Comments on Demo designs and issues

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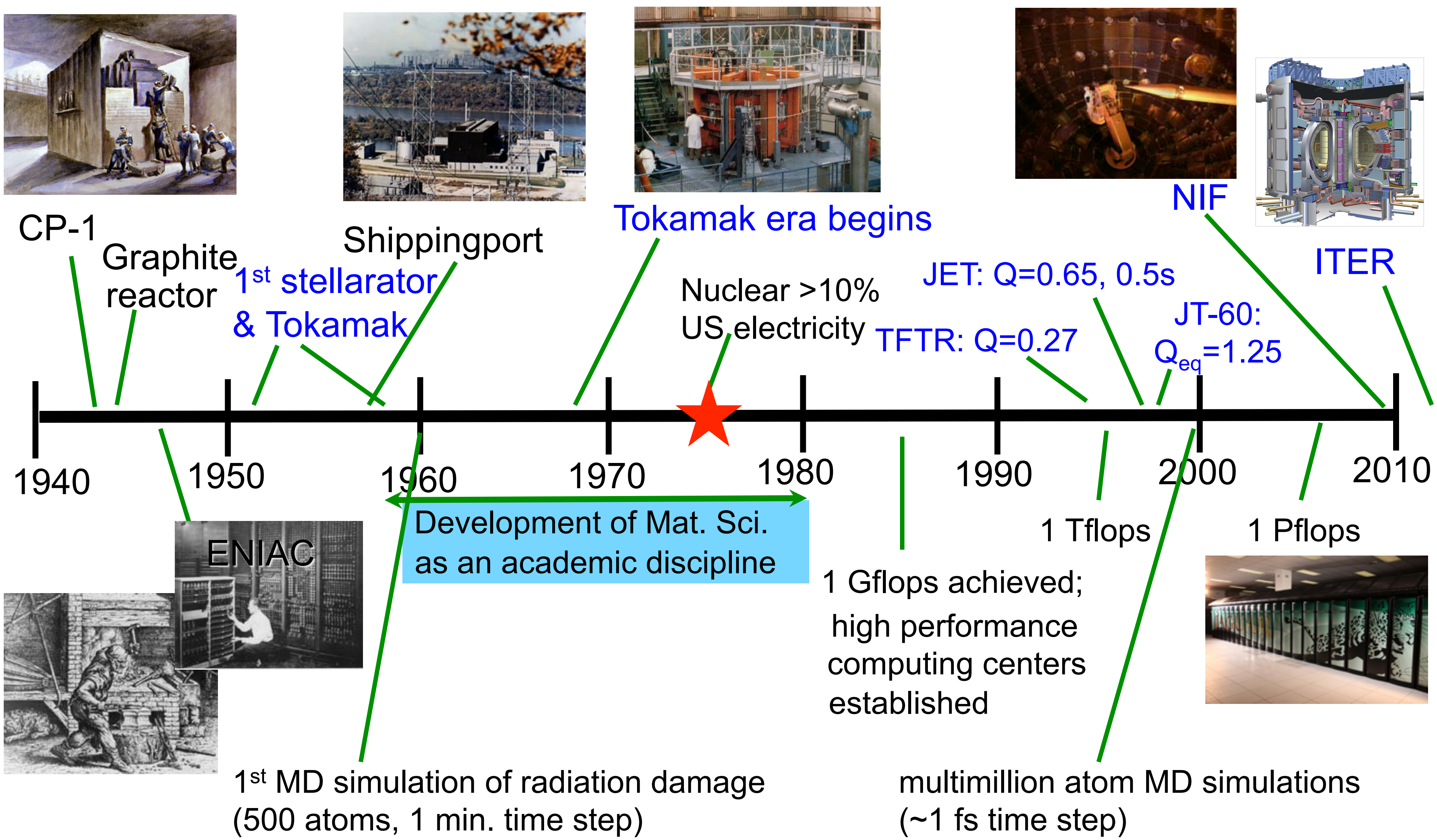
OAK RIDGE National Laboratory

General Comments regarding the Path to Demo

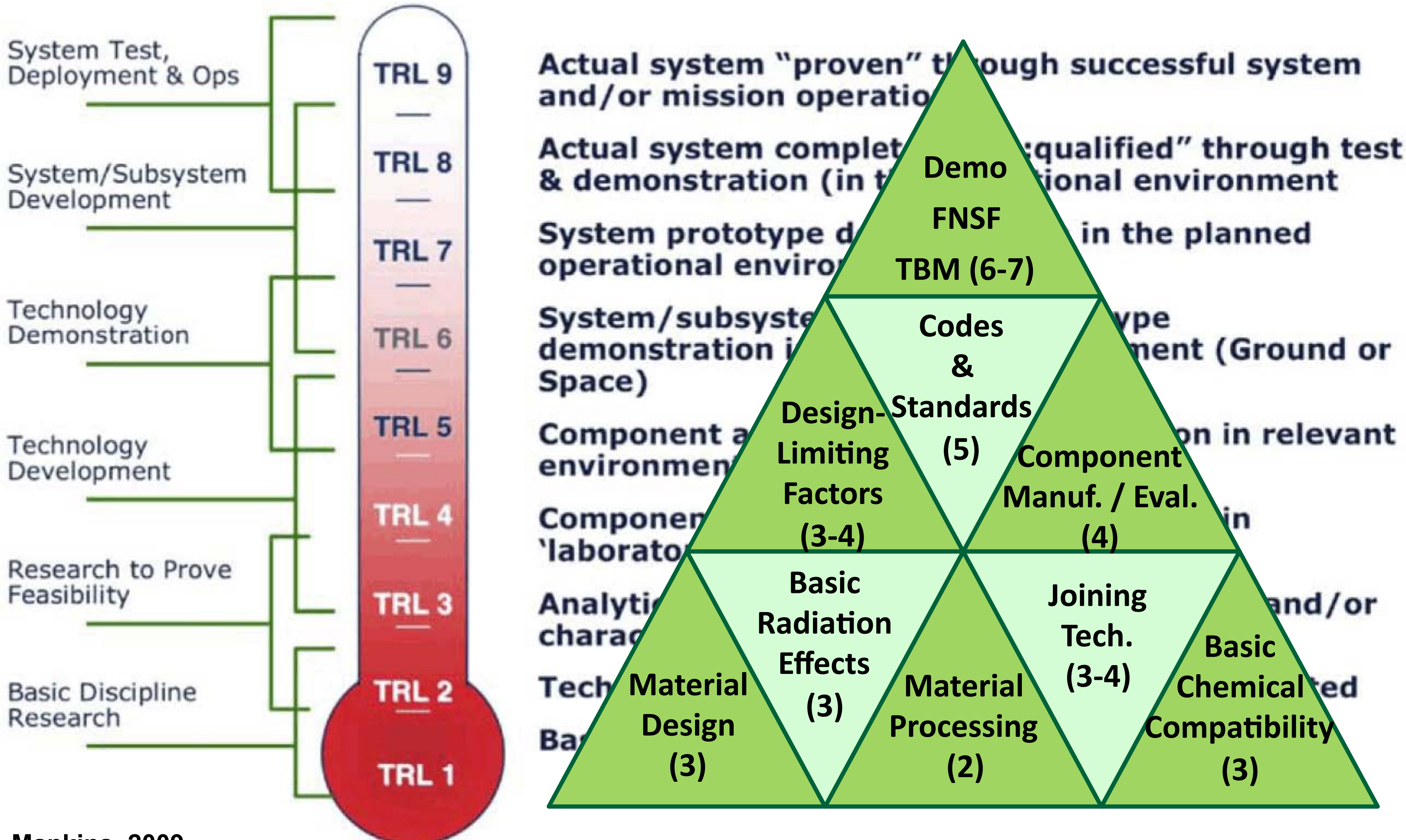
- Don't over-constrain DEMO mission
  - Feasibility vs. attractiveness (cost, ES&H, etc.)
  - A fusion nuclear science facility would be highly valuable for addressing multiple-effects issues (TRL 5-7)
- If burning plasma is not achieved, then fusion nuclear technology research is unnecessary
  - However, based on current timelines (e.g., ITER), critical path items for DEMO are mainly associated with fusion technology issues (PFCs, etc.)
- Near-term R&D should focus on critical-path issues
  - Especially low-TRL (i.e., low-cost) issues

Timeline of some key events for nuclear energy and materials and computational science



S.J. Zinkle, Fusion Sci. & Technol. 64 (2013) 55

Technology Readiness Level: Assessment of Functional Maturity



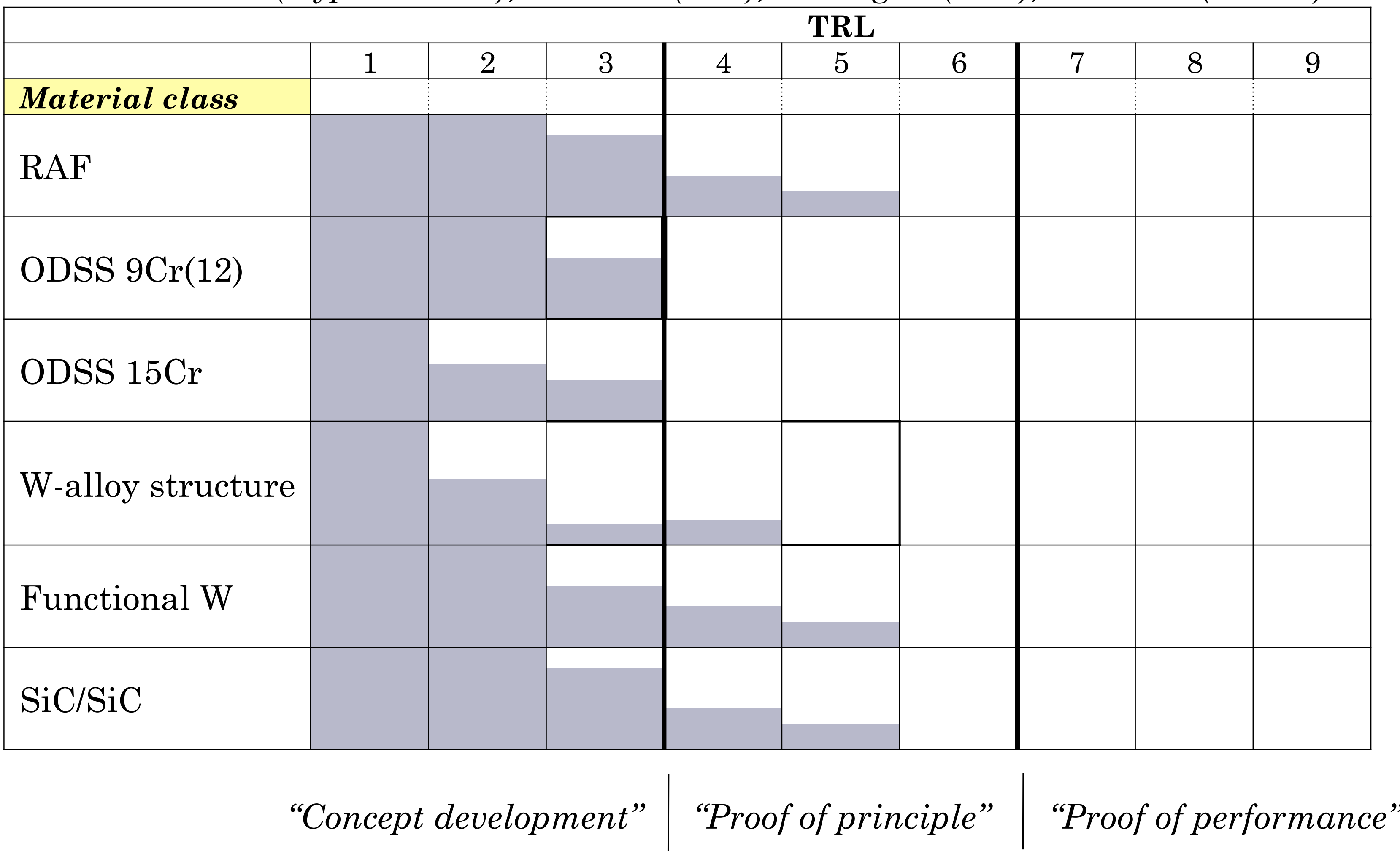
Mankins, 2009

Zinkle, Federici, Kessel, Konishi, Muroga & Snead, ICFRM-16, Beijing, 2013

The Technology Readiness Level of Fusion Materials was Evaluated by Experts at ICFRM-15

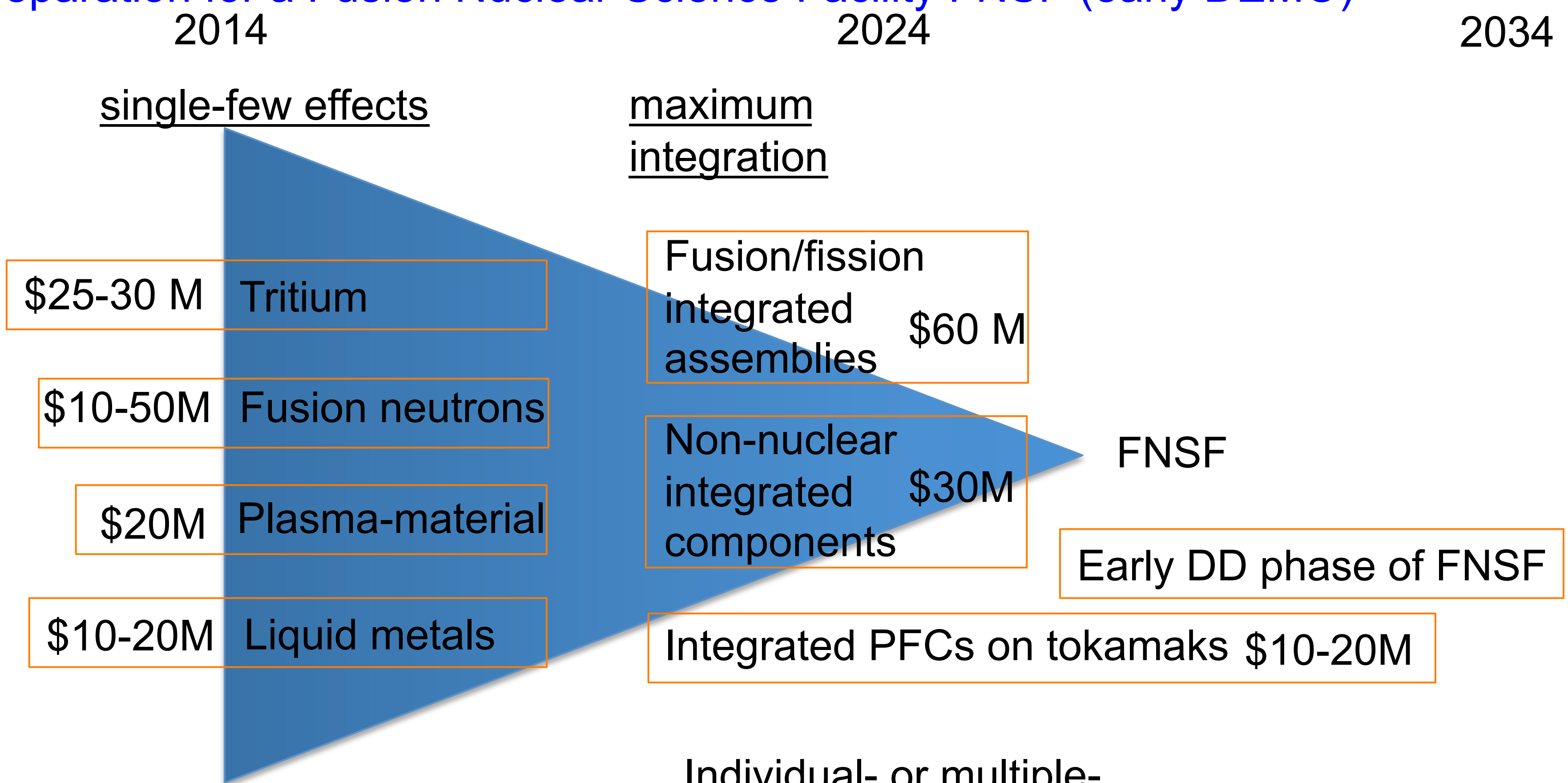
All evaluated materials are at a relatively low TRL~3

H. Tanegawa (JAEA), S. Zinkle (ORNL), A. Kimura (Kyoto U.),
R. Shinavski (Hyper-Therm), M. Rieth (KIT), E. Diegele (F4E), L. Snead (ORNL)



M. Tillack et al., ICFRM-15, Charleston, SC, 2011

A Visual Flow of Materials Research and Facilities to Accomplish that Research in Preparation for a Fusion Nuclear Science Facility FNSF (early DEMO)



Aggregate of smaller materials-focused facilities addressing 4 major areas and costing ~ $65-120 M

Individual- or multiple-effect test facilities addressing blanket, divertor, and special components in non-nuclear or nuclear environments, costing ~$100 M

Zinkle, Federici, Kessel, Konishi, Muroga & Snead, ICFRM-16, Beijing, 2013

Outstanding Challenges

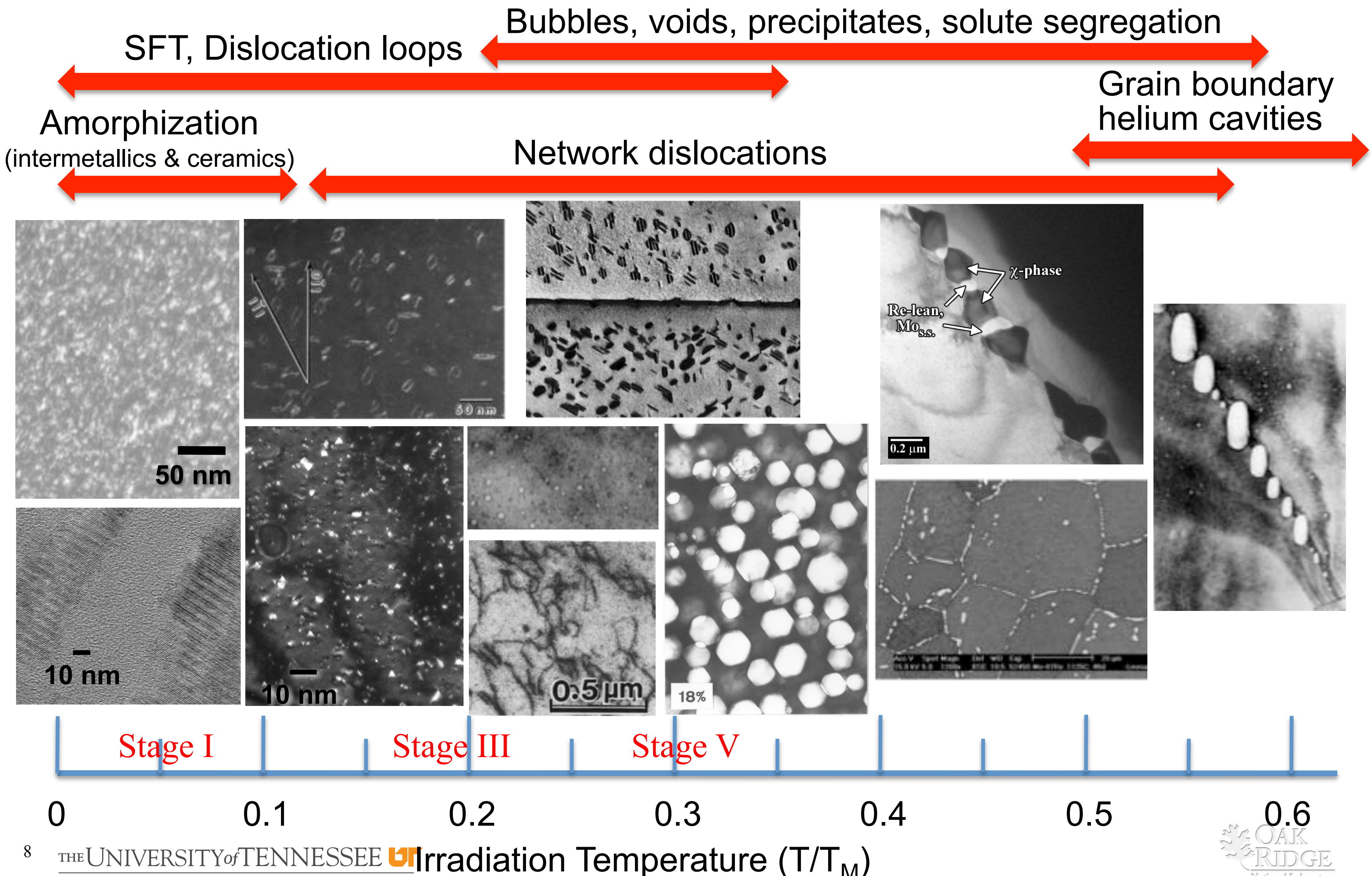
- Still a divergence of opinions on how to bridge the gaps to fusion power plants
- However, there are outstanding issues common to any next major facility after ITER, whether a DEMO, a Pilot Plant or a FNSF/CTF:

Key Design Drivers/ Areas where advances are needed:

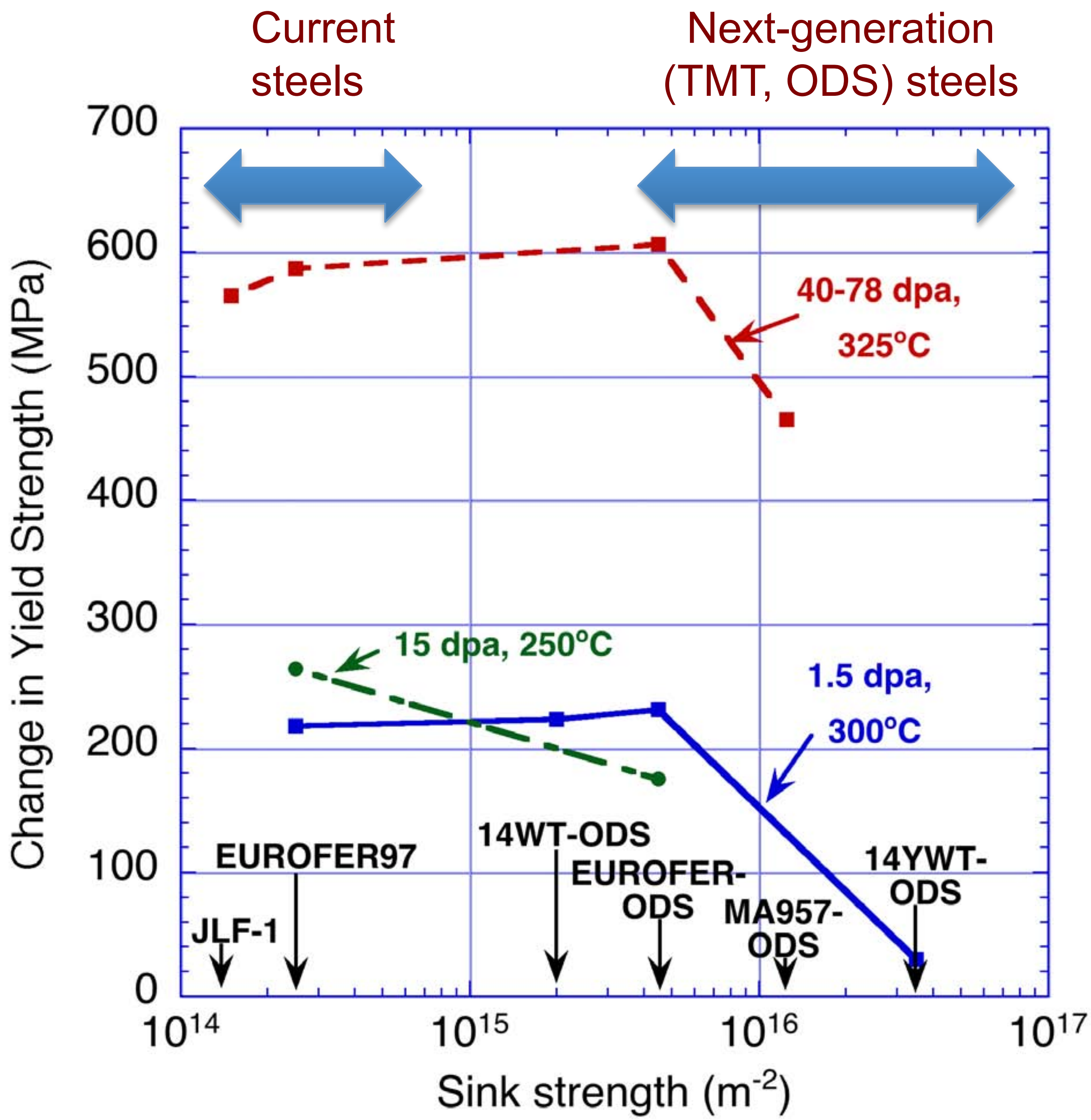
- Handling of heat exhaust (divertor and first wall)
- Tritium breeding + electricity production ⇒ mature Balance of Plant
- Structural and PFC materials
- Maintenance scheme ⇒ plant architecture
- Operating plasma scenario ⇒ CD requirements

Zinkle, Federici, Kessel, Konishi, Muroga & Snead, ICFRM-16, Beijing, 2013

Overview of Defect Microstructures in Irradiated Materials



Effect of initial sink strength on radiation hardening of ferritic/martensitic steels (fission neutrons ~300°C)

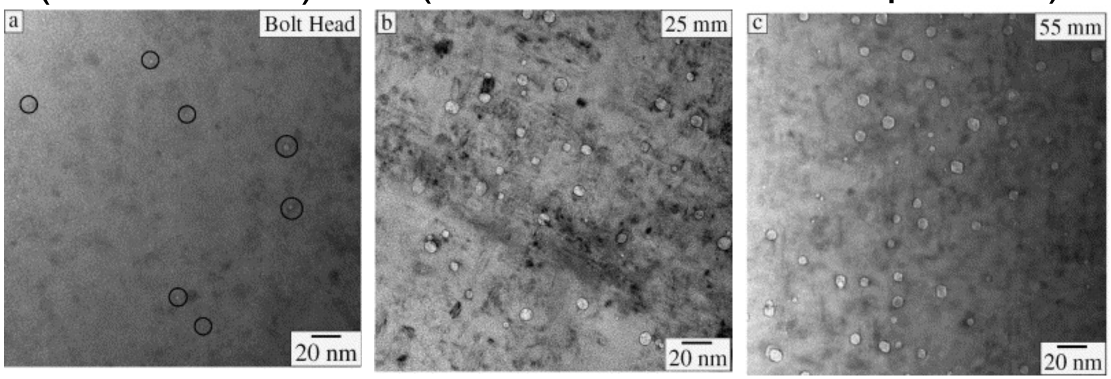


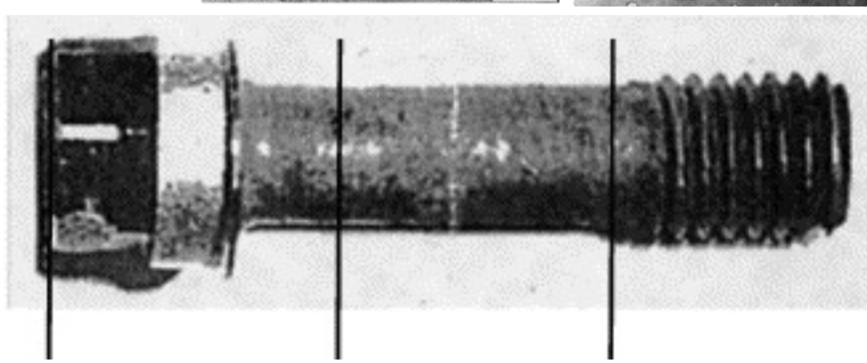
Zinkle, & Snead, Ann Rev. Mater. Res. 44 (2014)

H retention increases dramatically in the presence of cavity formation

3 to 5x increase in retained hydrogen when cavities are present, even with 2-3x reduction in neutron fluence exposure

500-700 appm H (few cavities) | 1700-3700 appm H (rad.-induced cavities present)



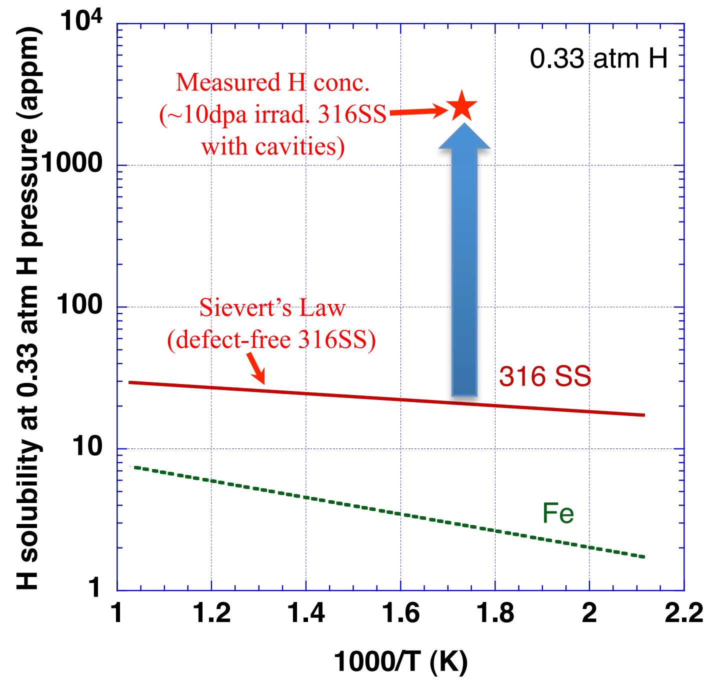


Bolt head
1 mm
320°C, 19.5 dpa

Bolt shank
25 mm
343°C, 12.2 dpa

Near threads
55 mm
333°C, 7.5 dpa

Retained H level is ~100x higher than expected from Sievert's law solubilities



Baffle-former bolt removed from Tihange-1 (Belgium) pressurized water reactor
Type 316 austenitic stainless steel

F.A. Garner et al., J. Nucl. Mater. 356 (2006) 122

Conclusions

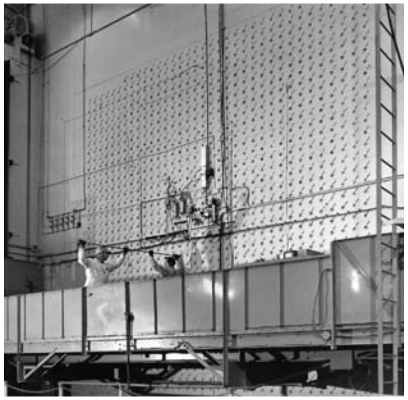
- In order to progress from ITER to DEMO, a dedicated intermediate-step fusion nuclear science facility is anticipated to be important to address integrated-effects phenomena (TRL~5-7).
  - ITER and mid-scale facilities are expected to provide necessary but insufficient fusion nuclear science information to enable high confidence in the optimized design for DEMO
  - **A detailed US fusion energy roadmap (at least at the level of detail as other international roadmaps) needs to be jointly developed by DOE-FES and the research community**
- The specific objectives and concept for FNSF need to be established
  - Key questions to address include whether FNSF needs to be a prototypic design for DEMO (versus a non-prototypic magnetic configuration simply used for component testing)
- The time to initiate community discussions on FNSF is now

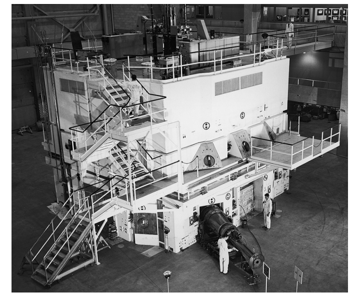
The development of fission energy faced numerous technological barriers (e.g., Zr alloy cladding)

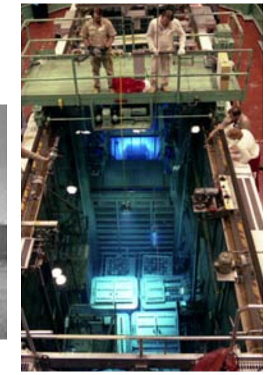
- **1950: US annual production of Zr was ~200 lbs (~10^6 lbs/yr needed by late 1950s); $240/lb cost was ~30x higher than economical limit**
- **"At the time of this decision there was no assured source of Zr, no estimate of how much would be needed, no certainty that any known or conceivable process could produce the required amount, and no specifications for the nuclear, mechanical, or corrosion qualities the metal had to possess." (Nautilus launched Jan. 17, 1955 using Zry2 cladding that was first specified in Aug. 1952)**

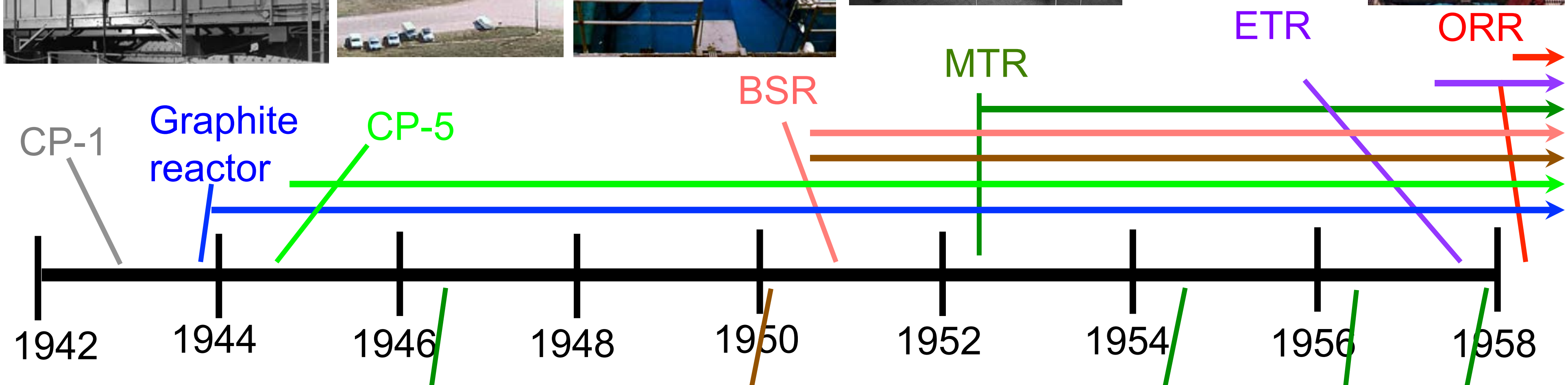
H.G. Rickover, History of the development of Zr alloys for use in nuclear reactors, NR:D:1975

Detailed timeline of some key facilities for nuclear energy and materials

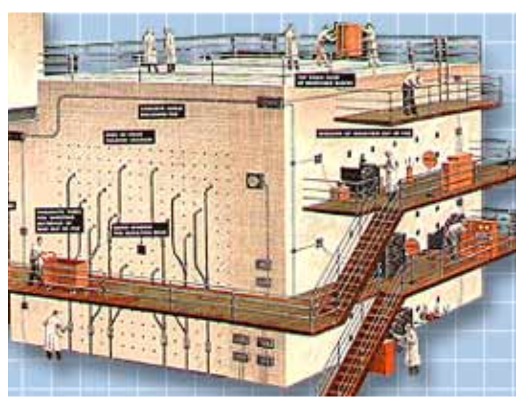


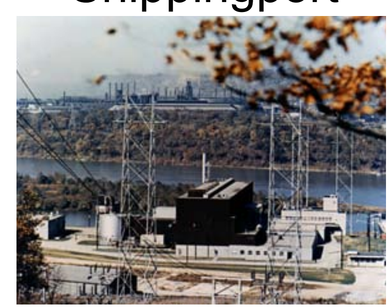







1st radiation damage paper
E.P. Wigner
J. Appl. Phys. 17 (1946) 857





Several materials-tritium issues require additional investigation

- Identification of a robust, efficient and economic method for extraction of tritium from high temperature coolants
  - Large number of potential tritium blanket systems is both advantageous and a hindrance
- Current materials science strategies to develop radiation-resistant materials may (or may not) lead to dramatically enhanced tritium retention in the fusion blanket
  - Fission power reactors (typical annual T_2 discharges of 100-800 Ci/GW_e; ~10% of production) are drawing increasing scrutiny
  - A 1 GW_e fusion plant will produce ~10^9 Ci/yr; typical assumed releases are ~0.3 to 1×10^5Ci/yr (<0.01% of production)
  - Nanoscale cavity formation may lead to significant trapping of hydrogen isotopes in the blanket structure
  - Tritium trapping efficacy of precipitates and nanoscale solute clusters (blanket & piping) is poorly understood from a fundamental perspective

Comments on fission vs. fusion energy development

- **Fission Q=1 was much easier to experimentally achieve**
  - Hence, numerous Demo fission reactors could be quickly built in the 1950s to explore multiple-effect physics and engineering issues
- **Global political environment in 1950s and 1960s was favorable for fission energy research (national security impact)**
  - Lack of long-term (and well-funded) energy strategies in many countries is an impediment to progress
- **Much more aggressive approach to rapidly obtaining results at all costs in 1950s & 1960s (different ES&H attitudes)**
- **There was a dynamic, (over?)aggressive champion for US fission energy R&D during its formative years**

- **Is fusion sometimes caught up in the pursuit of the optimal answer, when an inelegant placeholder solution might suffice?**