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# *Towards establishing fusion's credibility*

*Presented by*


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*To the Committee on the Prospects for Inertial Confinement Fusion Energy Systems*
*The National Academies*

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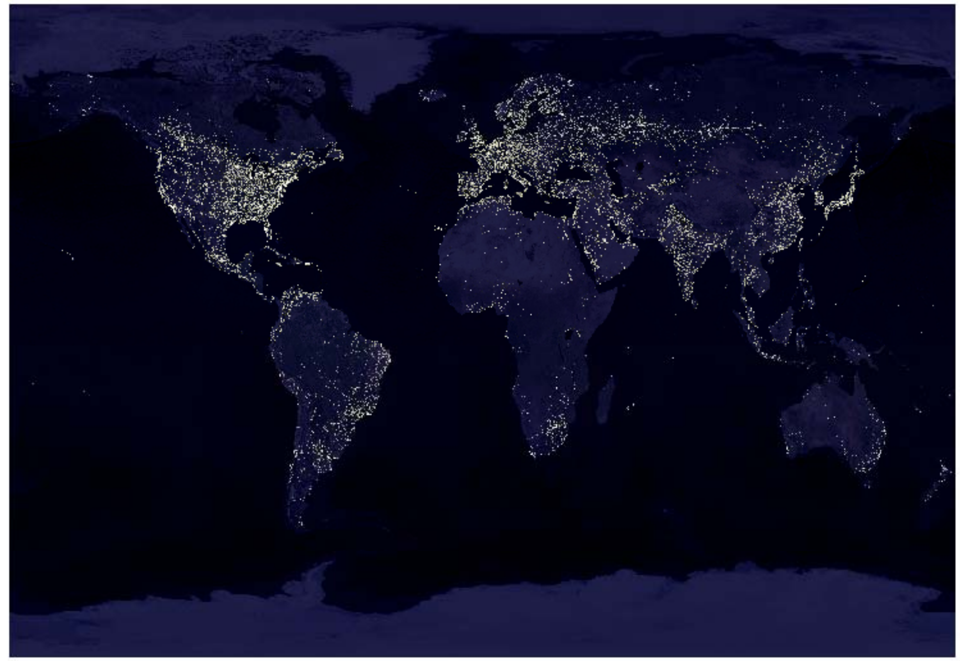
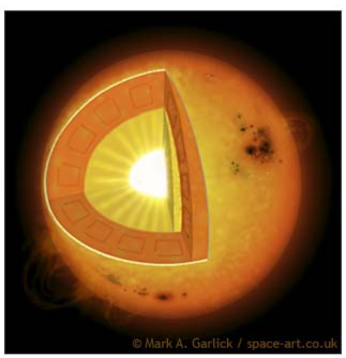
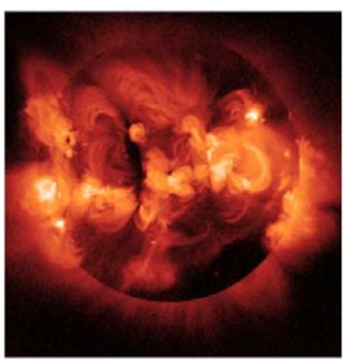
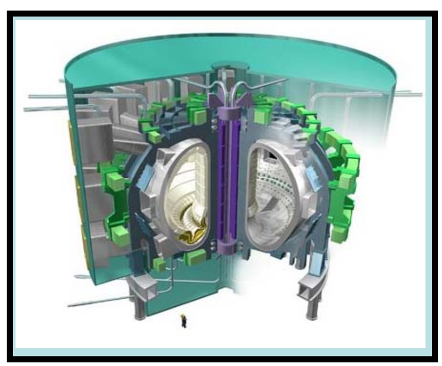
# We need to have a shared sense of opportunity and urgency

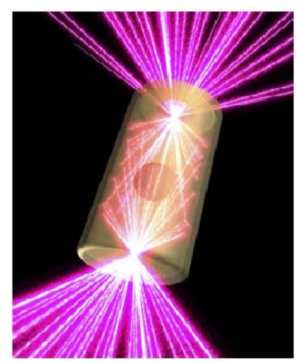
- In the coming decade, the fusion energy sciences must undergo a transformation in how we conduct our research to match the urgency and scientific opportunities of the times









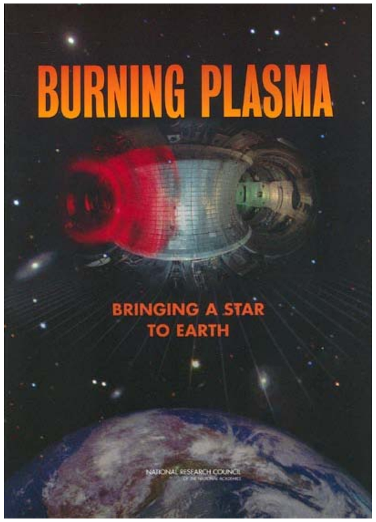
# Transformations are required in order to successfully advance fusion

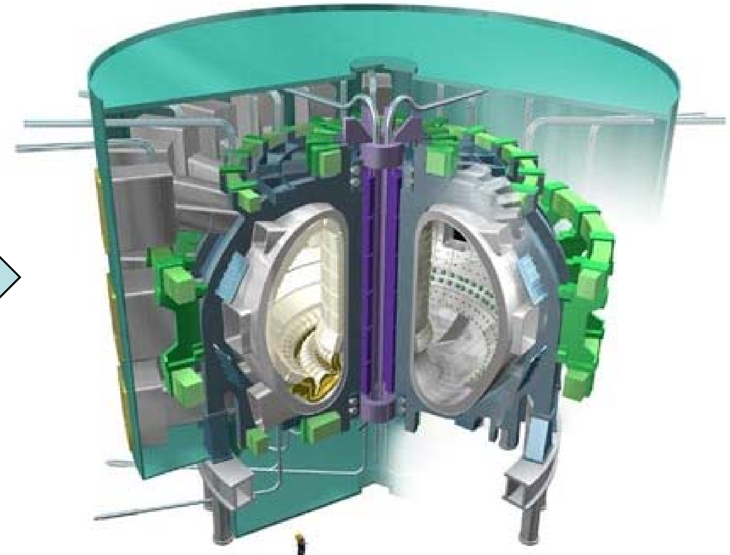
- **Credibility** is the key issue for fusion. For IFE, NIF ignition will be a critical part of establishing this, but the challenge is deeper. Both the science and technology need to be advanced in concert for IFE to establish needed credibility

- Fusion can help itself by recognizing and **levering common interests between** MFE, IFE, **and advanced fission**. This will be of value scientifically and for program stability and growth.

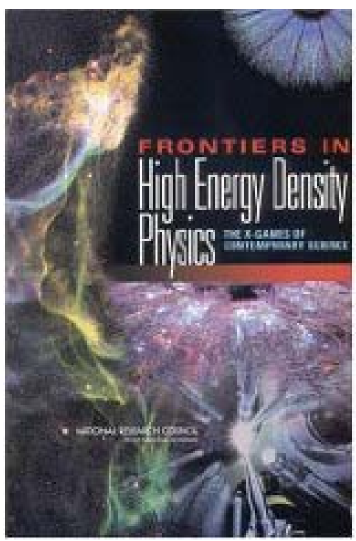
# National Academies assessments have lent much needed credibility to our endeavor

**Urgency and readiness of a burning plasma step in MFE**



**HEDLP**




**+**

**National Academies Study on ICF for Energy**

**Starting…**

**?**

# In this talk…

*Some background*

*High level scientific needs for fusion*

*Plasma dynamics and control needs for IFE*

*Materials science needs for IFE*

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# In this talk…

*Some background*

*High level scientific needs for fusion*

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# A slice of my professional background that informs my views…

- 1988 – 2005: PPPL. Experimentalist, strong engagement with theory in energy and particle transport. Moved into program management on TFTR and became the Director of Research on NSTX. Collaboration on other national MFE facilities

- January 2006 – June 2009: Leader of Office of Science's Fusion Energy Program at LLNL. Engagement with both MFE and IFE.
  - Saw much untapped potential regarding SC/NNSA engagement
  - Position included management responsibilities with Heavy Ion Fusion Sciences Virtual National Laboratory (an SC program, with LBNL, PPPL).
  - Through negotiation with FES, I redirected an MFE program at LLNL to IFE-related HEDLP, yielding the creation of new multi-institutional fast ignition program. Emphasis on establishing validated predictive capability, with NIF research and deployment a leading goal.

- June 2009 – present: Associate Director for the Office of Science, leading the Fusion Energy Sciences program: Presently $380M/year, about $30M in HEDLP, both IFE-related and also for scientific discovery

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# In this talk…

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*High level scientific needs for fusion*

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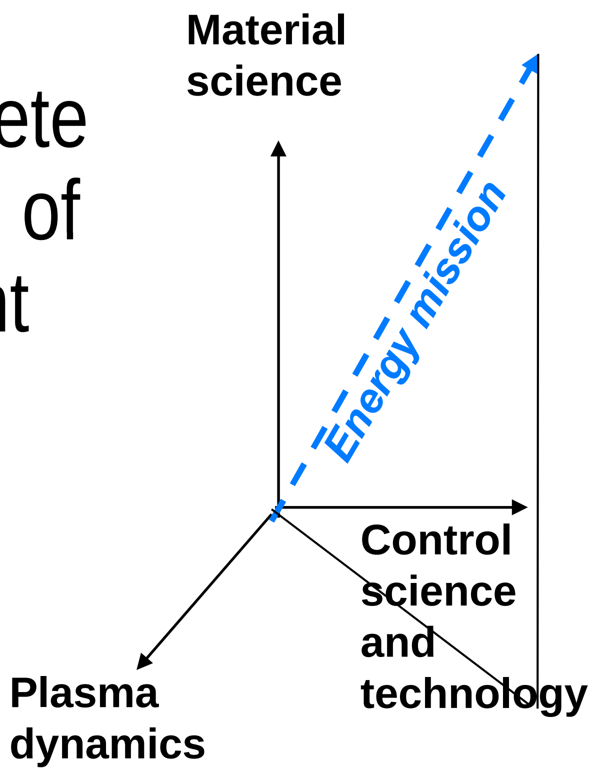
# Much of the science we need to develop can be represented in a fairly simple space

There are many “frames of reference” we could choose, but this seems fairly complete

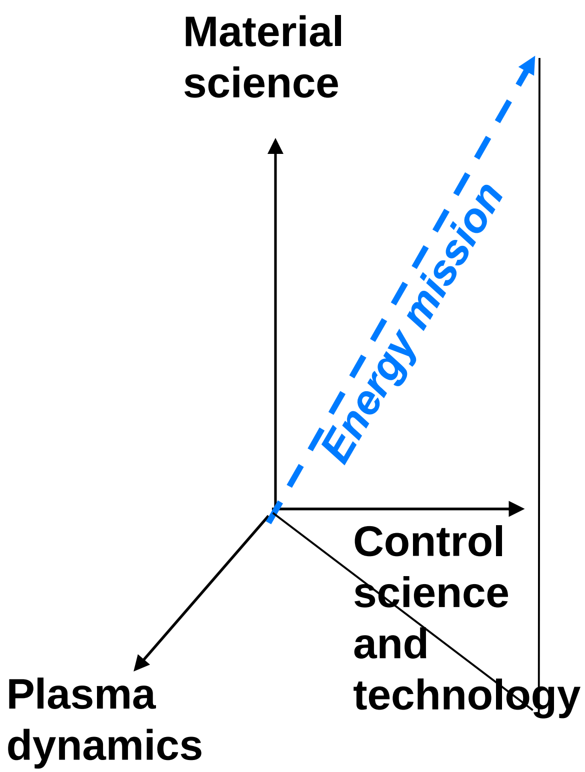
Credibility for fusion ➔ forming a complete enough basis set to enable a description of the requirements for energy development and the accompanying risks



# IFE target requirements intimately link plasma physics and the driver

*For IFE: target configuration, ignition scenario, and driver development are all in the plasma /control science plane. The target configuration, its physics upon fuel assembly, and the driver development are coupled.*

*FES's present program is engaged in the plasma/control plane through a joint HEDLP program with NNSA*



# Two broad areas are key to both MFE and IFE

*In both IFE and MFE,*

- ***Plasma dynamics and control science** will determine requirements of all major systems that generate the required plasma state for creating fusion energy. The robustness of our scenarios will determine the requirements and attractiveness of the systems that will generate the desired plasma state. The integrated nature of each plasma system demands a similar set of intellectual tools be brought to bear on both IFE and MFE. We presently do not take advantage of this common element well.*

- ***Materials science** questions will determine the attractiveness of operating and maintenance scenarios, and the attractiveness and viability of closing the fuel cycle and extracting fusion power. The details of the questions for both IFE and MFE range from similar to identical. It will be to fusion's great advantage for IFE and MFE to work together with a common purpose in this arena.*

# In this talk…

*Some background*

*High level scientific needs for fusion*

## *Plasma dynamics and control needs for IFE*

- *Plasma physics and connections to drivers*
- *Scientific questions and how they can determine metrics. Common elements with MFE*

*Materials science needs for IFE*

# The high confidence we will need in answering key plasma/control science questions will govern our choice of metrics

- A sample overarching question that might drive research approaches is: "*How robust is the operating space of any potentially attractive ignition scenario?*"

Related sub-questions might include:

- *For a given driver, how does the reproducibility of initial target conditions affect mix and fusion gain?*
- *With a hohlraum, can acceptable laser-plasma interactions be obtained with economical target materials?*
- *Do we have high enough confidence in our codes to justify advanced ignition scenarios that may allow significant relaxation of symmetry requirements of ion or laser drivers?*

*For NAS: In developing any future IFE program, it will be of high value to FES to understand your views on the value of this class of question*

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# The high confidence we will need in answering key plasma/control science questions will govern our choice of metrics (2)

- Another example of an overarching question that we would do well to answer soon: "What is our confidence level in transferring NIF indirect drive results to other driver types?"
  - For example, the transferability of indirect drive NIF ignition results to, say, indirect drive heavy ion fusion, will have a big impact on the steps required and the attractiveness of pursuing HIF. What scientific standard (metric) has to be demonstrated to allow this?

*For NAS: Your assessment of the question regarding the transferability of NIF science to non-laser-based approaches will be of high value, as it will impact roadmaps for such approaches*

# FES is concerned about what has been unbalanced investment between potentially viable drivers

- To mitigate risks, it makes sense to invest in a lead technology and at least one leading alternative
- However, there have been significant differences in investment levels between technologies
- As an example, the FES heavy ion fusion science program has made great progress on limited funds, but a different level of investment and activity is needed to responsibly assess the potential of heavy ion drivers. The same can be said of pulsed power for IFE applications.

*For NAS: What metrics do alternative drivers have to meet in order to proceed (or not) to the next development level?*

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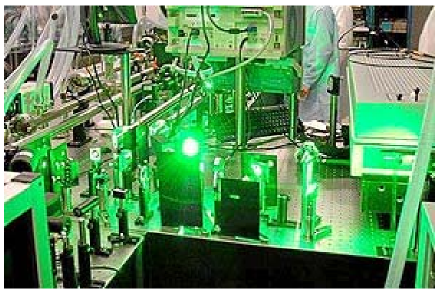
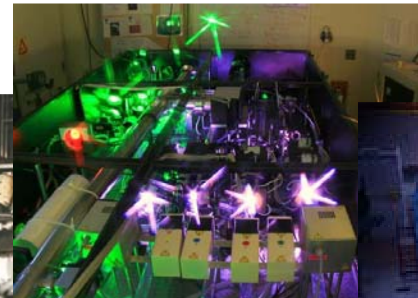
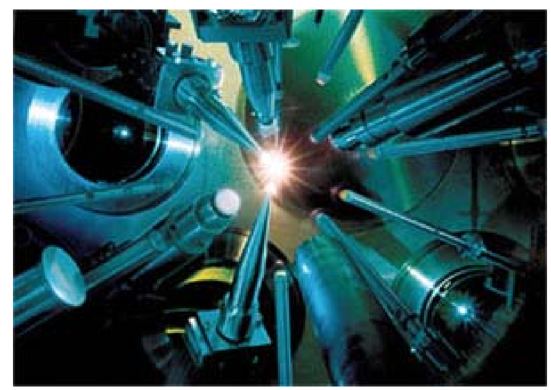
# Posit: The range of facilities NNSA facilities is impressive and that range can form the basis of scientifically smart national research efforts

*e.g. Petawatt lasers at Texas, LLNL, Michigan, Rochester…*





*Omega-EP (Rochester) Users Group*



***For NAS:** Your views on this claim might help us develop national approaches to addressing critical problems where big labs and universities alike can engage*

***➔ Can these resources provide scientific leverage and program stability?***

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# The multiscale character of IFE plasma physics challenges demand validated predictive capability take a step up

- Personal impression: the relationship between codes and measurement in IFE vs. MFE is quite different. Different nature of the physics problems? Differences in measurement accessibility? Culture? I suspect all three play a role

- Taking a qualitative step up in validated predictive capability is part of a redirection being executed for MFE.
  - Motivation: add credibility, reduce technical risks for development
  - NNSA's success in integrated, multiscale simulation in ICF serves as a model on which to draw for MFE.

- IFE's challenges seem to rival MFE's in their multiscale character and complexity.

***For NAS:*** ***What standards or metrics should a validated predictive capability achieve in order to serve as a credible tool that can substantially reduce development risks? What can be the role of the entire range of available facilities in developing this capability?***

## Summary of these examples: NAS comment on the science questions particular to the target physics and its relation to the driver choice will be of high value

- Robustness of the ignition event will be a factor in determining the extrapolability of any ignition result and to the attractiveness of the driver.
  - *Your comments on this and proposed metrics will be helpful in framing and justifying future solicitations*

- Taking a step up in predictive capability is essential to establishing development paths with acceptable risks.
  - *Your views on how IFE and MFE, as NNSA and SC enterprises, can best engage to take validated predictive capability to the next level of credibility in developing advanced ignition scenarios and making driver choices will be valuable.*

- The range of facility capabilities (e.g. for lasers, university petawatt to OMEGA to NIF) provides a resource for addressing critical problems.
  - *Your views on this claim would help us develop national approaches to addressing critical problems where big labs and universities alike can engage → provide scientific leverage and program stability*

# In this talk…

*Some background*

*High level scientific needs for fusion*

*Plasma dynamics and control needs for IFE*

## *Materials science needs for IFE*

- *Common elements with MFE*
- *Scientific questions and how they can determine metrics*

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# IFE and MFE share many issues and interests related to materials

**many common interests**

- **Materials performance** - response to fusion environment
- **Breeding blankets, Neutron multipliers**
- **Tritium concerns**
  *recovery, processing, accountability, minimizing inventory*
- **Integration & high-temperature operation**
- **Corrosion - liquid metals & molten salts**
- **Erosion & dust**
- **Advanced neutronics tools**
- **Design modeling & tools**
- **Maintenance**
  *ease, rapid replacement/repair, robotics*
- **Rad-hard diagnostics/instrumentation**

**some aspects unique for IFE**

- **Geometry not constrained by burn physics**
- **More flexibility for FW threats**
- **No MHD effects (most blanket types)**
- **High DT burn fraction, reduced D/T throughput**
- **Thick liquid FW designs preferred**
- **Easier maintenance - chamber & driver separated**

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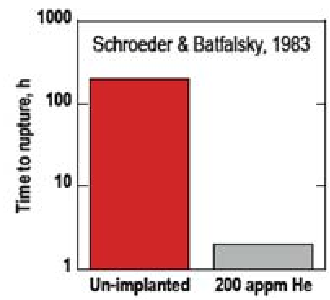
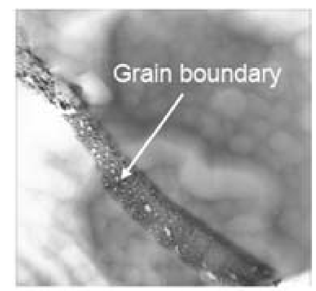
# The effects of neutron irradiation are not subtle, and some aspects are unique for fusion

- Material swelling of steels, for example is impressive and disturbing


- While there is overlap and we can learn much from fission, helium as a transmutant product distinguishes fusion and drives the need for testing on a fusion neutron source

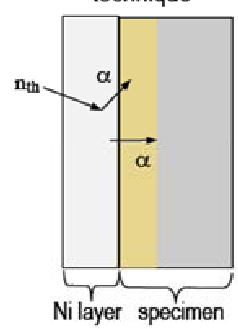
| Damage Phenomenon | Temperature Range, $\%T_M$ | Dose Level, dpa | Fusion | Fission |
|---|---|---|---|---|
| Hardening & Embrittlement | <0.4 | ≥0.1 | Y (+He) | Y |
| Phase Instabilities | 0.3 - 0.6 | >1 | Y (+He) | Y |
| Irradiation Creep | <0.45 | >10 | Y | Y |
| Volumetric Swelling | 0.3 – 0.6 | >10 | Y (+He) | Y |
| He Embrittlement | ≥0.4 | >10 | Y | N |



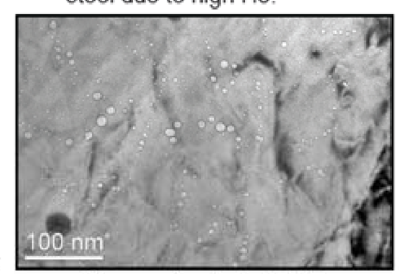




- Need to develop science so that material choices can be narrowed down. Go beyond “cook and look”

*In situ* He injector micro-IFMIF technique



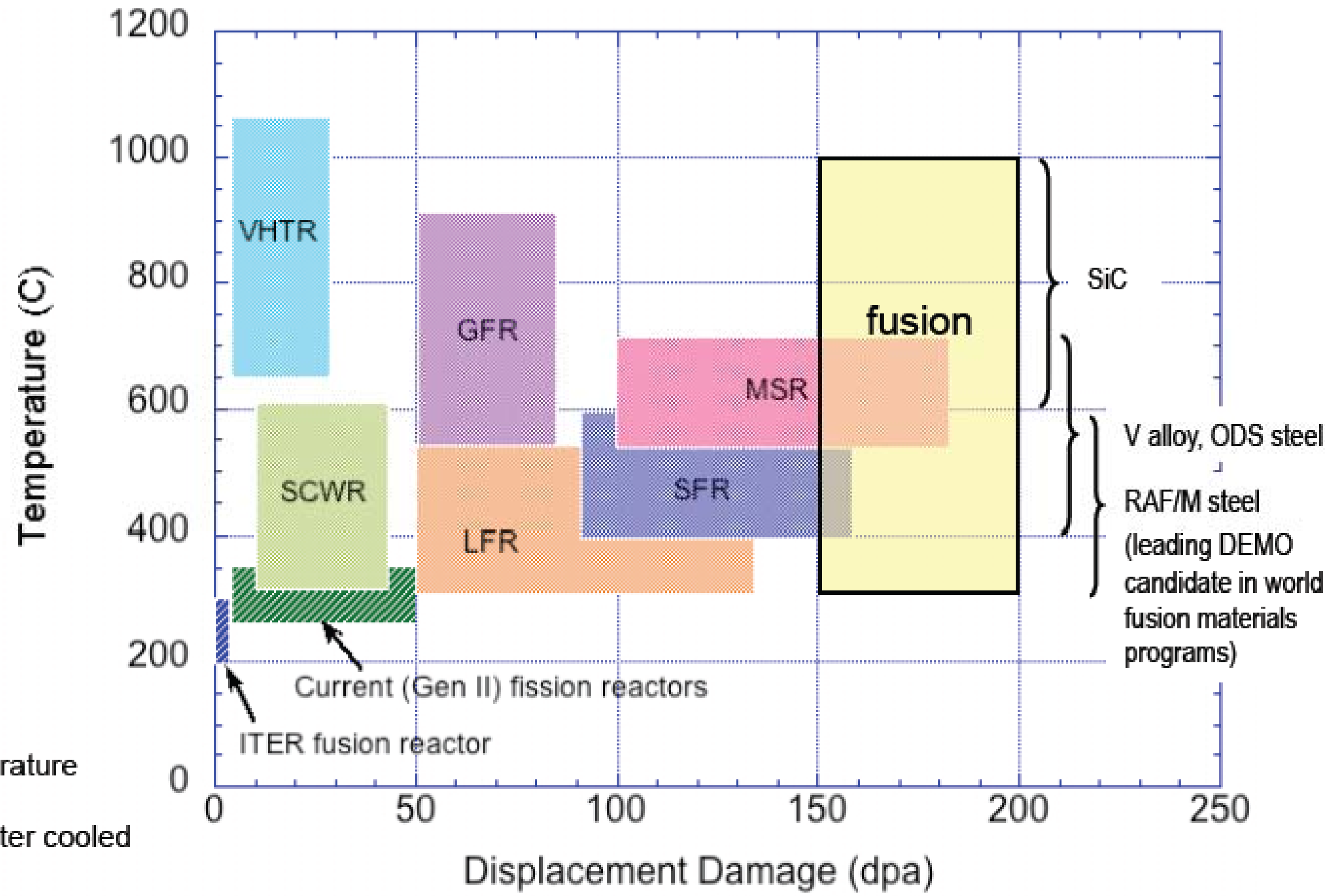

Voids & bubbles in RAF/M steel due to high He.




Yamamoto, et al., 2009

# The demands on materials for fusion are tremendous and overlap or exceed those of Gen IV fission in terms of dpa's

S.J. Zinkle, 2007




VHTR: Very High temperature reactor
SCWR: Super-critical water cooled reactor
GFR: Gas cooled fast reactor
LFR: Lead cooled fast reactor
SFR: Sodium cooled fast reactor
MSR: Molten salt cooled reactor

*A common theme for fusion and advanced fission is the need to develop high-temperature, radiation resistant materials.*

# FES has launched a Fusion Nuclear Science Pathways Activity

- Identify research and development activities in a series of topical areas representing fusion nuclear science
  - Materials science and technology
  - Plasma facing components and plasma material interface
  - Power extraction and tritium sustainability
  - FNSF/DEMO detail design studies
  - Enabling technologies
  - Plasma duration and sustainment
  - Reliability, maintainability, availability, and inspectability
  - Safety and environment
- Motivate these R&D activities by rolling back from DEMO definitions, and from rolling forward from scientific needs studies
- Establish what is to be done, why it must be done, how it will be done and when it needs to be done

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# Your views on the benefit to IFE of a vigorous materials science program will be of value

- FES view: this is an opportunity/necessity for both IFE and MFE. Getting it right is key to credibility

- Let the IFE and MFE competition ebb for a minute, and consider a "black box" that produces copious 14 MeV neutrons for materials and component testing. There would be myriad customers for such a facility, regardless of whether the source of neutrons is a toroidally confined or an HED plasma: IFE, MFE, NNSA…

***For NAS**: Your assessment of the state of materials science for fusion and the standards that must be met will be of high value. Commentary on the potential role of computational searches for advanced materials will be welcome. Your assessment of the potential of leverage with advanced fission research will also be of value*

# Establishing fusion's credibility is the overarching task

- **Credibility**: Both IFE and MFE need a qualitative sharpening of science and technology metrics for success so as to become credible, viable options for energy development. Both can benefit from like needs and approaches.

- **Science ⇔ technology**: A future IFE program needs to be deeply scientific as well as technologically aggressive. Technological development (e.g. in drivers or advanced ignition scenarios, for example) will require a strong scientific basis to create attractive innovation pathways.

- Critical elements that require progress are linked and are found in plasma science, control science and technology, and materials science.

# *Thank you*