EDEN
RADIOISOTOPES

NRC Pre-application Meeting 12-16-2019

Subjects for Discussion

1. **Design and Documentation Update**

2. **Licensing path**

3. **Fuel element distinctions**

4. **Fuel element qualification**

5. **Startup program**

6. **General**

Design and Documentation Update - Reactor

Reactor

1. Neutron Transport and Kinetics complete
   - Monte Carlo N-Particle (MCNP) for Eigenvalues, Profiles, Feedback (Doppler, density, void, spectral)

   (many hundreds of independent calculations)
   - PARET and other coupled kinetics and thermal hydraulic codes for dynamic behavior under accident conditions

2. All in-core and ex-core components in final design stage
   - Working with Consolidated Nuclear Security (CNS)/Y12 on fuel elements (Driver Targets and Nominal Targets)
   - Working with Materion on Be reflector design
   - Work with Mirion for nuclear instrumentation, Eberline for rad protection, and Curtis Wright for Balance of Plant (BOP)

3. All safety analysis done
   - Accident and annual releases meet 10 CFR Part 20 criteria

4. Draft SAR and Tech Specs near completion.
   - Upgrading from PSAR to FSAR levels

Design and Documentation Update – Processing (HCF)

Processing

1. Conceptual design complete
   - Facility layout
   - Disassembly, dissolution, extraction, waste pkg and storage

2. All safety analysis complete and safety systems requirements identified
   - Shielding, isolation, separate ventilation, filtration, xenon hold up

3. Preliminary design in progress
   - Continue work on improving the Cintichem process implementation
   - Working on automation and controls
   - LEU extraction

4. Safety documentation in progress
   - The Integrated Safety Analysis (ISA) draft work is 80% done and continuing
   - Some other safety drafts have been prepared
   - How it is handled from this point on depends on the licensing path selected

Design and Documentation Update – Fuel Fabrication

Fuel Fabrication Plan

1. **Initial**
   - Will be performed by CNS/Y12. They can support us until we become commercial
   - Options for future include BWXT etc. or Eden
2. **Future**
   - Will be performed onsite by Eden
     - Tech transfer from CNS/Y12 to Eden
     - Reuse recovered LEU
     - Reduces LEU acquired from and returned to DOE ULTB
     - Saves on LEU and transportation costs
3. **Status**
     - Fabrication space and equipment needs established with CNS support
     - Accommodated in the Hot Cell Facility (HCF) building design
     - CNS continues R&D for fabrication and qualification on Eden elements, funded by NNSA
     - Eden will perform similar R&D using surrogate material
     - ISA work has been initiated

Design and Documentation Update - Other

Environmental Report (ER)

- Draft complete, formatted, and ready for formal peer review
  - Radionuclide transportation sections are not complete - awaiting code release
- Completed portions have had one round of informal peer review

Safeguards Information (SGI)

- Draft has been completed and is being peer reviewed
- Pertinent requirements are being disseminated to the appropriate Eden team members
- Discussions are underway to define SGI thresholds beyond those defined by CFRs

Physical Security Plan

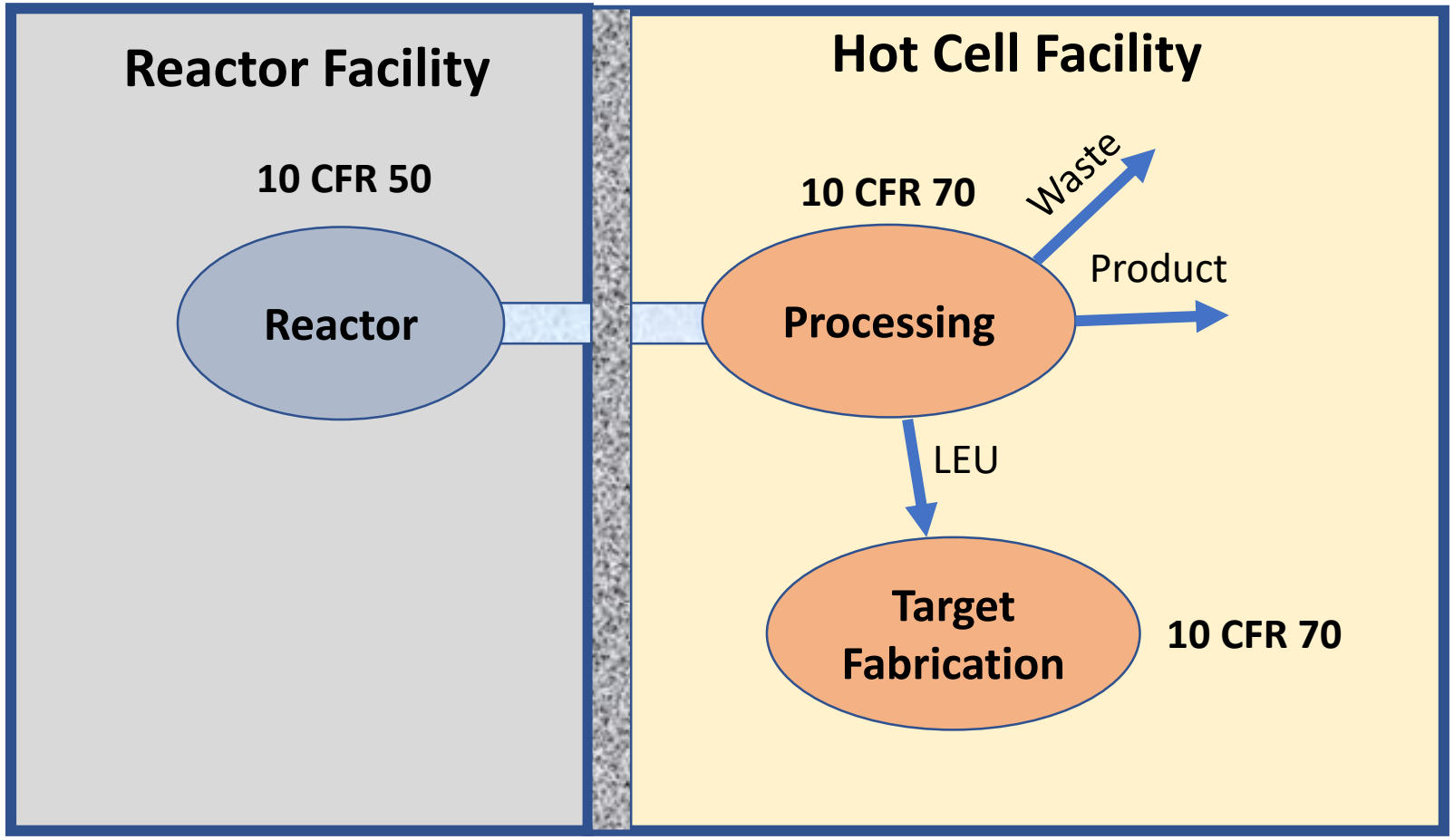
- Draft has been completed and is being peer reviewed
- Pertinent requirements are being disseminated to the appropriate Eden team members
- Discussions are underway to define areas of concern and implementation of plan

MC&A

- Drafted and in review

Training Plan for SGI, Physical Security, and MC&A to be developed shortly

Selecting the Desired Licensing path



Production Facility Definition

Introduction

- In previous pre-application meetings, Eden's hot cell facility has been discussed
- Eden interprets its hot cell facility to meet exemption (iii) of 10 CFR 50.2 definition of a production facility, making it eligible for a Part 70 license for both, the hot cell facility and the target fabrication facility
- Before requesting a formal interpretation from the NRC, Eden would like to present more information to prepare the NRC staff

Production Facility Definition

(3) Any facility designed or used for the **processing** of **irradiated materials** containing special nuclear material, **except**

(i) laboratory scale facilities designed or used for experimental or analytical purposes,

(ii) facilities in which the only special nuclear materials contained in the irradiated material to be processed are uranium enriched in the isotope U-235 and plutonium produced by the irradiation, if the material processed contains not more than 10^{-6} grams of plutonium per gram of U-235 and has fission product activity not in excess of 0.25 millicuries of fission products per gram of U-235, and

(iii) facilities in which processing is conducted pursuant to a license issued under parts 30 and 70 of this chapter, or equivalent regulations of an Agreement State, for the receipt, possession, use, and transfer of irradiated special nuclear material, which authorizes the processing of the irradiated material on a batch basis for the separation of selected fission products and limits the process batch to not more than 100 grams of uranium enriched in the isotope 235 and not more than 15 grams of any other special nuclear material.

Box	NRC Activities Being Conducted
Target Receipt Box	Possession
Dissolver Box	Processing and Separation
Purification Box	Processing and Separation
Packaging Box	Possession

Batch limit is different than possession limit for license

Interpretation

- Processing of Irradiated materials is interpreted to mean:
  - Irradiated materials such as uranium being taken into solution form during chemical separation of fission products
- A batch in exception (iii) refers to a batch of processed irradiated materials
- Physically, a batch is limited to the quantity of this processed irradiated material in a given hot cell box, which
  - Limit interaction between batches (are segregated)
  - Have independent shielding and ventilation systems
- Eden's restricts batches of irradiated uranium solutions with < 100 g U-235
- These batches only occur when Eden processes in the dissolver and purification boxes of its hot cells

- **Thus, Eden's facility will meet exception (iii) of the 10 CFR 50.2 definition of a production facility and therefore, believes that NRC could license its hot cell facility and target fabrication facilities under a Part 70 license**

Genesis Targets

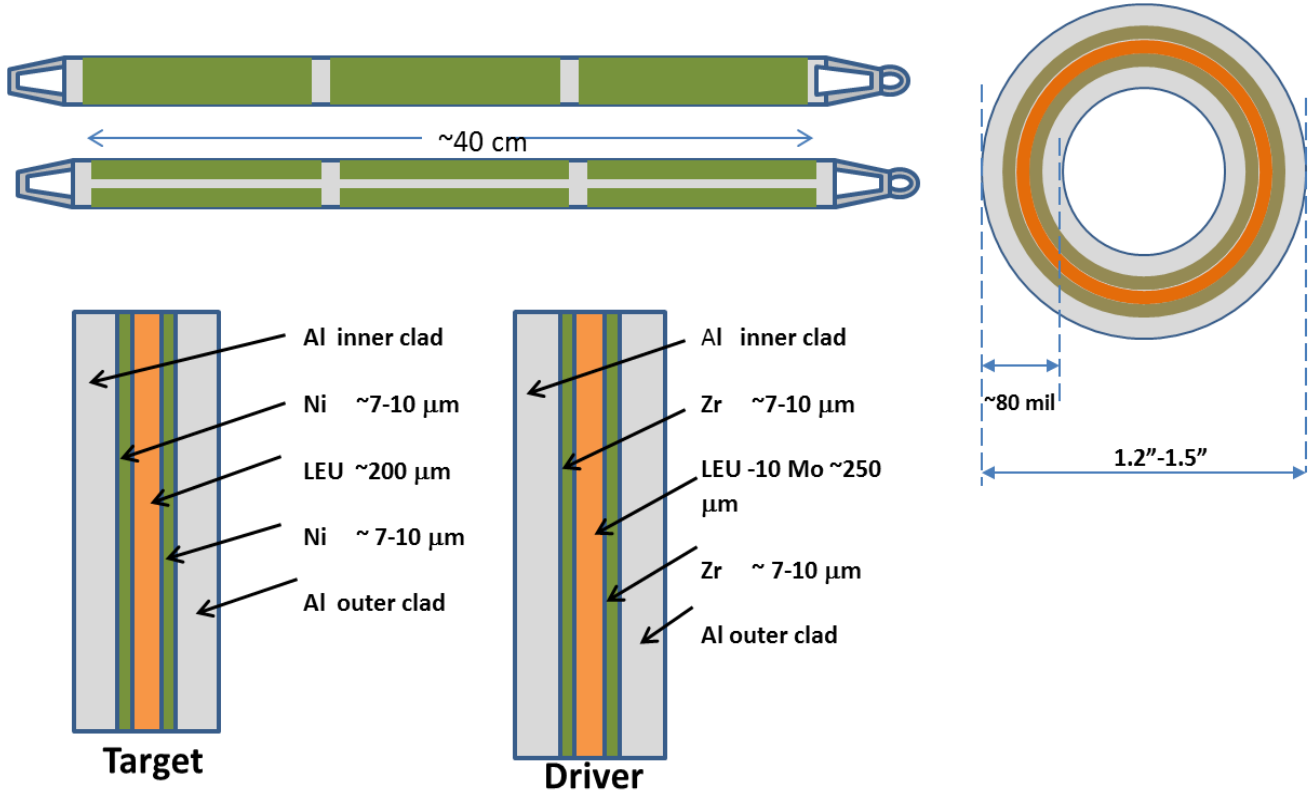
Discussion of Driver Targets and Nominal Targets

Introduction

- In previous pre-application meetings, Eden's Driver Targets and Nominal Targets were discussed
  - The novelty of the all-target approach as well as the novelty of the targets, themselves, are part of Eden's license application
- Driver Targets and Nominal Targets share similarities to NRC definitions of "fuel" and "targets"
  - By nature of design, both share characteristics of "fuel" and "targets" that will be addressed in the safety analysis
- The following slides provide Eden's "first principles" analysis of the technical, safety basis, and licensing approach of its targets with the NRC staff

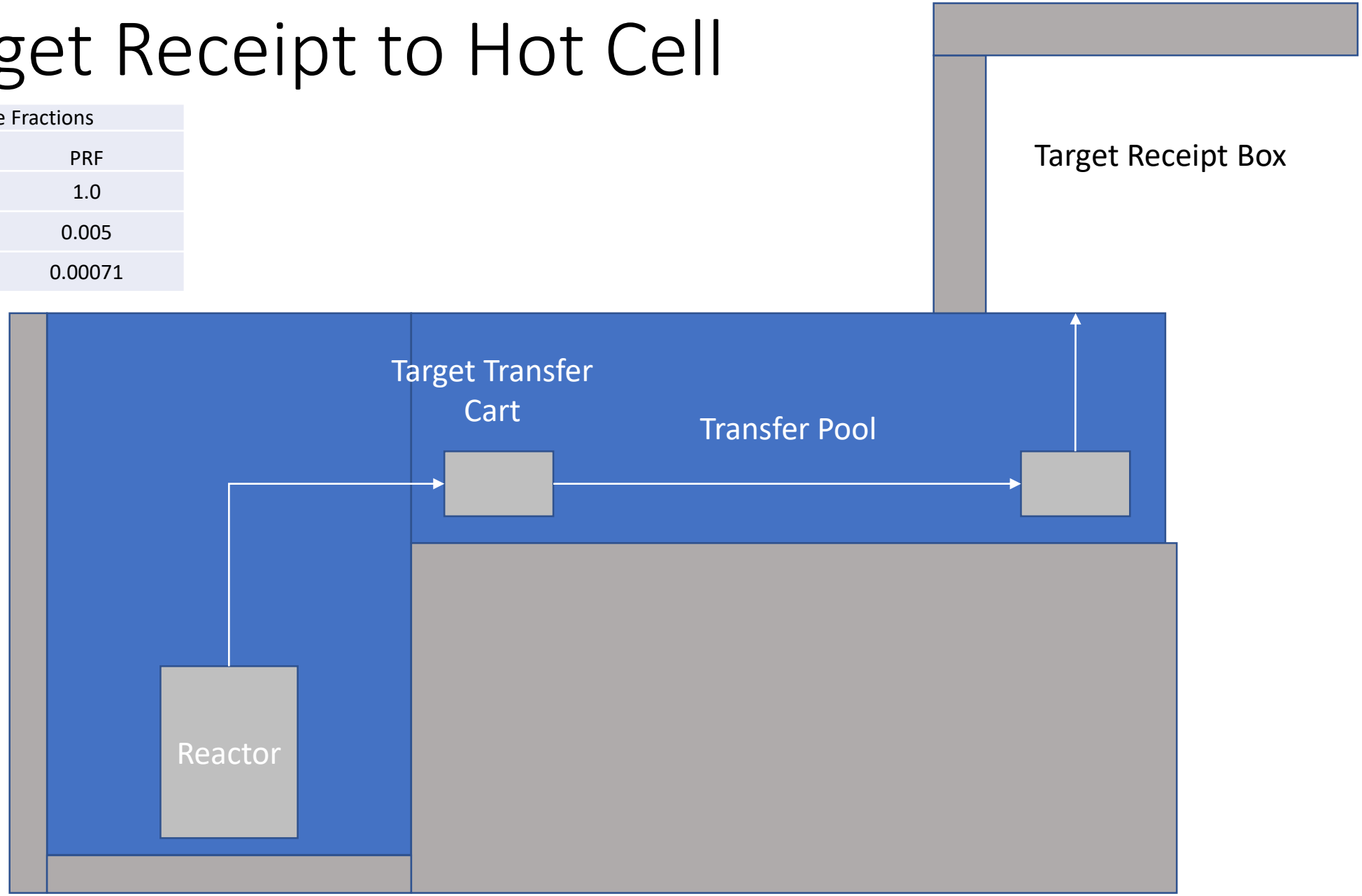
Targets: Driver Targets vs. Nominal Targets

- Almost identical in design and nuclear and thermo-hydraulic performance
- Primarily differ in stability in hostile temperature and irradiation environment.
- Driver Targets are to supplement Nominal Targets for reactivity need without non-productive sacrifice of Nominal Targets.
- Driver Targets are useful, but not necessary.



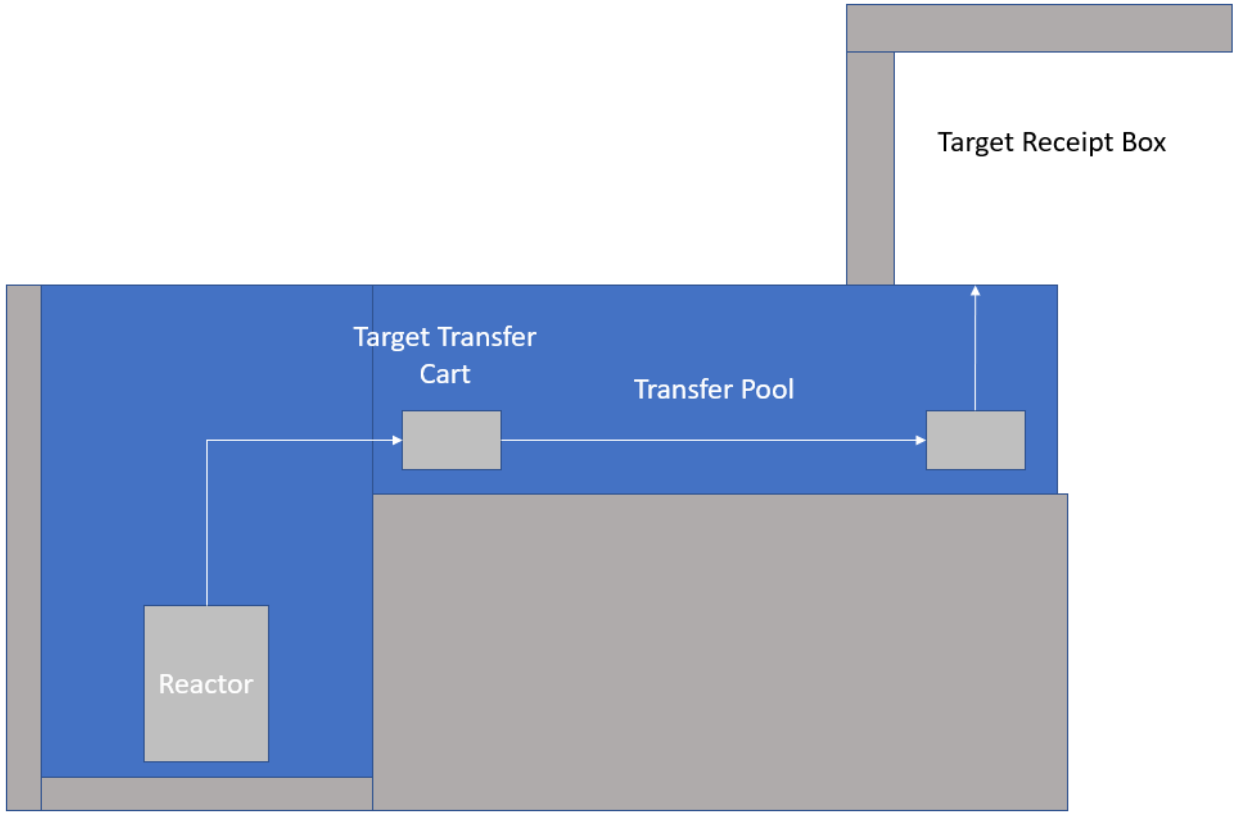
Target Receipt to Hot Cell

Pool Release Fractions	
Chemical Group	PRF
Nobles	1.0
Halogens	0.005
Others	0.00071



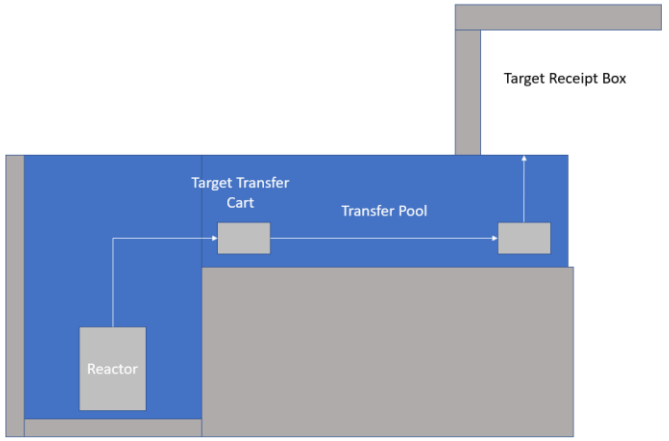
Unique aspects of Genesis Facility

- In most TRIGA SARs, the MHA is a drop of an irradiated element outside of the pool
- In the Genesis facility, irradiated elements are either under water (reactor pool or transfer canal) or in the hot cell processing area



Unique aspects of Genesis Facility

- Nobles and halogens reach saturated activity around 21 days
  - Pool water effectively scrubs all FPs except for nobles and halogens
  - HEPA and charcoal filtered ventilation systems reduce release by >100x for all FPs except for nobles
  - Dose in MHA are equivalent for drivers and targets (<100 mrem)
  - Actinide waste inventory can be managed through control of actinide %/gm by adding to the Nominal Target waste stream



Pool Release Fractions

Chemical Group	PRF
Nobles	1.0
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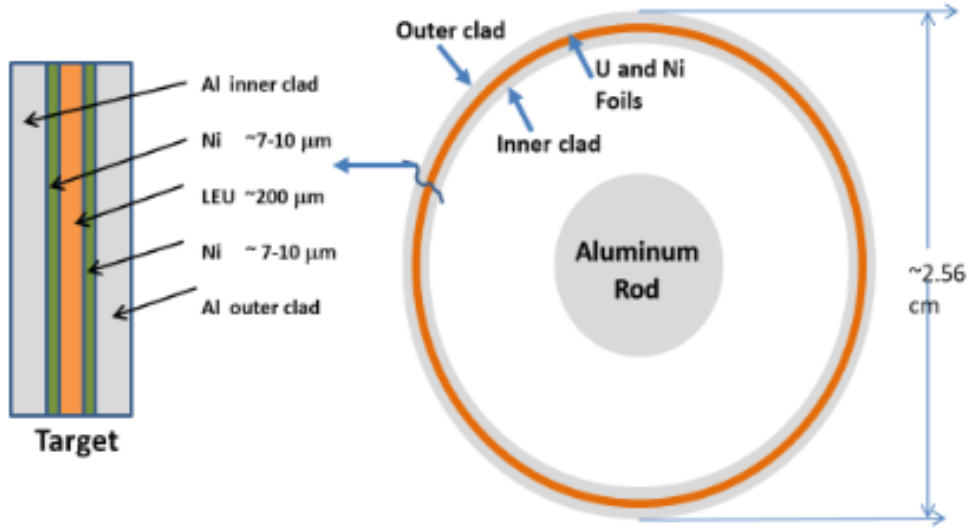
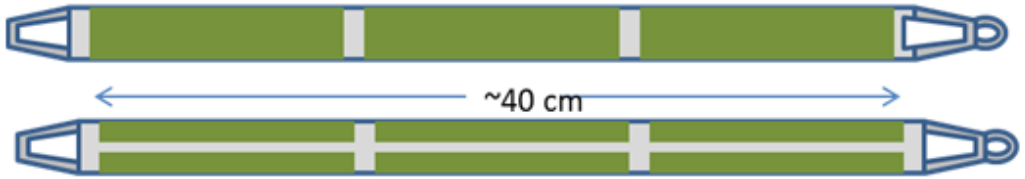
Nominal Targets: Purpose and Constraints

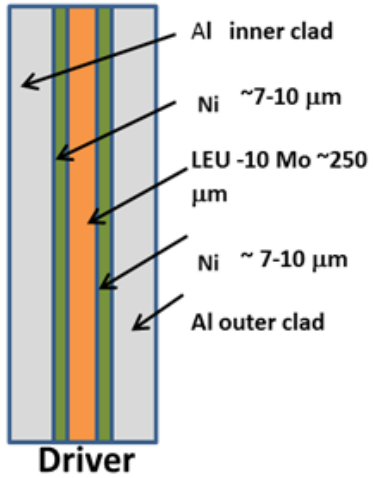
- Nominal Targets will be processed for Mo-99 production. They must comply with nuclear safety requirements, but also meet product specifications for customer.
- Low burnup of 7-21 days
  - After 21 days, accrual of alpha emitters may prohibit end-product from meeting product specifications
  - If overexposed, they could be useful for supplementing reactivity; however, unacceptable irradiation damage from the anisotropic nature of the orthorhombic crystalline structure may limit lifetime.

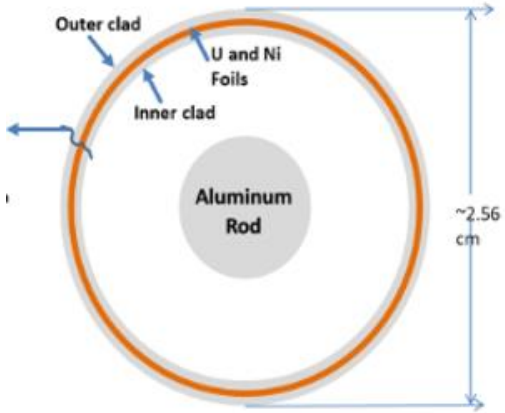


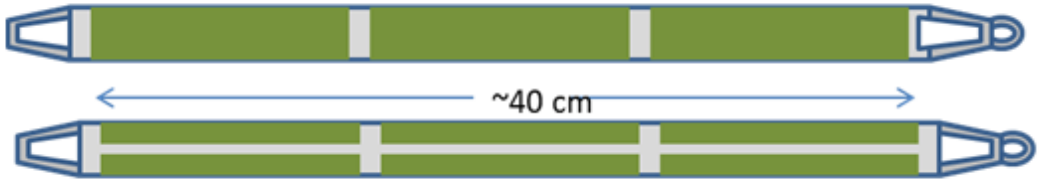


Driver Targets: Purpose and Constraints

- Driver Targets do not need to meet product specifications, but may still be processed. Product from Driver Targets will not be sent to customers
- Driver Targets are fueled with isotropic body centered cubic gamma stabilized U-10 w/Mo and expected to have a much longer useful lifetime before unacceptable irradiation damage occurs (up to 180 days, 8-25x useful life of nominal targets)
- Driver Targets allow the reactor core to maintain a consistent reactivity environment while reducing economic burden of Nominal Targets. This would be quite useful during:
  - Startup Testing
  - Initial operations
  - Training





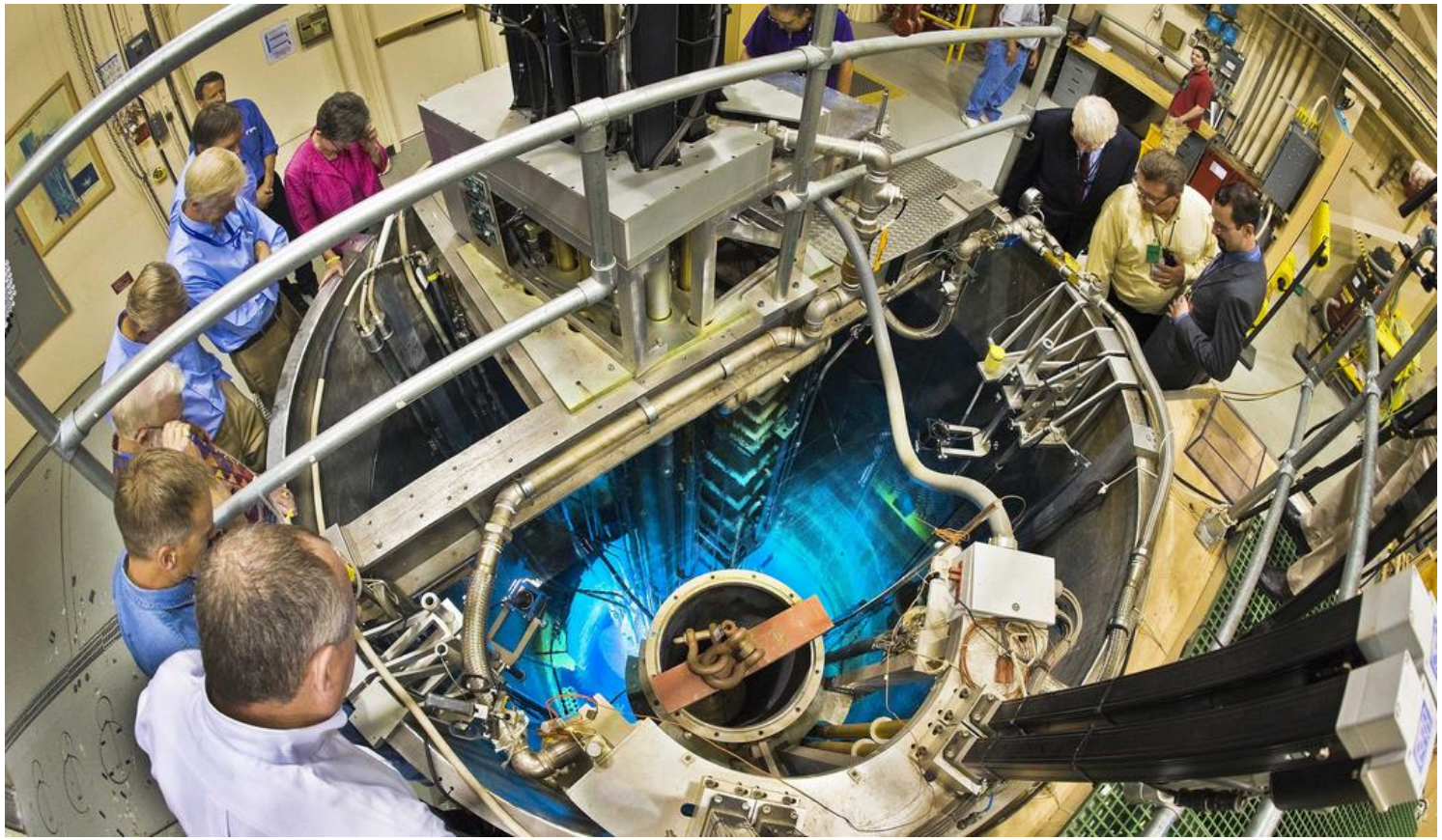


Nominal Targets: Safety Basis

- Key Safety Features:
  - Low fission product inventory
  - High heat transfer (inside and outside)
  - Design precludes accrual of fission products in “gaps” between fuel and cladding
    - Cladding damage would not release substantial fission products
    - Fuel melt would result in release of radionuclides and damage to cladding
- Analyzed as fuel in Chapter 4 and Chapter 13 of the FSAR
- Startup and Testing Program
- Waste and radioactive characteristics are described in Chapter 11 of the FSAR

Driver Targets: Safety Basis

- Same Safety Features as Nominal Targets with addition of:
  - Longer irradiation lifetime (perhaps up to 180 days)
  - Can be allowed decay between periods of use
- Difference in Driver Targets does not affect release consequences:
  - Noble and halogens reach saturated activity in less than 21 days
  - Long term fission products almost completely mitigated by ventilation system or pool water in various accidents
- Waste consideration
  - Driver Targets contribute more actinides and long-lived fission products to the LLW stream per unit than do Nominal Targets. When added to the nominal waste stream, the waste stream remains well below LLW disposal limits for the waste disposal site.
- Analyzed as fuel in Chapter 4 and Chapter 13 in the FSAR
- Startup and Testing Program
- Waste and radioactive characteristics are described in Chapter 11 of the FSAR



Hazards and Accident Scenarios: Reactor Facility

- As designed, the consequences from loss of clad integrity is less for the Genesis targets than for traditional cylindrical targets since there is no significant gap or other volume for radionuclide gases to accumulate and be released when the clad is breached
- The only significant potential for release of the noble gases and halogens would occur when the fuel melts
- MHA: Melt/damage during reactor operations prompted by manufacturing defect in the target
  - Mitigated by qualification of the target
  - Similar consequences for both Driver Targets and Nominal Targets (<100 mrem to public)

Hazards and Accident Scenarios: Hot Cell Facility

- Consequences are the same for Nominal Targets and Driver Targets
- MHA: Release of noble gas inventory
  - Noble gases reach saturated activity < 21 days
- Unintentional damage/release of targets in Target Receipt Box
  - LT FP's are mitigated by ventilation system
- Release of FPs from waste:
  - Higher inventory of LT FPs in waste
  - Waste inventory will bound fission product inventory of even Driver Targets
  - Waste will be diluted to meet specifications of transportation and cask
- Direct Radiation hazards:
  - Shielding (hot cell walls, pool water, windows, etc…) are engineered around bounding radiation levels

Conclusion

Driver Targets and Nominal Targets are nearly identical in form and design. Longer irradiation time of Driver Targets do not affect safety basis significantly different from the Nominal Targets

Both have similarities to fuel and targets. Eden's FSAR will adequately address the technical and safety considerations throughout the report

New design will have thorough analysis and conclusions will be supported in startup and testing program

Startup and Testing Program

Inspection and Testing

- Testing is performed throughout the fabrication process to ensure that the targets and materials meet specifications for grain size, grain orientation randomness, void gap, surface quality, and other physical dimensions
- Metallographic techniques will be used to examine grain size and orientation. To the extent practical, radiation and/or sonic techniques will be employed to detect gaps and to confirm loadings. Dye and other techniques, including helium-based leak tests, as practical, will be used to check the soundness of the end swage closure and/or welds
- Each Driver Target and Nominal Target is assigned and marked with a unique identification number and all test and inspection results associated with that target separately recorded
- Prior to use, the targets will be re-inspected by visual and dimension measurements to assure confidence in the use of that target

Irradiation and Post Irradiation Testing

- Eden plans to conduct confirmatory irradiation testing as part of the start up program. Lead targets will be exposed to various power histories for extended periods and their performance measured. Periodically, such targets will be transferred to the hot cell facility for close visual inspection and physical measurements
- As appropriate select targets will be disassembled for further inspection of the component parts
- In addition to close visual examination, physical measurements, and sonic techniques, metallographic techniques, to the extent warranted and practical, may be used to determine the extent of irradiation and thermal cycling damage, if any, caused by the exposure history of that target
- To the extent possible, the lead test targets may be instrumented and monitored
- This information will supplement the other data gathered in the start up phase to arrive at practical limits for operation and for integrated exposure history. Based on the results of the start up testing and other examinations, limits will be placed on the reactor power levels, target exposure times, and other operating parameters