Oak Ridge National Laboratory

Transformational Challenge Reactor NUREG-1537-based Authorization Observations and Recommendations

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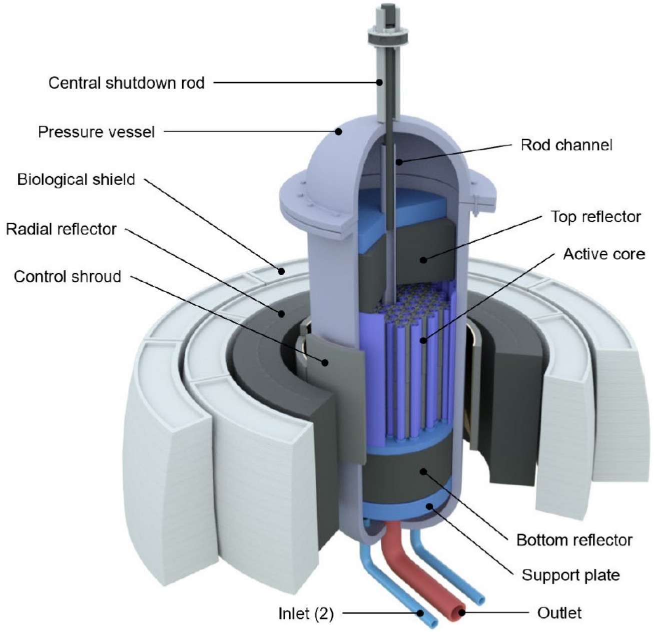
U.S. DEPARTMENT OF ENERGY

TCR background

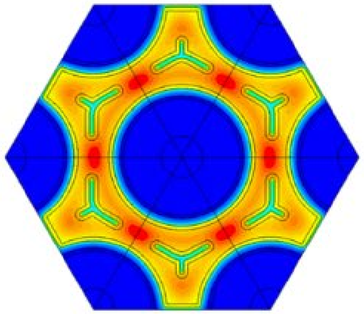
- FY19-20, TCR completed conceptual and preliminary designs
- TCR demonstration undergoing authorization by the DOE (10 CFR 830)
- Site selected at ORNL with a completed draft environmental assessment
- FY21 demonstration suspended in favor of more focused research areas

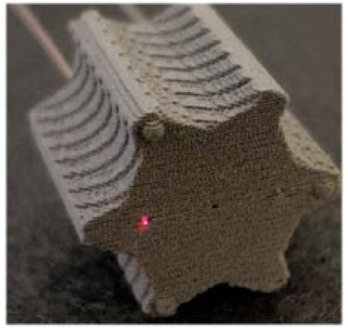


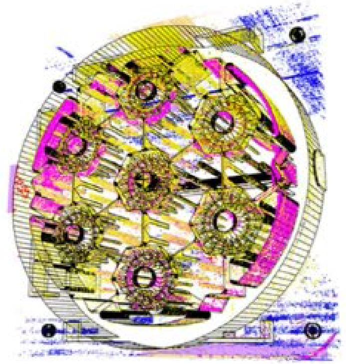
Attribute	Value
Reactor Type	Gas-cooled, thermal spectrum
Fuel Form	UN TRISO in SiC Matrix
	19.75% enrichment
Moderator	Yttrium-hydride
Power level	3 MWt
Operational life	1 EFPD
Coolant	Helium
Outlet temperature	550
Inlet temperature	300

FY21 and FY22* areas of research

AI-informed Design	Advanced Materials	Integrated Sensing and Control	Digital Platform
Using AI to navigate an unconstrained design space and realize superior performance	Leveraging AM** to arrive at high-performance materials in complex geometries	Exploiting AM to incorporate integrated and distributed sensing in critical locations	Using AI to assess critical component quality using in situ manufacturing signatures







*TCR is merging with another DOE program, advanced methods for manufacturing under NEET

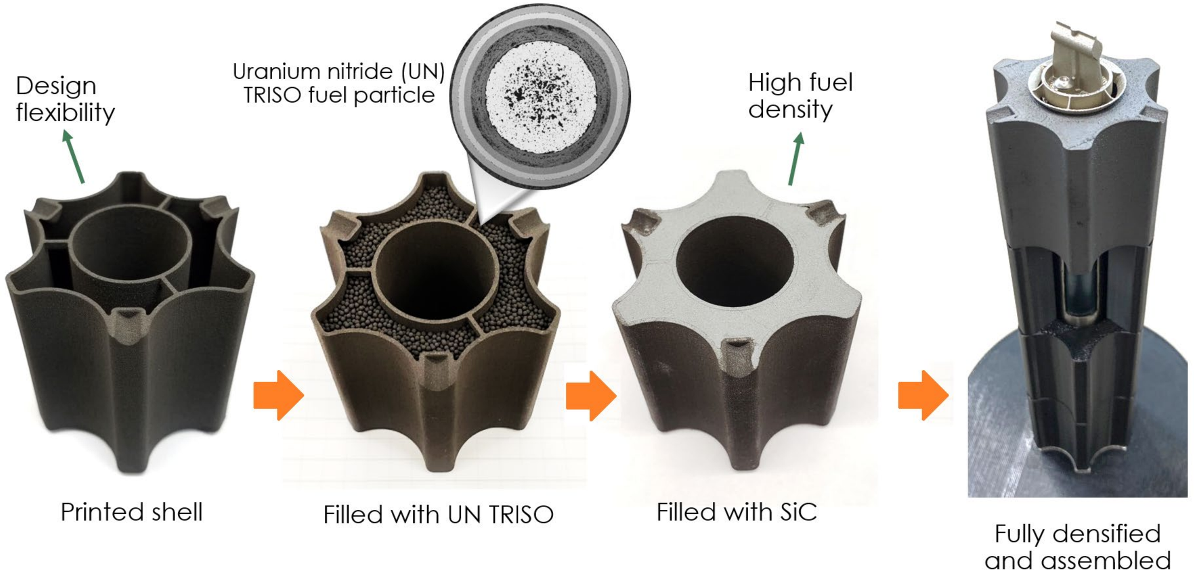
FY21 regulatory support for key thrust areas

1. **Document observations and provide recommendations for future NUREG-1537 advanced reactor applications**
    - Assessment of NUREG-1537 for AMT**-derived components
    - Component safety classification and dose thresholds
    - Engineering safety features and fundamental safety functions
        - ✓ **Report published on 6/30/21, *ORNL/TM-2021/2013***
2. Develop an approach for using a digital platform to inform the certification of components derived from additive manufacturing
    - ✓ **Report published on 9/30/21, *ORNL/TM-2021/2210***

**AMT and AM are generally interchangeable in the context of this work

Motivation for documenting observations and recommendations for NUREG-1537

- TCR produced AM components for both the fuel and other core structures
  - AM materials unique from non-AM
- Many other advanced reactor concepts are low power and microreactor range, like other research and test reactors
  - Considering NUREG-1537 for either demonstration/research or possibly commercial versions
  - May also employ a range of AMT-derived components



Assessment of NUREG-1537 for AMT-derived components

- Possible extend of use of AM components throughout many sections and chapters of NUREG-1537
- Suggested modification to NUREG-1537 for advanced nuclear technologies utilizing components derived from AM:
  - ***Include any unique design features*** afforded by AM (*e.g.*, non-traditional components)
  - ***Include AM manufacturing process information*** which may affect critical material properties and performance of the component
  - ***Identify/include any unique failure modes or potential safety concerns*** with AM

Component Classification and Dose Thresholds

- ***Problem:*** confusing and different safety analysis processes for coupled DOE-STD-3009 and NUREG-1537 applications
  - How to classify components, which dose thresholds for what type/class of accident?

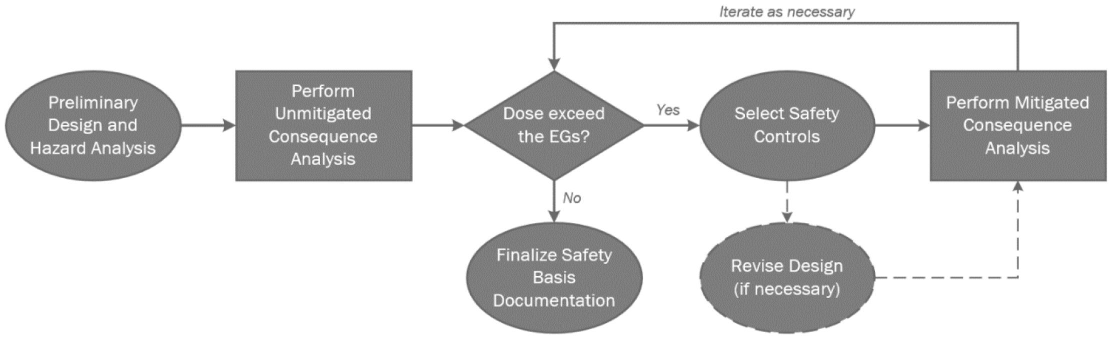


Table 3. Consequence thresholds (EGs).

Consequence level	Public[1,4]	Colocated worker[2, 4]	Facility worker[3]
High	≥ 25 rem Total Effective Dose (TED)	≥ 100 rem TED	Prompt death, serious injury, or significant radiological exposure
Moderate	≥ 5 rem TED	≥ 25 rem TED	No distinguishable threshold
Low	< 5 rem TED	≤ 25 rem TED	No distinguishable threshold

[1] Maximally exposed offsite individual (MOI): A hypothetical individual defined to allow dose or dosage comparison with numerical criteria for the public. This individual is an adult typically located at the point of maximum exposure on the DOE site boundary nearest to the facility in question (ground-level release), or he or she may be located at some farther distance where an elevated or buoyant radioactive plume is expected to cause the highest exposure (airborne release); see Section 3.2.4.2 of DOE-STD-3009. The MOI used here is not the same as the Maximally Exposed Individual or the Representative Person used in DOE Order 458.1 for demonstrating compliance with DOE public dose limits and constraints.
[2]A colocated worker at a distance of 100 m from a facility (building perimeter) or estimated release point.
[3] A worker within the facility boundary and located less than 100 m from the release point.
[4]Although quantitative thresholds are provided for the MOI and colocated worker consequences, the consequences may be estimated using qualitative and/or semiquantitative techniques.

DOE Safety Design Process and Consequence Thresholds

Component Classification and Dose Thresholds

- ***Problem:*** confusing and different safety analysis processes for coupled DOE-STD-3009 and NUREG-1537 applications
  - How classify components, which dose thresholds for what type/class of accident?

- ***Proposed solution:***
  - Have transparent documentation in Chapter 13, and clearly the define the function and purpose of:
    - Unmitigated consequence analysis, → Bounding-type of analysis for hazard characterization and analysis
    - Mitigated consequence analyses, → For the assessment of safety controls, starting from the unmitigated case
    - Postulated accidents, → Chapter 13 accidents that show satisfaction of safety and dose thresholds with those selected safety controls
    - Maximum hypothetical accident → A hypothetical accident condition that bounds the consequences from all postulated accidents

Engineering Safety Features

- *"ESFs are active or passive features designed to mitigate the consequences of accidents and to keep radiological exposures to the public, the facility staff, and the environment within acceptable values. The concept of ESFs evolved from the defense-in-depth philosophy of multiple layers of design features to prevent or mitigate the release of radioactive materials to the environment during accident conditions."*

Chapter 6 of NUREG-1537 defines typical ESFs:

1. Confinement
2. Containment
3. Emergency Core Cooling System

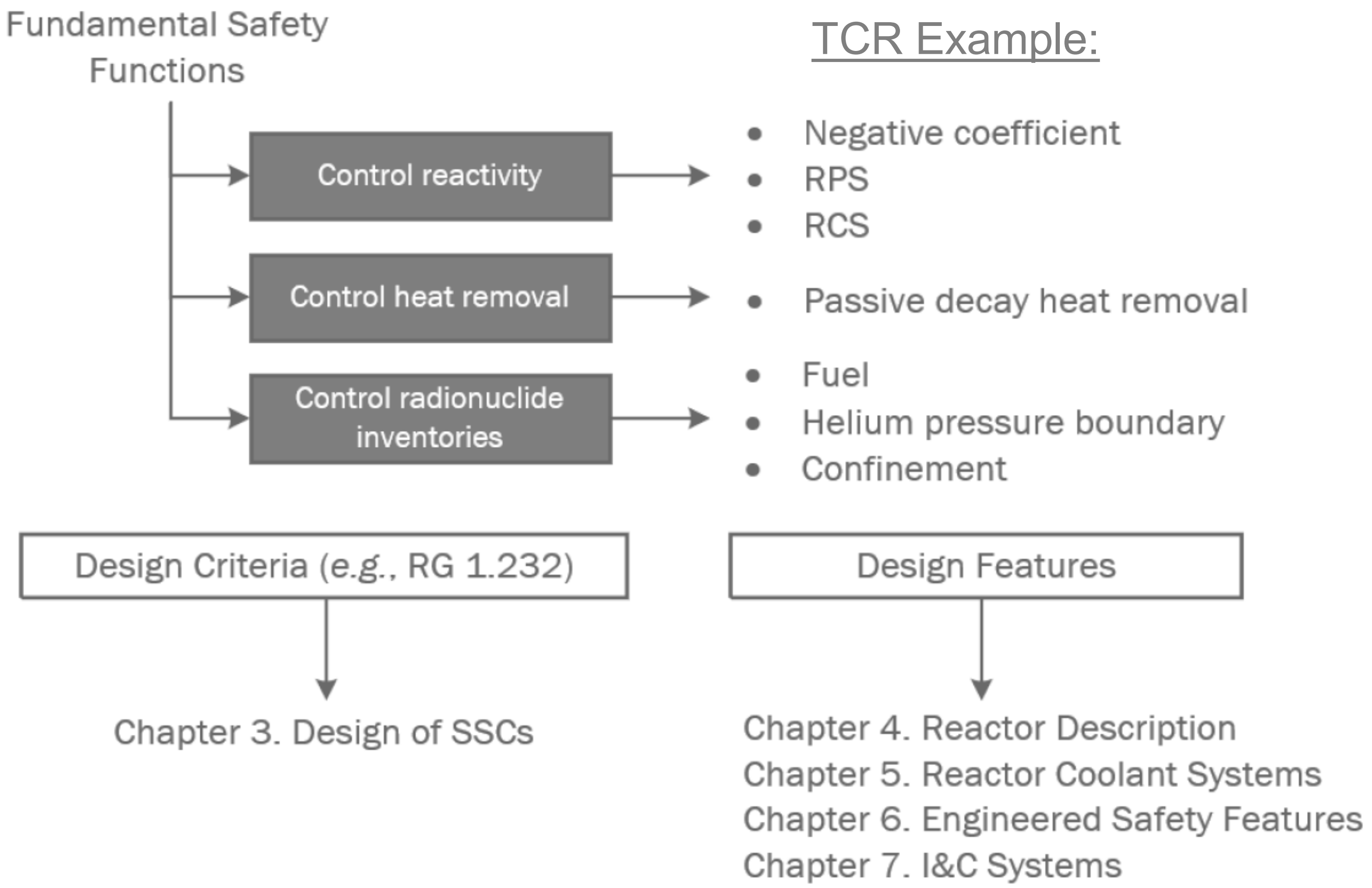
Problem:

Light water reactor-specific, not applicable to many advanced reactor concepts

How to select which components/systems as an ESF that may have other plant functions (e.g., primary heat exchangers)?

Fundamental Safety Function-based Solution to ESFs

- ***Proposed solution:***
  - Re-order chapter 6 around the discussion of fundamental safety functions (FSF)
  - **Design features which satisfy a FSF should be described in chapter 6**
  - Other design features may be described elsewhere



Conclusions

- Provided several recommendations based on TCR authorization experiences following NUREG-1537
  - Provide a clear and transparent approach for safety classification, accident analyses, and relationship to dose consequence limits
  - For many advanced reactor concepts, modification of chapter 6 with focus on satisfaction of fundamental safety functions
  - Suggested additions for systems relying heavily on AMT-derived components

> *"The TCR program's focus since its onset remains on elevating the readiness level of advanced technologies with a focus on additive manufacturing to enable optimal and cost-effective nuclear energy. The program strives to develop and demonstrate these technologies at high readiness level to facilitate widespread industrial and regulatory adoption. The specific nature of these demonstrations will be based on the guidance that we will receive from our managers at US DOE."*

- TCR Director, Ben Betzler

Questions

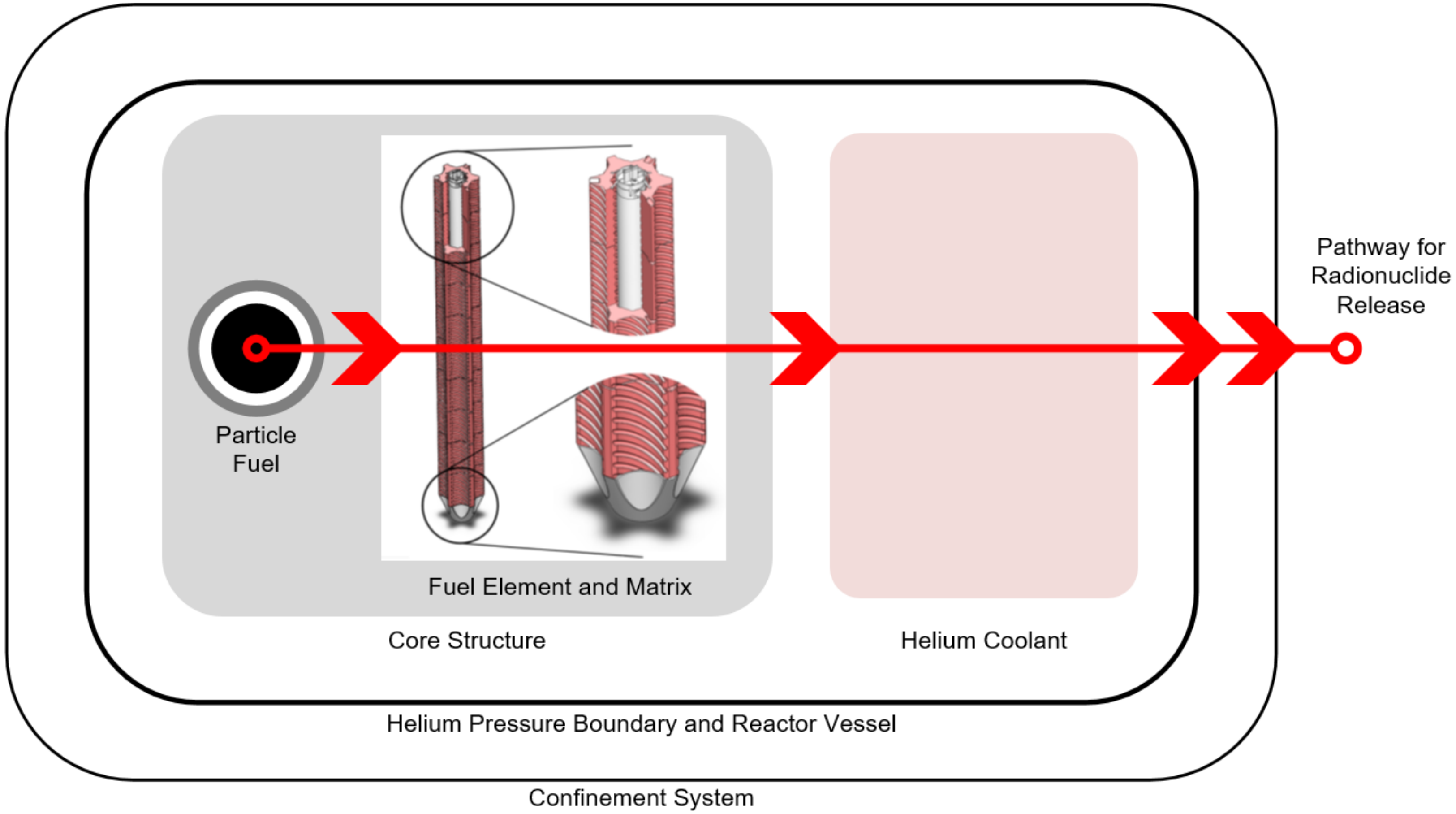
THANK YOU!

Backup and Other Slides

Example TCR FSF: Control Radionuclide Inventories

Barriers:

- Particle fuel
- Element and matrix
- Helium coolant and helium pressure boundary
- Confinement system



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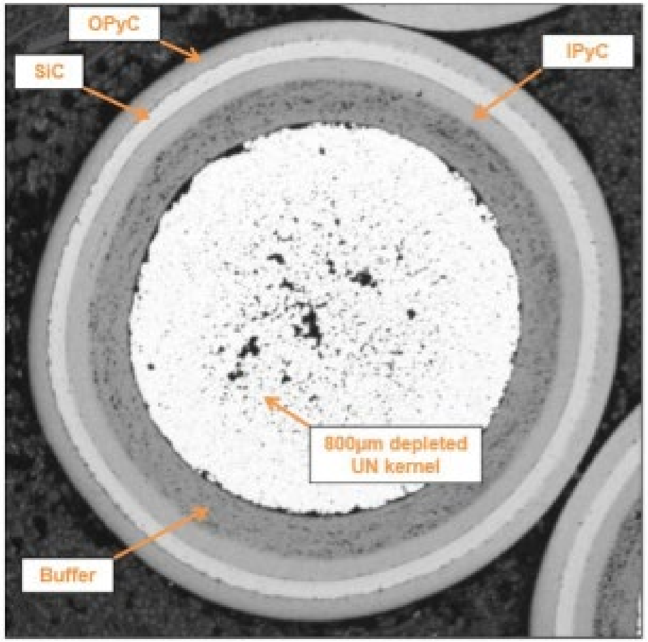

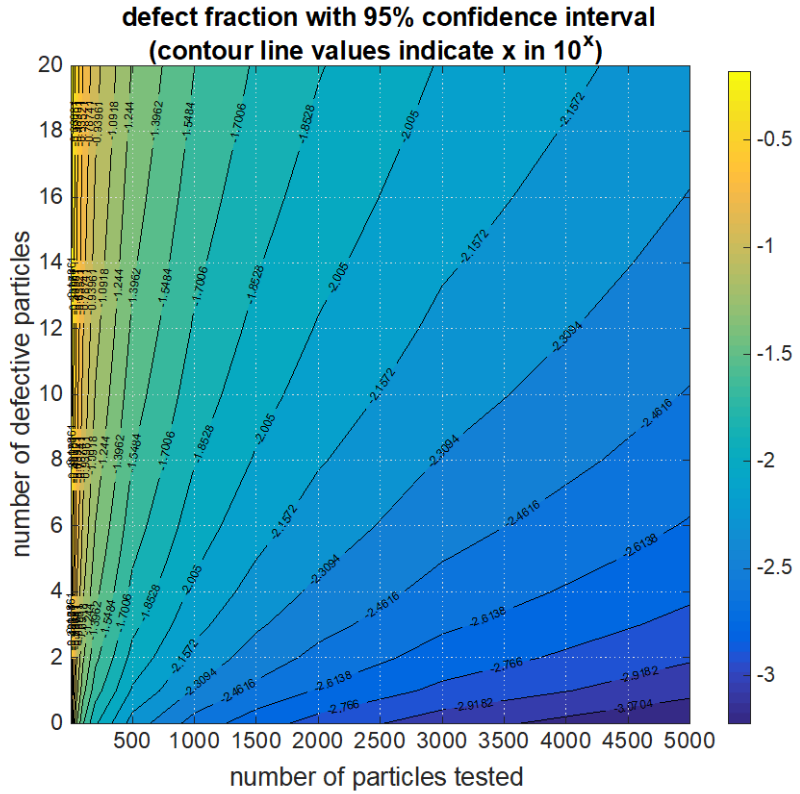

All fission products except H-3, Ag, possible Sr, possible Eu, are retained in SiC

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