Overview of the Eden Radioisotopes Medical Isotope Production Complex

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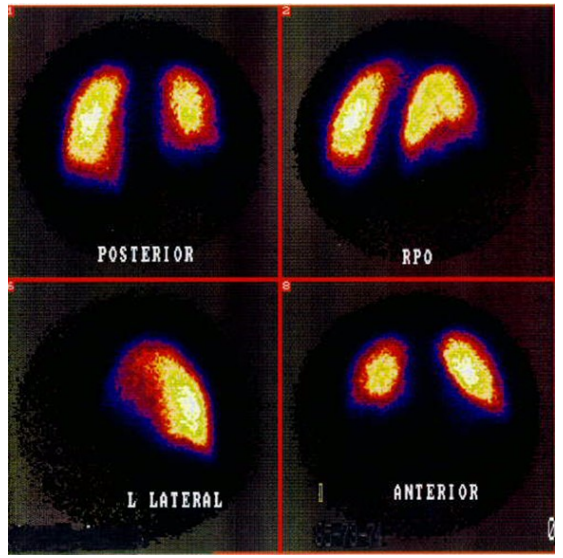
Eden's mission is to bring a new, reliable, large-scale commercially viable medical radioisotope production facility to the U.S. with the capability to produce up to 100% of demand for the diagnostic imaging isotope Mo-99/Tc-99m and the therapeutic isotope Lu-177.

Medical Radioisotope Types and Uses

Medical radioisotopes are made by -

- Natural decay
- Neutron activation
- Fission of U-235
- Accelerators (ion reactions - high and low energy particles)
- LINACs (electrons – e,γ,n reactions)



Diagnostic - Ingestion/Intravenous

Purpose – to identify organ functionality and tumor locations

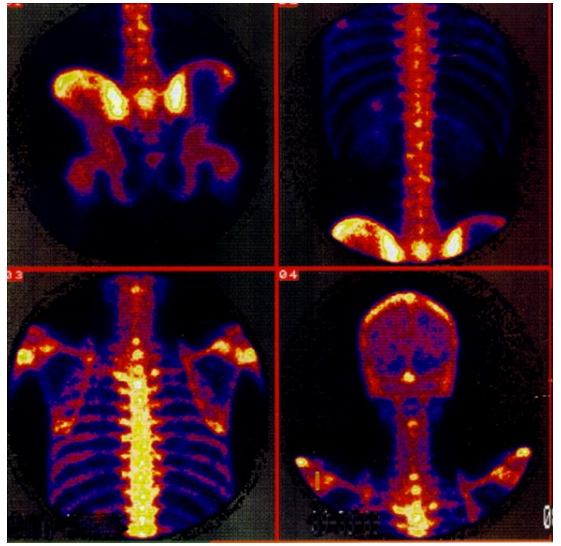
Types and current isotopes of interest -

Single Photon Emission Computerized Tomography (SPECT)

Gamma Camera – Mo-99 $T_{1/2}$=2.75d decay to Tc-99m $T_{1/2}$=6.0h (γ) fission

Positron Emission Tomography (PET)

Coincidence Gammas – F-18 $T_{1/2}$=1.8h (β+) cyclotron



Therapeutic - Ingestion/Intravenous, Brachytherapy (seeds)

Purpose – to destroy cancer cells by localized energy deposition

Current isotopes of interest -

Ac-225 (α), $T_{1/2}$=10.0d – natural decay and accelerator

Lu-177 (β-,γ), $T_{1/2}$=6.7d – neutron activation

I-131 (β-,γ), $T_{1/2}$=8.0d – fission and neutron activation

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Mo-99/Tc-99m Usage

- Technetium-99m (Tc-99m) is the radioactive daughter product of molybdenum-99 (Mo-99).
  Tc-99m has a short half-life (6 hrs) and emits a low-energy gamma ray (140 keV).
  It is readily “tagged” to a pharmaceutical that transports it to the location of interest in the body.
- Tc-99m is the primary medical radioisotope used today for performing diagnostic imaging procedures.
- Tc-99m imaging can be performed on the skeleton, blood, intestines, brain, heart, thyroid, lungs, liver, gallbladder, kidneys, and muscles.
  It is used to detect stress fractures, blood flow abnormalities, tumors, and organ function abnormalities.
- 80% of all medical radioisotope procedures use Tc-99m.
  Tc-99m is used in more than 30 radiopharmaceuticals.
  About 40,000 Tc-99m-based diagnostic procedures are performed in the US every day.
- Usage is growing at 5-10% per year.

If you have ever gone into the hospital for a nuclear imaging procedure, chances are you were given Tc-99m!

Mo-99 Shortages and Supply Vulnerabilities

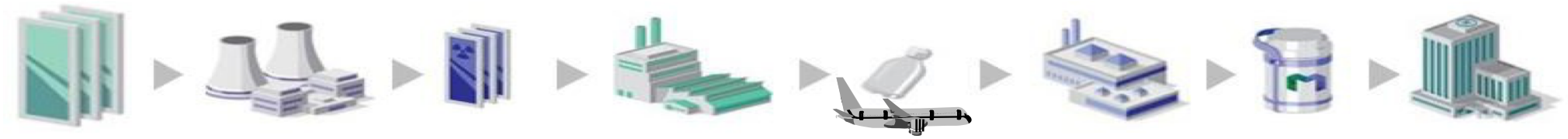
- Mo-99 cannot be stockpiled - it is virtually all decayed within a few weeks
- There have been several planned and unplanned outages at the reactor production sites over the past 30 years
  - NRU reactor (Canada) was down in 2010 for leak repairs in heavy water tank
  - HFR (the Netherlands) was down for 26 weeks in 2010
- The current reactors are old (50 years)
- The current reactors are owned and subsidized by their governments
- The current reactors do not have commercial production of medical radioisotopes as their only mission
- There is no domestic supply – there is no backup domestic supply
  A backup supply was to exist at SNL in the 1990s using LANL fabricated targets
- Canada no longer produces Mo-99 (2016 NRU reactor)
  MAPLE reactor program cancelled (2008)
- There is no North American producer

Worldwide Mo-99/Tc-99m Distribution

All of the Mo-99 produced in the world today is made using government owned and operated reactors, none of which are in the U.S. or North America.

There are currently no commercially owned reactors providing Mo-99.

Established supply chain meeting global Mo-99 requirements



LEU (U-235) Targets

Reactor Facility

Government Owned

4 in Europe

1 in Australia

1 in South Africa

None in U.S. or North America

Irradiated Target Shipment

Mo-99 Processing Facility And Waste Disposal

Mo-99 Bulk Liquids Shipment

Generator Facility

Commercially Owned and Operated

MO & MA in US; Netherlands in EU

Mo-99/Tc-99m Generator Shipment

Radiopharmacies / Hospitals

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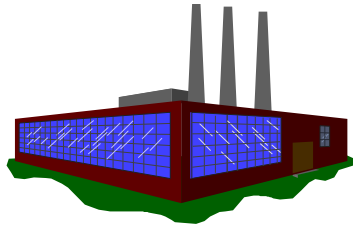
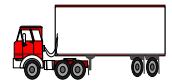
Transportation Links in the Mo-99 Production Process

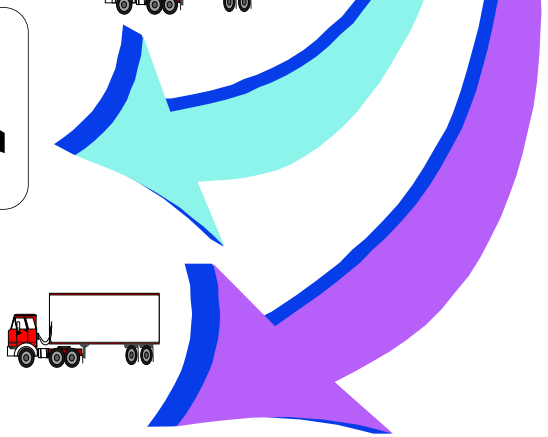


LEU Target Fabrication

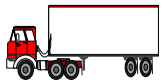
Target Irradiation

Separation Hot Cell Facility





Generator Facility



Radiopharmacy/ Hospital

Low-Level Waste Disposal Site

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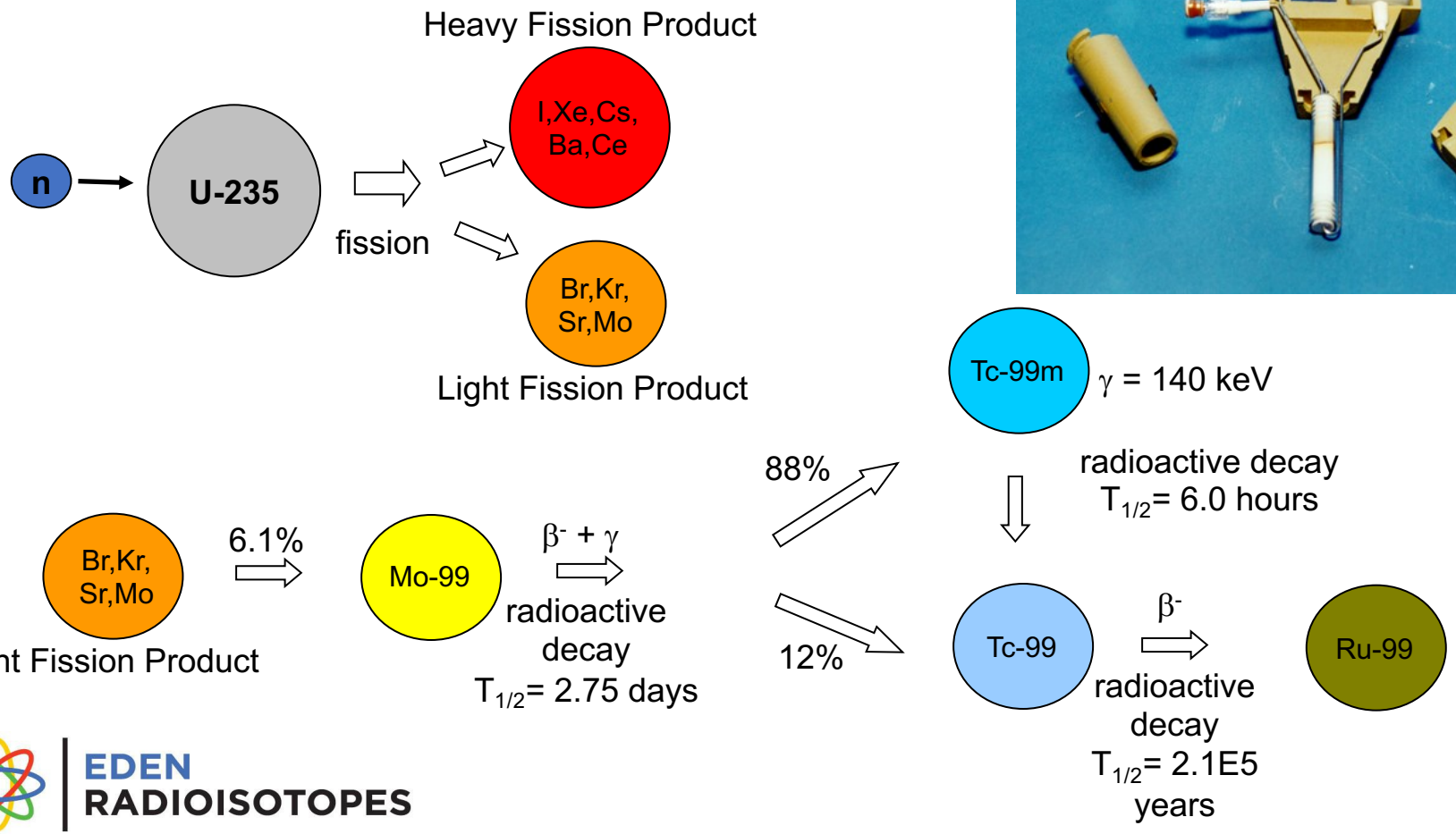
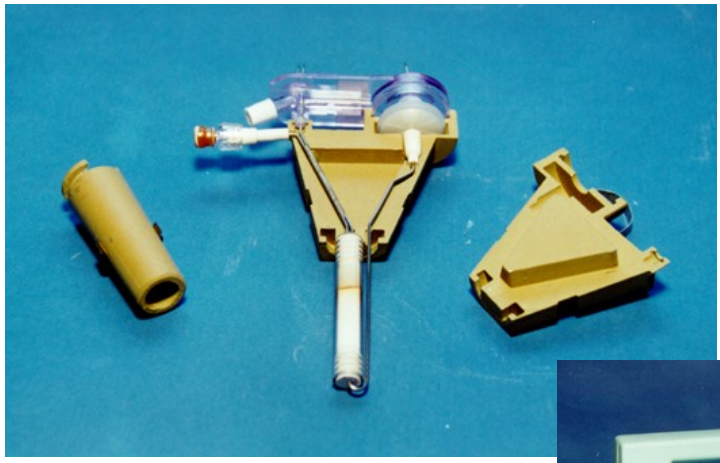
Mo-99/Tc-99m Production Using Fission

Although Mo-99 can be made by neutron activation of Mo-98, or other exotic accelerator techniques like e,γ,n reactions on Mo-100, the world's supply is currently made by fission of U-235 – "fission moly." Fission moly allows for a high production quantity and a high specific activity.





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Mo-99 Production Requirement to Meet US Demand

Assumptions

- 7-day U-235 target irradiation
- All targets are processed every 7 days
- 2-days for processing and shipping time to the generator facility
- 5000 Ci with 6 days of decay is the current US production requirement

5000 6-day Ci of Mo-99 is equivalent to ~38,000 production Ci

Fission Power Required at 5.6 $Ci_{6\text{-}day}$/kW = 900 kW or about 1 MW

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Requirements for a US Commercial Producer of Mo-99

General Requirements -

- Robust, well-developed technology – no research projects
- Produce a significant quantity of Mo-99 – large fraction of the U.S. demand
- Economically viable - profitable at current Mo-99 prices – full cost recovery +
- Produce significant quantity of activation isotopes concurrently with Mo-99 production
- Ship product easily and timely to generator companies by air or road

For Fission Mo-99 production -

- Must use low-enriched uranium (LEU)
- Reactor and collocated hot cell facility
- Commercial reactor viability operating 24 hours per day, 7 days per week
- Attainable fuel cycle
  - Fuel available for reactor and targets
  - No spent fuel generated for reactor or targets
- No greater than Class C waste generated

Eden's All-Target Reactor Concept

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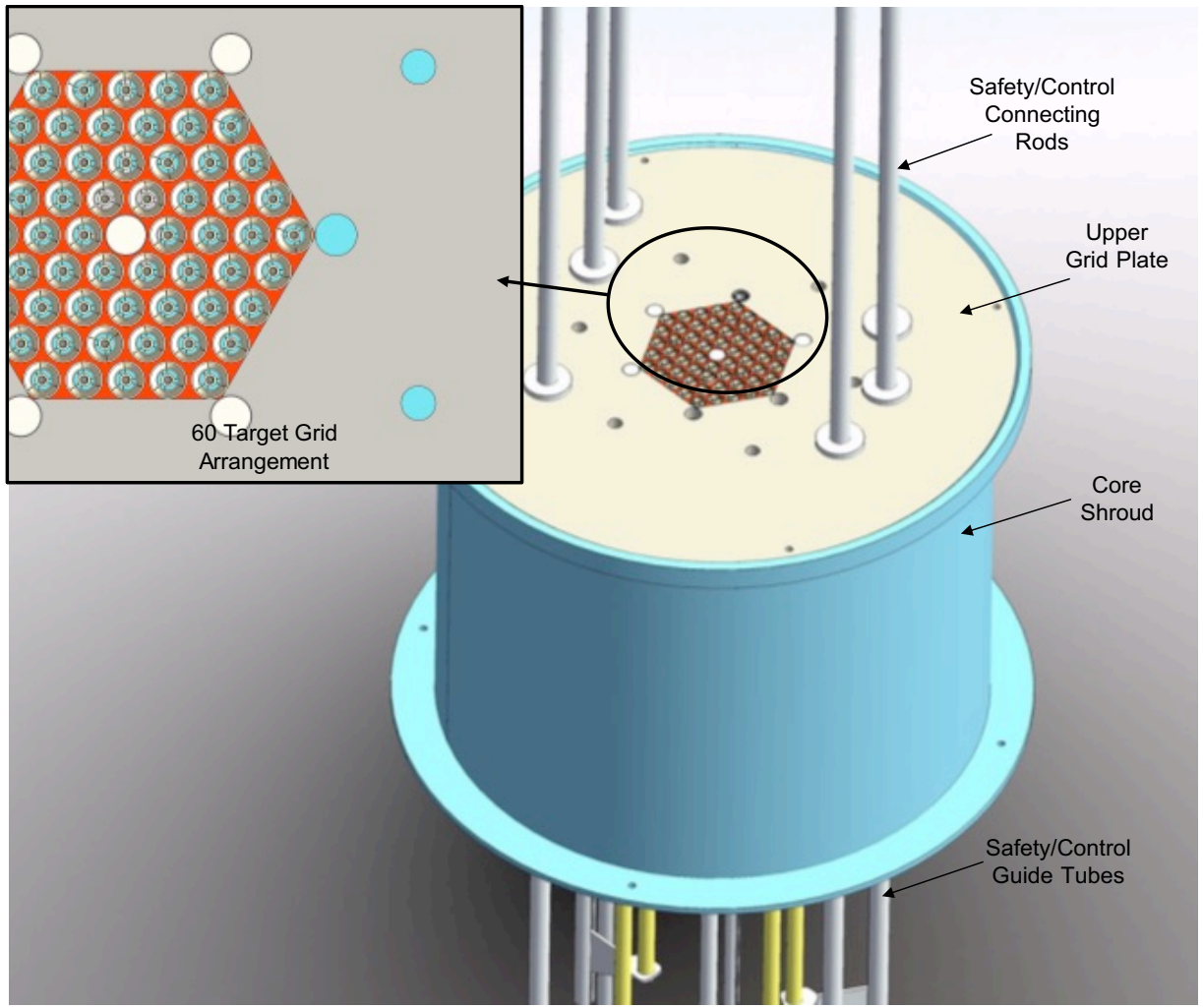
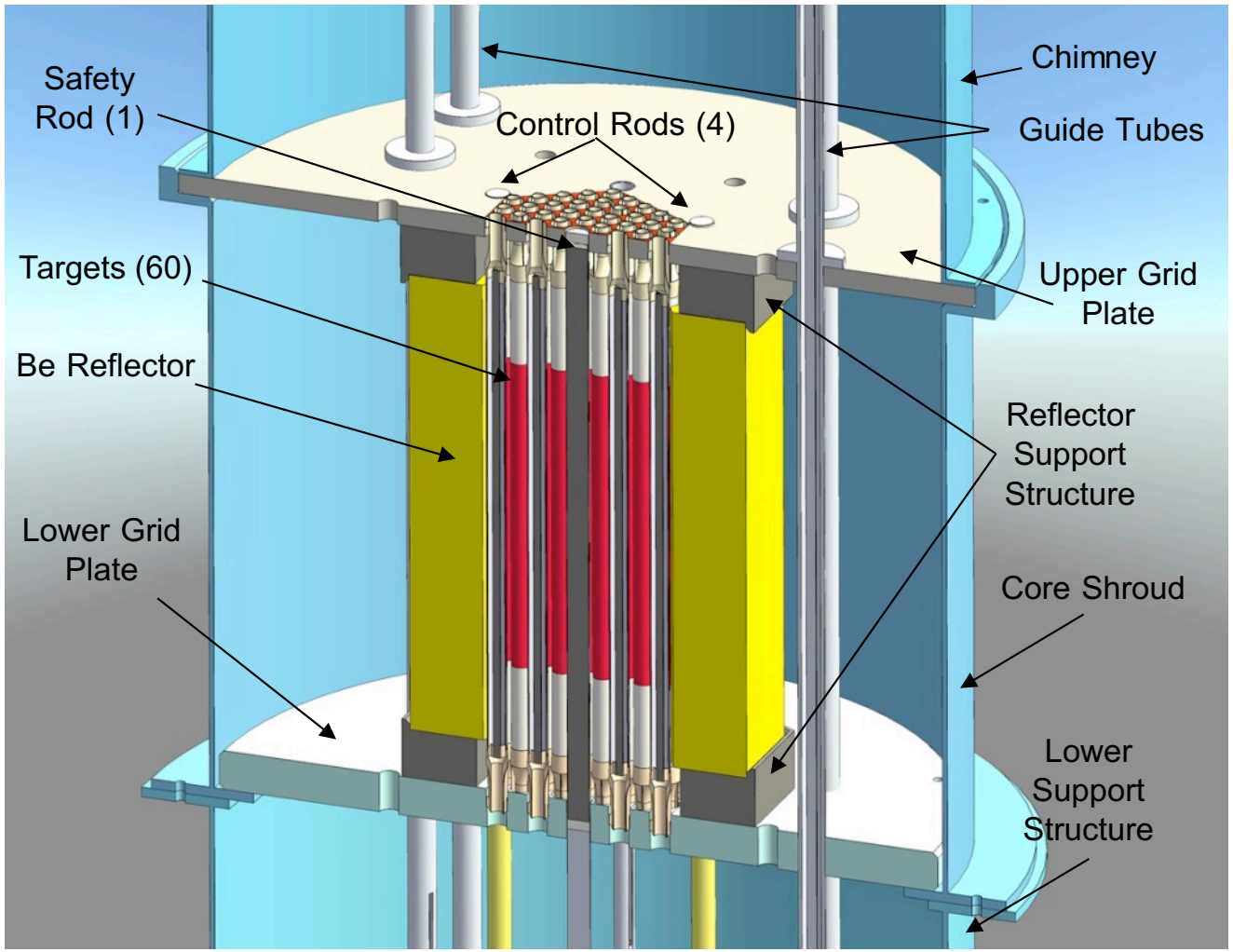
The All-Target Reactor Core





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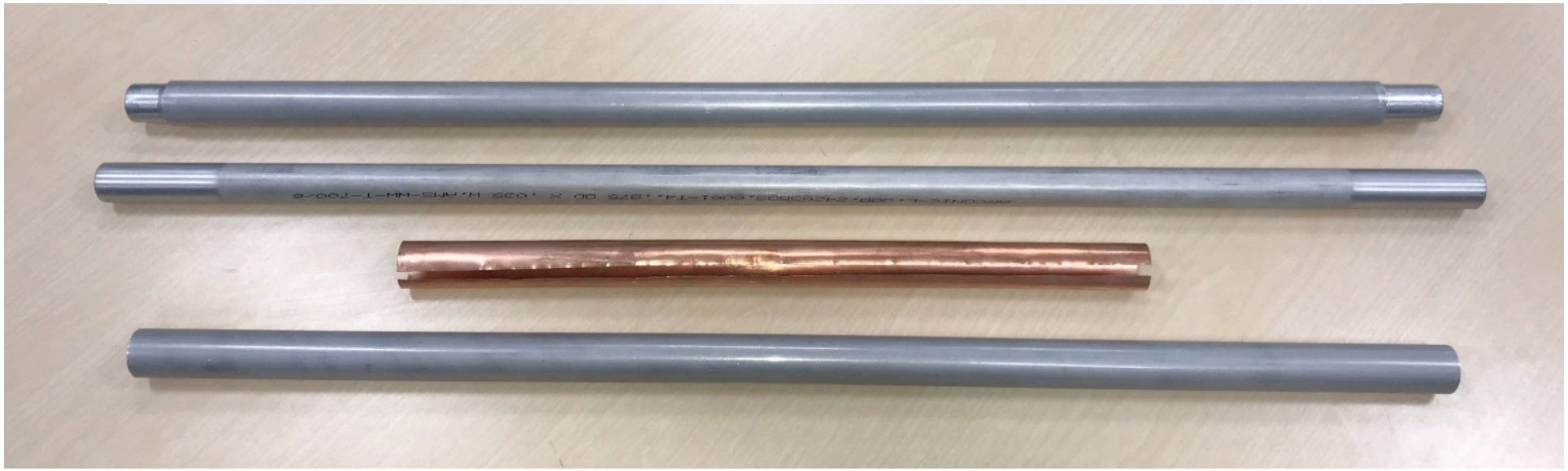
Target Design



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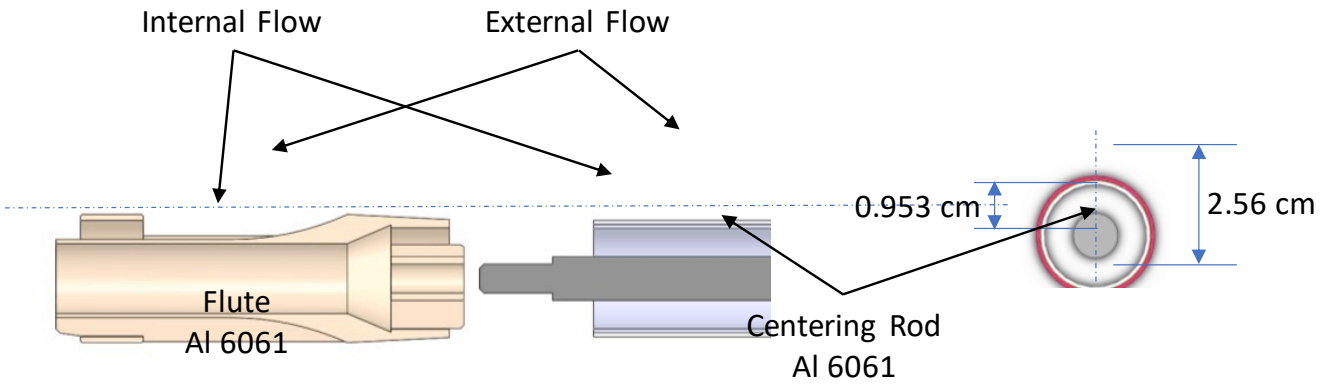

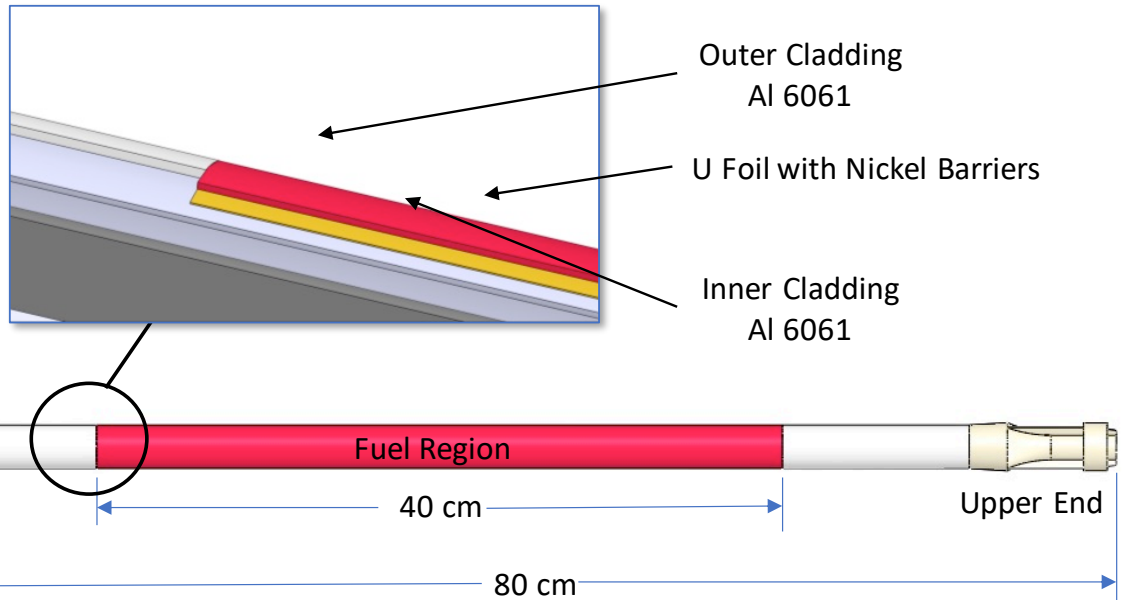

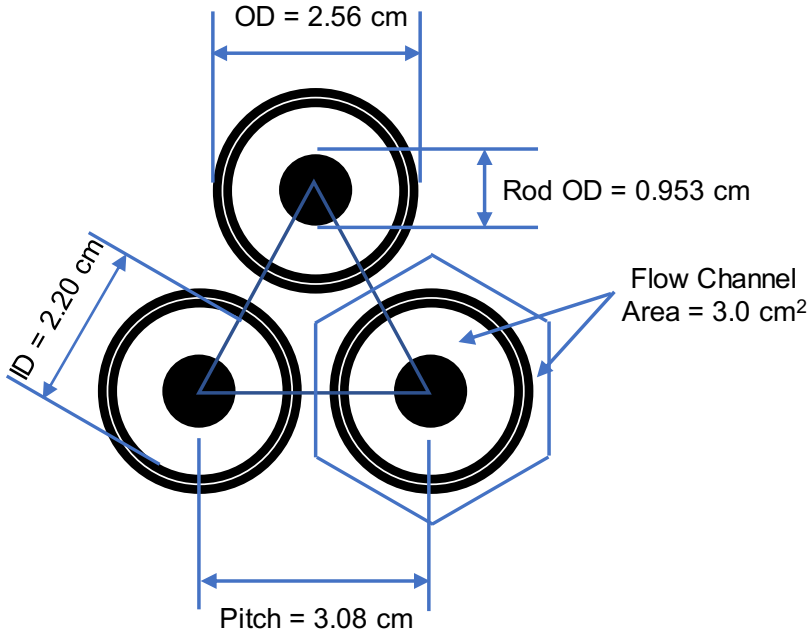

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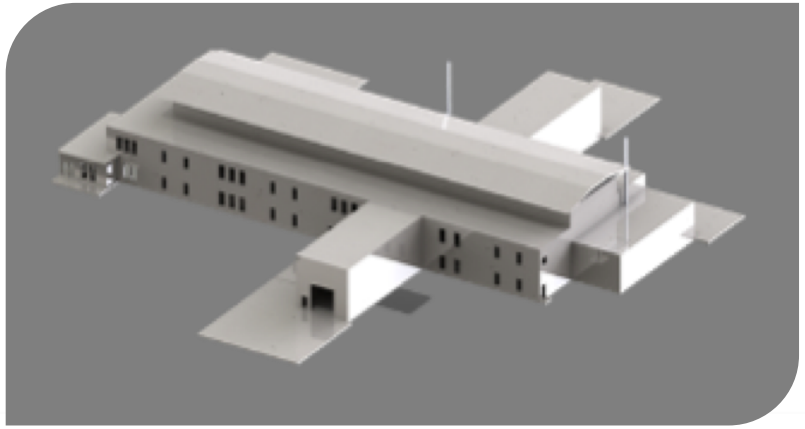
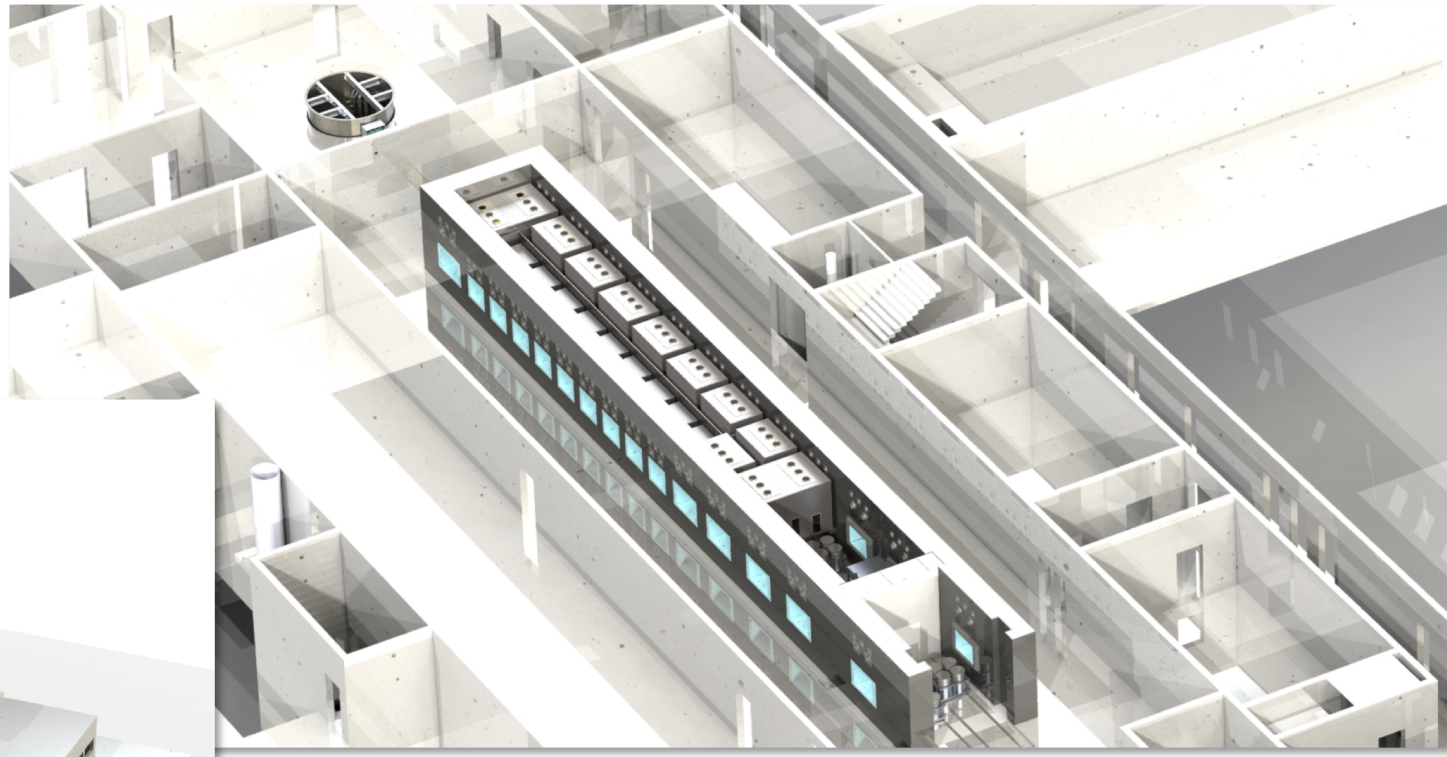
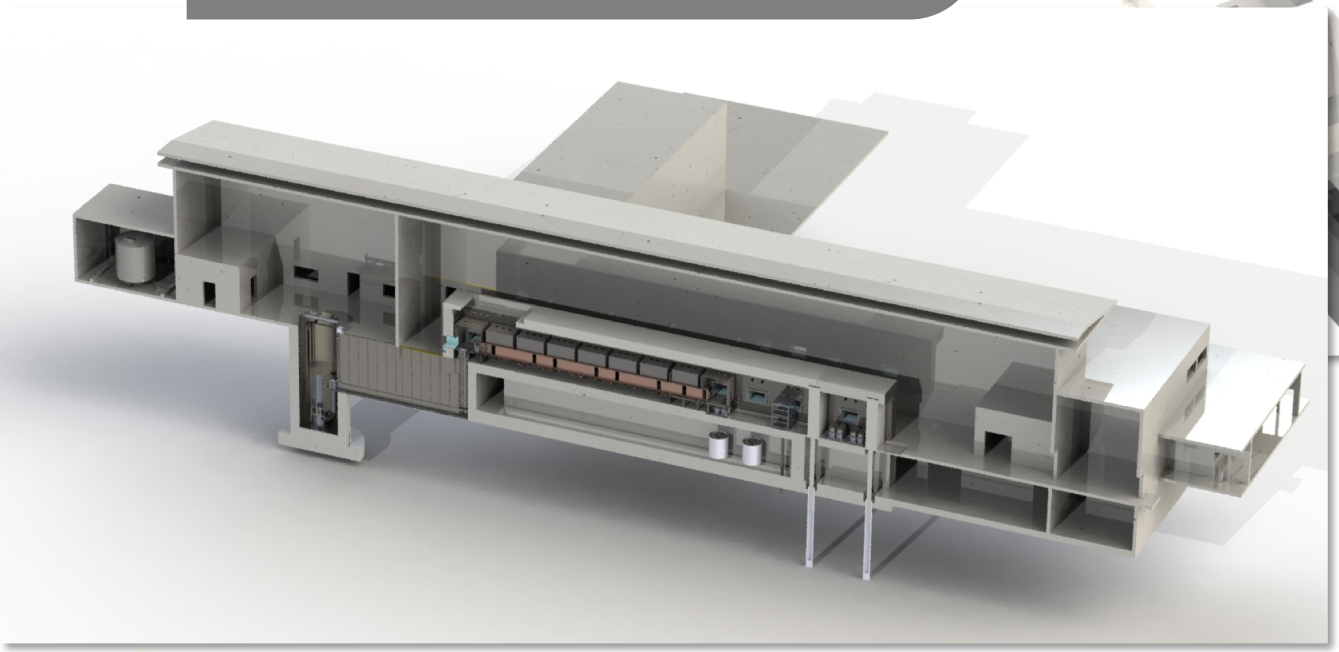
Eden Medical Isotope Facility (EMIF)







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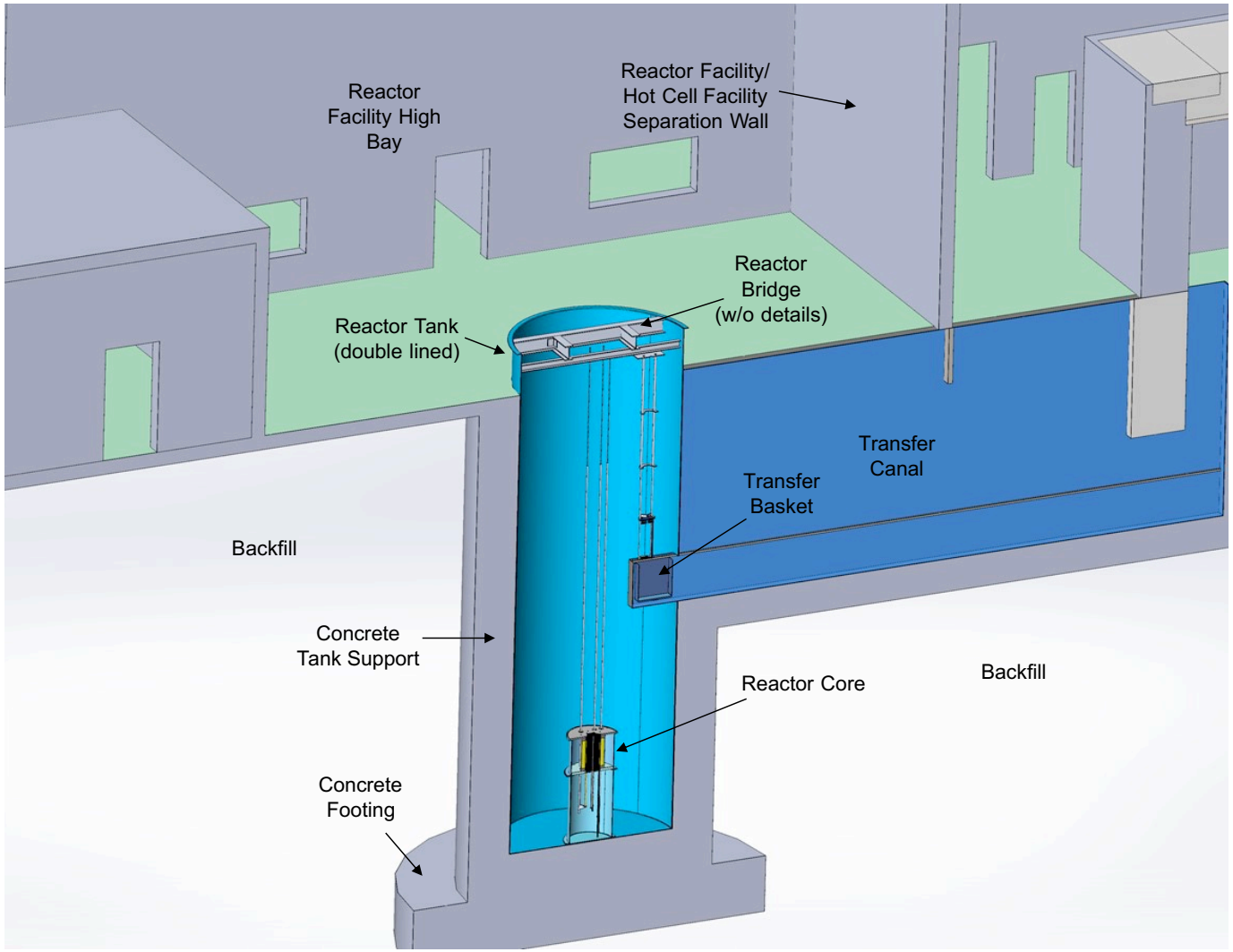
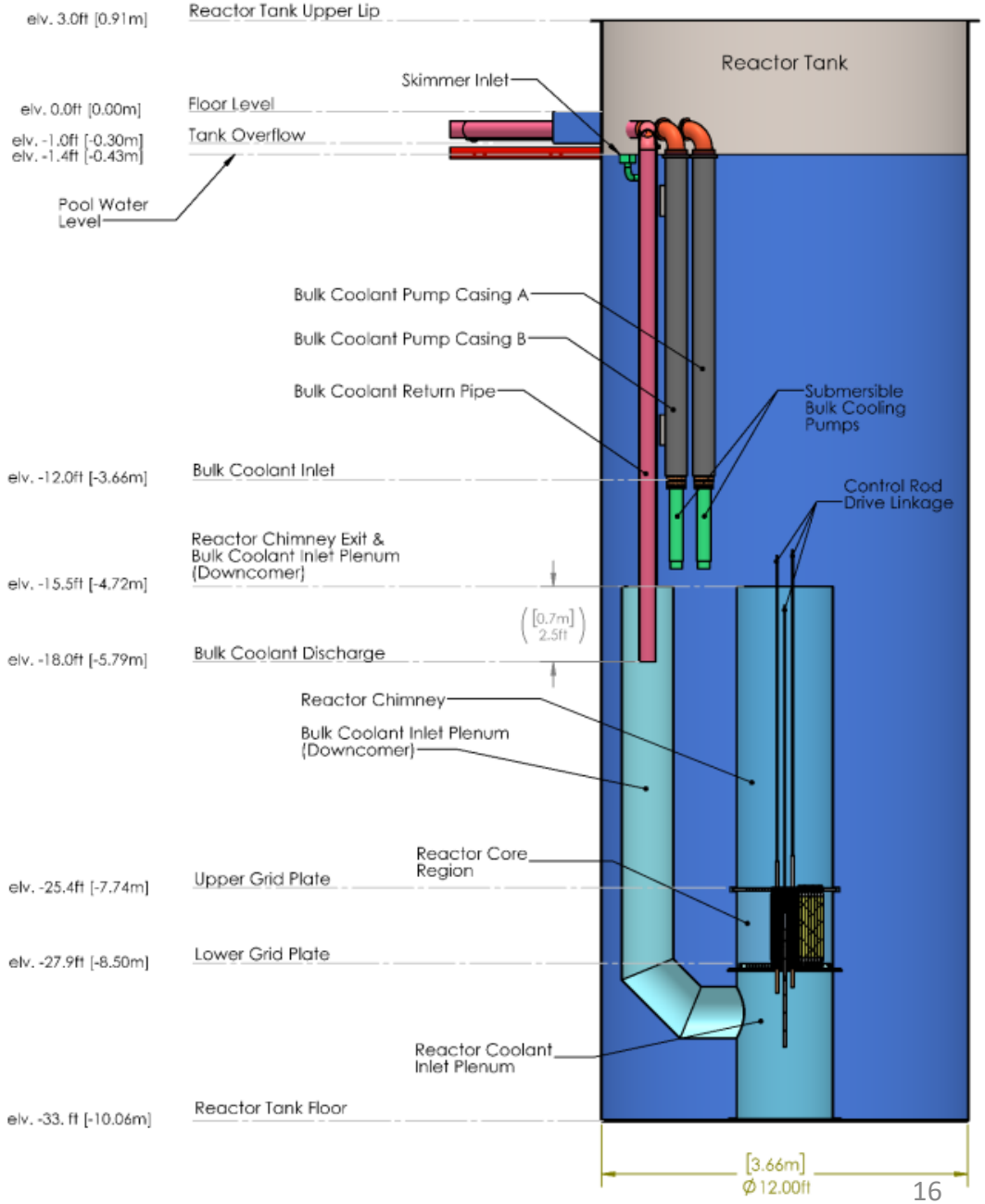
Reactor Tank/Pool





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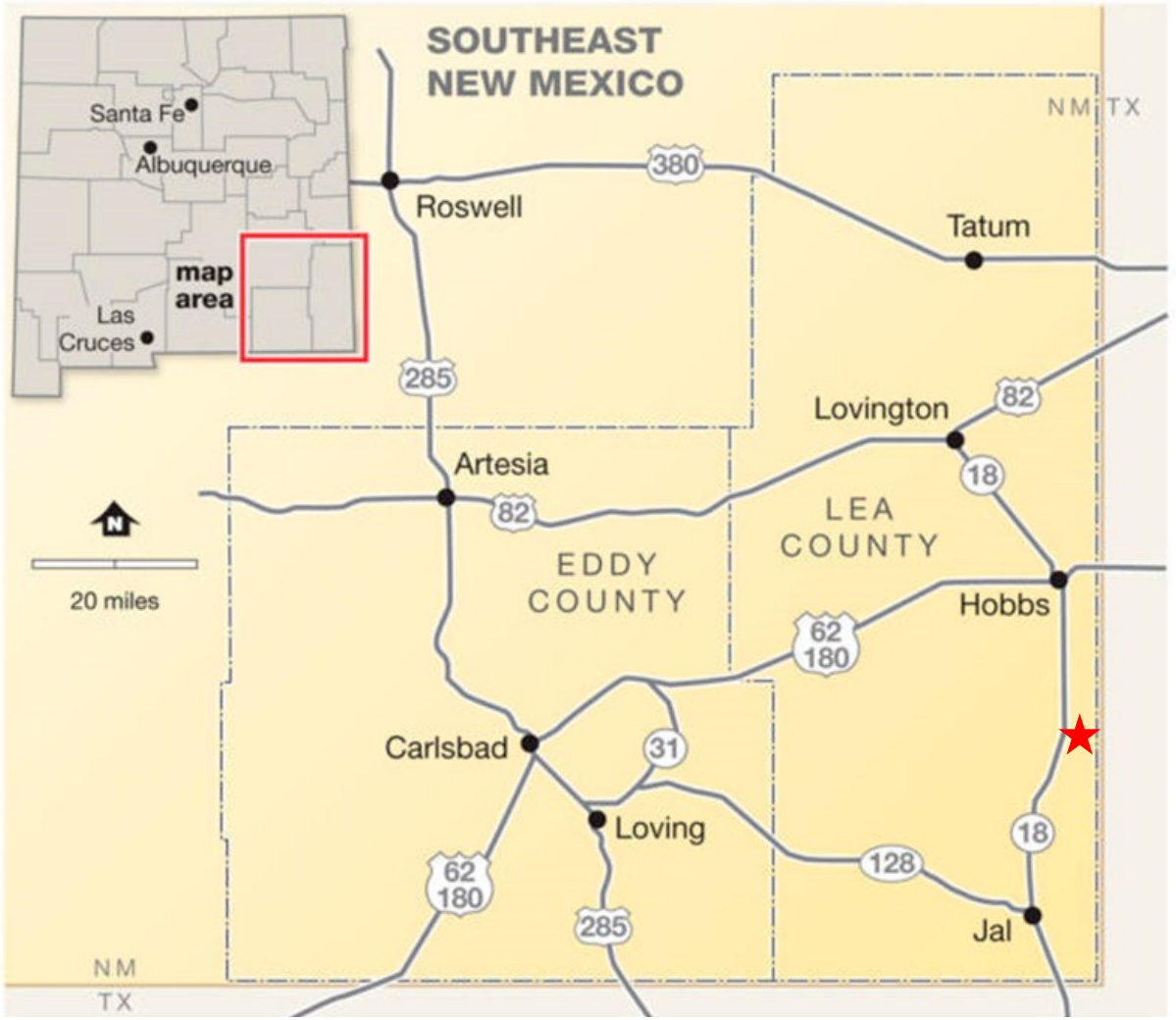
Eden Facility Site Location

- Airport
- Nuclear Friendly Community
- Waste Disposal - WCS
- URENCO Across the Highway



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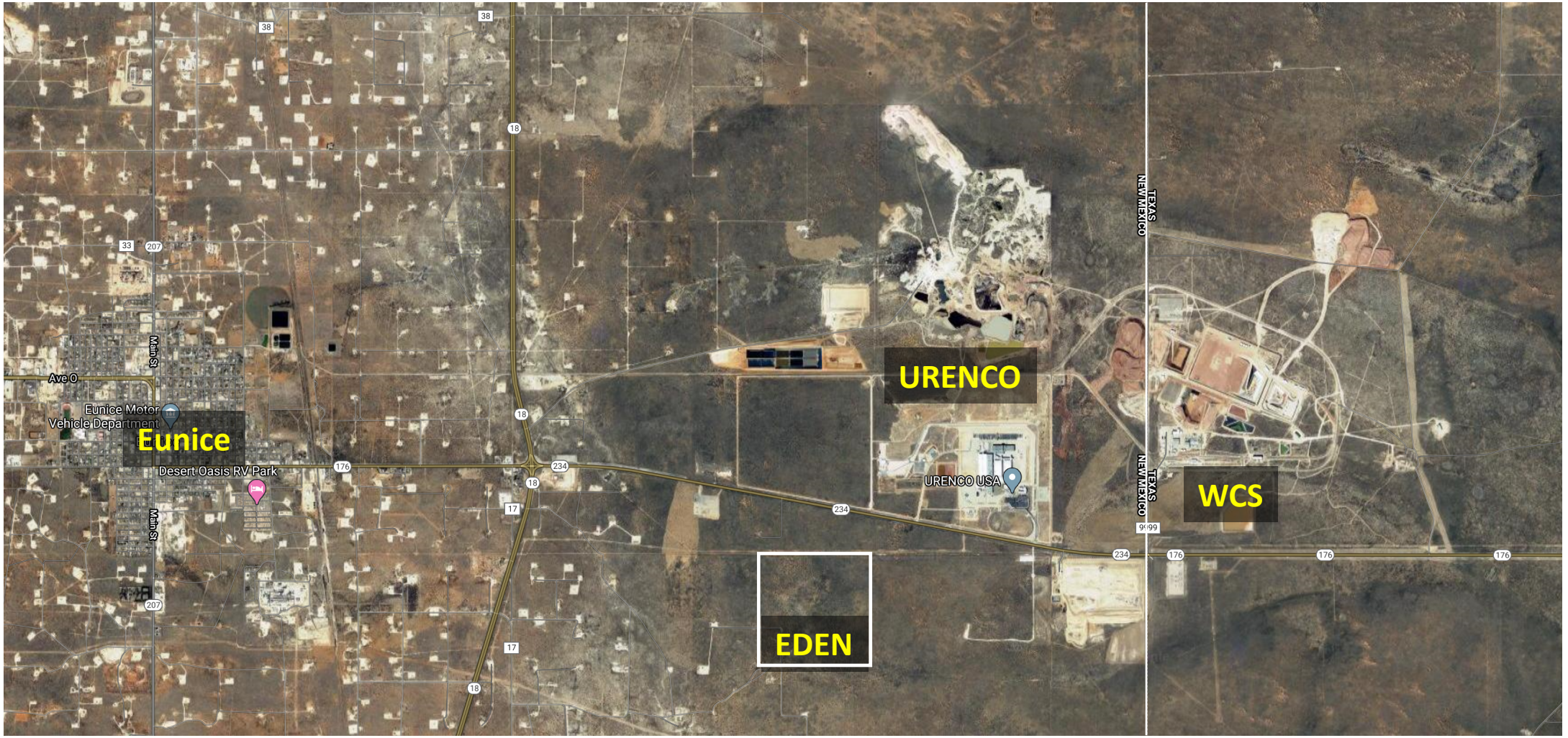

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Conclusion

Will a commercially viable medical isotope production reactor/hot cell facility ever be built in the US???

Eden believes that our approach is the answer

- Collocated reactor and hot cell facility
- Low power reactor but able to achieve the US demand for Mo-99
- No spent fuel generated – “All Target” concept
- No greater than Class C waste generated
- Large thermal neutron flux for activation isotope production

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Questions?

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