work unit (SWU) calculators to calculate the cost of uranium enrichment. The problem is that no one is actually enriching to 19.75% U-235 enrichment.

Fuel Plate Fabrication

- The fabrication method for HEU fuel plates are well established and minimizes the scrap and rejected material being generated during fabrication.
- The fabrication method for LEU U-Mo fuel plates are still being developed. The current methods of rolling and sizing the fuel core produce significantly more scrap material than HEU. Recovery of this unirradiated material is essential for the success of LEU conversion.
- Fabrication of the LEU fuel element assembly is essentially unchanged from the HEU design.



LEU Conversion Inventory Requirements

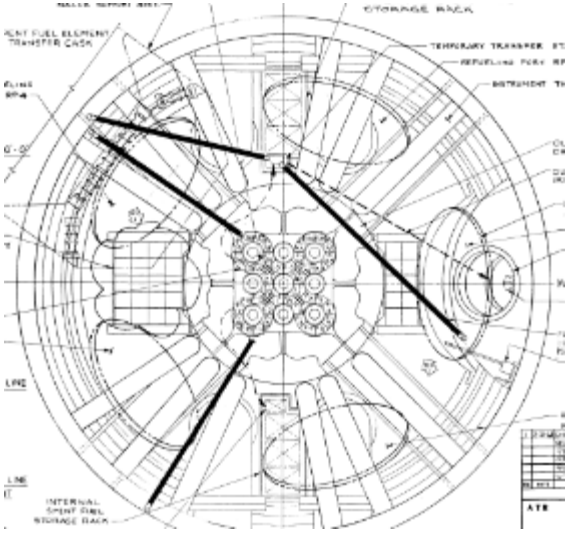
- There is a misperception that the USHPRRs will require less U-235 inventory after they are converted to LEU.
- U-235 Inventory for ATR fuel elements
  - HEU = 1075 grams U-235
  - LEU = 1648 grams U-235
- This is a 53% increase to compensate for neutron absorption losses within the LEU fuel core.
- More U-235 inventory per fuel element will increase the cost of production, but may allow the fuel element to be used for more or longer operating cycles.
- U-238 Inventory for ATR fuel elements
  - HEU = 75 grams U-238
  - LEU = 6696 grams U-238
- LEU fuel elements will require nearly 8X as much U-metal as HEU elements.

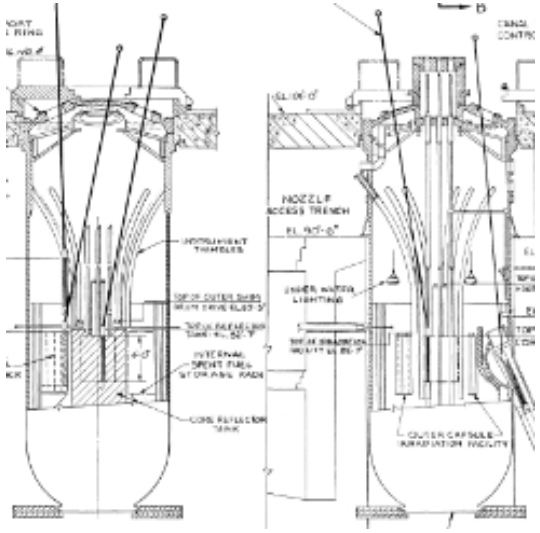
Recycle Potential

- Recovery of unirradiated scrap and rejected material generated during fabrication is the most likely application of recycling.
- Existing HEU is relatively easy to dissolve the aluminum in the UAlx fuel core and protective cladding. The inventory of U-metal can be chemically separated and returned to the stockpile for future use.
- The current fabrication methods for LEU U-Mo fuel cores results in more scrap than HEU fabrication methods. The current LEU U-Mo fuel plate designs include a zirconium diffusion barrier which makes recycling and recovery of the U-235 from unirradiated fuel more challenging. Recovery methods are still being evaluated.
- The U.S. is not likely to attempt recovery of irradiated fuel material to complete the uranium “life cycle.” Recovery of irradiated LEU material has never been economically justified.

Weight of ATR Fuel Elements

- HEU ATR fuel elements weigh 10 kgs (22 lbs).
- LEU ATR fuel elements were calculated to weigh 19 kgs (41 lbs).
- All ATR fuel elements are handled and transported manually on the end of a 20 foot long tool. There are very few straight vertical lifts. Almost every lift requires personnel to flex or bend the handling tools to lift ATR fuel elements. Efforts to prevent exceeding the personnel lifting limit of 50 lbs will be challenging.





LEU Conversion of ATR

- Correcting some of the misconceptions from earlier in this presentation:
  - LEU fuel requires more U-235 than HEU fuel.
  - Although enrichment to 19.75% costs less than enrichment to 93%, the greater mass of U-metal may cost more.
- Politically, LEU conversion of ATR is the right thing to do.
- Technically, there are still many issues that must be addressed.

- Questions?