Assessment of User Needs for Irradiation Testing

Presentation to the Nuclear Energy Advisory Committee

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Charge from NE-1 (July 29, 2016)

"… form a team" … "to assess the need and determine the requirements for an irradiation test reactor which would augment existing domestic capabilities to support the development and deployment of advanced non-light water reactors as well as to accommodate the future needs of light water reactor technologies."

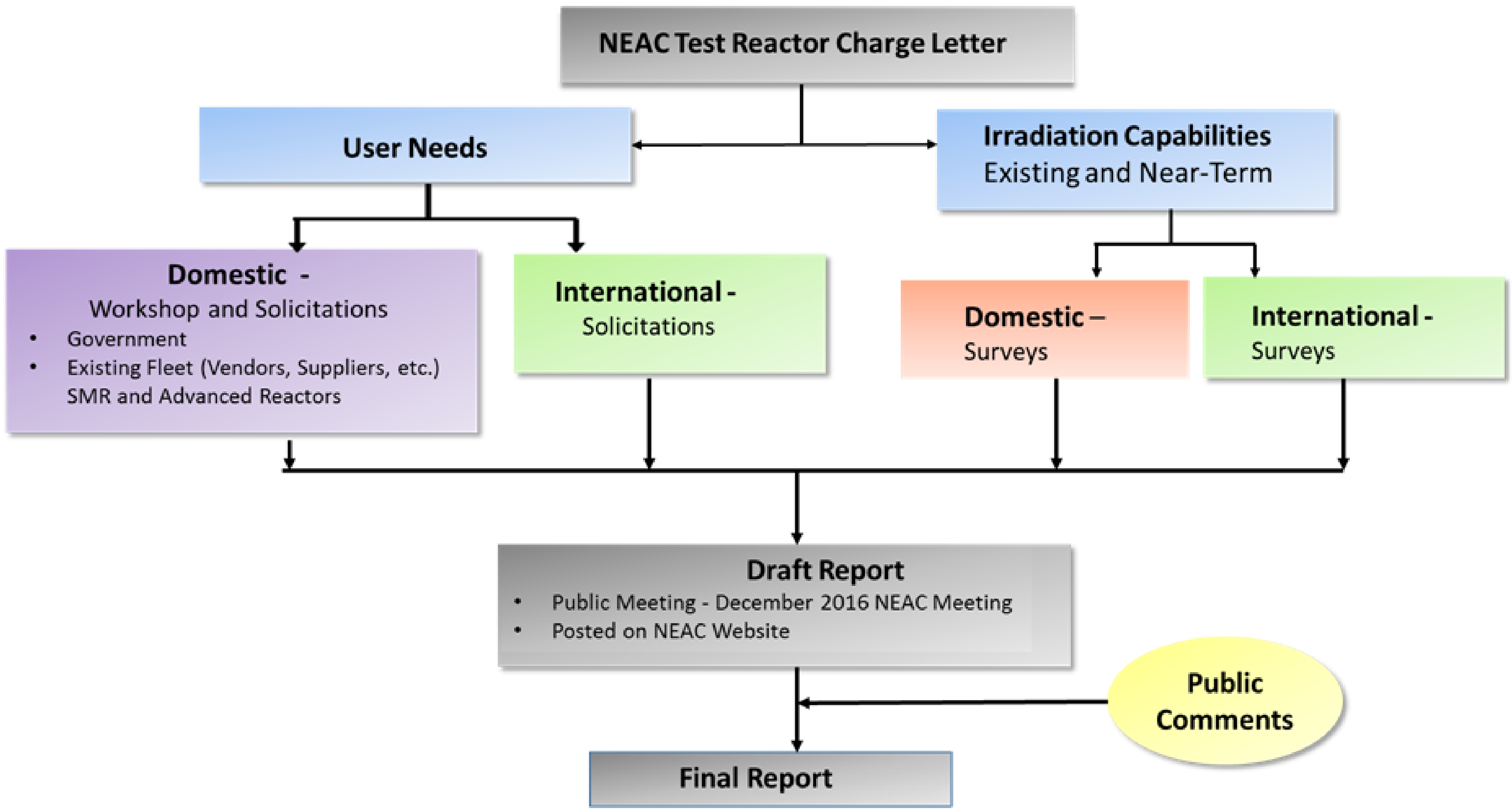
" … independently determine the requirements and overall capabilities (e.g., neutron spectrum/spectra, testing environments, etc.) for a new irradiation test reactor and compare these requirements with alternate existing facilities, methodologies, and approaches for meeting these needs…"

"The requirements review team should consider the needs of the entire community…as well as the time frame, if needed, that an irradiation test reactor capability would be required."

Motivation

- Nuclear power is an important carbon-free power source.
- Starting in 2030, a significant number of operating US nuclear reactors will reach 60 years of age.
- Some operating reactors will not seek subsequent license renewal.
- DOE-NE draft vision and strategy indicates that replacement nuclear power options will include a combination of advanced LWRs, SMRs, and advanced reactor technologies employing non-LWR coolants. Some non-LWRs will employ fast spectrum reactors.
- Deployment of new fuels and materials for advanced reactor technologies and evolutionary fuels and materials for existing LWR technologies requires irradiation data to demonstrate their performance.
- US materials and test reactors are aging (typically over 50 years old).

Approach


NEAC Test Reactor Charge Letter
User Needs
Irradiation Capabilities
Existing and Near-Term
Domestic -
Workshop and Solicitations
• Government
• Existing Fleet (Vendors, Suppliers, etc.)
SMR and Advanced Reactors
International -
Solicitations
Domestic –
Surveys
International -
Surveys
Draft Report
• Public Meeting - December 2016 NEAC Meeting
• Posted on NEAC Website
Public
Comments
Final Report

US Irradiation Facility Assessment

- NEAC Facilities Subcommittee relied on several publicly-available assessments (OECD, IAEA, DOE, EPRI, INL, NAS) and prior Subcommittee assessments.
- Concurred with evaluation priorities/considerations listed in "Facilities for the Future of Nuclear Energy Research: A Twenty-year Outlook" DOE-NE, 2009:
  - Focus on core set of materials test reactors, hot cells, and specialized facilities needed to support nuclear energy R&D for 20 years
  - Evaluate DOE's existing research facilities against needed capabilities, considering functionality, capacity and demand, operating status, adequacy of supporting infrastructure, and economy achieved through co-location with other needed facilities
  - Use same criteria to assess university, industry, and international facilities
  - Consider facilities in standby when no suitable operating facilities exist
  - Building new facilities to satisfy capability requirements will be considered if no other reasonable alternative exists in the U.S. or internationally, and will be necessarily justified and funded by the sponsoring program
  - New facilities may best be located at remote sites, where existing infrastructure can support new capabilities
  - Facilities need not be co-located with research expertise, provided experts have access to the facilities".

Key US Irradiation Facilities and Capabilities

	ATR	HFIR	MIT-II	MURR	NBSR
Owner	US DOE/INL	US DOE/ORNL	MIT	Univ. of Mo.	US Dept. of Commerce/NIST
Power, MW_{th}	250	85	6	10	20
Maximum Thermal Flux, n/cm^2-s	1.0 E+15	3.0 E+15	7.0 E+13	6.0 E+14	4.0 E+14
Maximum Fast Flux, n/cm^2-s[1]	5.0 E+14	1.0 E+15	1.7 E+14	1.0 E+14	2.0 E+14
Initial Criticality	1967	1965	1958 MIT-I; 1975-MIT-II	1966	1967
Irradiation capabilities	6 loops 1 rabbit 47 in-core positions 60 reflector/pool positions 0 beam ports	0 loops 3 rabbits 37 in-core positions 42 reflector positions 4 beam ports	1 loop 2 rabbits 3 in-core positions 9 reflector positions 9 beam ports 2 rabbits 9 beam ports	0 loops 2 rabbits 3 in-core positions 15 reflector /pool positions 6 beam ports	0 loops 10 in-core positions 7 reflector/pool positions 5 rabbits 18 beam ports
Largest fast flux test position (fast flux) (thermal flux)	2x 13.7 cm dia. /122 cm height (5.0 E+14) (1.0 E+15)	8x 4.6 cm dia./ 61.0 cm height (5.3 E+14) (9.7 E+14)	2.5 cm dia./ 55.9cm height (1.2 E+14) (3.6 E+13)	13.6 cm dia./ 61.0 cm height (6.0 E+13) (6.0 E+14)	4x 6.4 cm dia./ 74.7cm height (3.0E+14 est.) (3.0E+14 est.)
Test Conditions[2]	PWR[3], GCR, static capsules	GCR, static capsules	PWR, BWR,GCR, static capsules	Static capsules only	Static capsules only

[1] E > ~ 0.1 MeV (location dependent)
[2] PWR- Pressurized Water Reactor; GCR - Gas Cooled Reactor; BWR-Boiling Water Reactor.
[3] Although boiling is not allowed in water loops, BWR chemistry can be simulated.

US Irradiation Facility Assessment Findings

- Existing US facilities provide significant capability for testing fuels and materials in a thermal neutron spectrum, but provide limited capacity for testing in a fast neutron spectrum (e.g., $5x10^{14}$ $n/cm^2/s$, E > 0.1 MeV or 6 dpa per year).
- Existing US facilities are not currently capable of irradiating fuels and materials in environments (thermal, hydraulic, mechanical, and chemical) representative of advanced liquid-metal or molten-salt reactors.
- Existing US facilities are approximately 50 years old. Appropriate investments are required for their continued operation.
- Limited instrumentation and experimental support capabilities are available at existing US facilities. Additional investment is required for US facilities to offer options available at international facilities.

International Irradiation Facility Assessment

- NEAC International Subcommittee is relying on several publicly-available assessments (OECD, IAEA, DOE, EPRI, INL, NAS, and GIF).
- Considered existing and expected near-term facilities under construction.
- Evaluation still ongoing; results should be available in the near term.
- Some updates to prior publicly-available assessments are occurring as responses from the international community are obtained.
- Nuclear Science User Facilities (NSUF) database will be updated as data from external sources becomes available; this provides a straightforward method to keep the information current with time.

Representative International Irradiation Facilities and Capabilities

Reactor	Halden BWR (HBWR)	Belgium Reactor-2 (BR2)	High Flux Reactor (HFR)	Japan Materials Test Reactor (JMTR)	JOYO	BOR-60	RJH (Reactor Jules Horowitz)
Country/Owner	Norway IFE	Belgium SCK-CEN	Netherlands EU	Japan JAEA	Japan JAEA	Russia ROSATOM	France CEA
Power, MWth	20	100	45	50	140	60	100
Maximum Thermal Flux, n/cm2-s	1.5 E+14	1.0 E+15	3.0 E+14	4.0 E+14	5.7 E+15	2.0 E+15	3.0 E+15
Maximum Fast Flux1, n/cm2-s	0.8 E+14	7.0 E+14	1.0 E+14	1.0 E+14	4.0 E+15	3.7 E+15	1.0 E+15
Initial Criticality	1959	1961	1961	1968	1977	1968	2018?
Irradiation capabilities	10 loops 40 in-core positions 5 reflector positions 0 rabbits 0 beam ports	1 loop 40 in-core positions 50 reflector positions 0 rabbits 0 beam ports	0 loops 19 in-core positions 12 reflector positions 0 rabbits 12 beam ports	2 loops 20 in-core positions 40 reflector positions 2 rabbits 0 beam ports	0 loops 21 in-core positions 1 reflector positions 0 rabbits 0 beam ports	0 loops 15 in-core positions 10 reflector positions 0 rabbits 0 beam ports	1 corrosion loop 10 in-core positions 26 reflector positions 0 rabbits 0 beam ports
Largest thermal flux test volume thermal flux, n/cm2-s)	7.0 cm dia. (open D_2O) 3.5-4.5 cm dia. (test capsule)	90 cm height 8.0 cm dia. 20 cm dia.	60 cm height (2.9 E+14)	3.6 cm dia. 85 cm height (4.0 E+14)			Special LWR Experiment rigs (MICA, CALIPSO, ADELINE, MADISON, etc.)
Largest fast flux test volume (fast flux, n/cm2-s)	High power booster rigs (4 - 6 E+13)		60 cm height (1.8 E+14)		60 cm height Fuel bundle-sized capsules (4.0 E+15)	4.4 cm width, 45 cm height 3.7 E+15	
Test Conditions2	PWR, BWR GCR, HWR, VVER	PWR	PWR, BWR, GCR	PWR, BWR, GCR	SFR	SFR	PWR, BWR, GCR, SFR

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1 E > ~ 0.1 MeV (location dependent)

2 BWR-Boiling Water Reactor, GCR-Gas Cooled Reactor,
PHWR - Pressurized Heavy Water, PWR-Pressurized Water Reactor
SFR-Sodium Fast Reactor, VVER- Vod0Vodyan Energetichesky Reactor

International Irradiation Facility Assessment Findings

- Japan well positioned with own SFR and HTGR test reactors for next 30 years
- Korea plans to build SFR by 2028 and currently uses BOR-60, but would be interested in participating in a new U.S. irradiation facility if based on sodium technology.
- China already has SFR test reactor with no plans to add a new one, but would be interested in participating in a new U.S. irradiation test reactor.
- UK does not have any test reactors; uses OECD Halden now and RJH in future; Fast flux is not adequate for advanced reactors (GFR, SFR, and LFR). Currently all planned experiments are in HBWR, but would be interested in new U.S. irradiation facility in 2030 if fast reactor capability of RJH does not materialize.
- Euratom interested in LFR, SFR, and GFR, but planning 'not well advanced'. Interest in new U.S. irradiation facility depends on EU circumstance at that time.
- Czech Republic has no plans for new irradiation facility and would utilize RJH when available. Interested in exploring collaboration with US on new irradiation facility. Their LVR-15 can be utilized in non-LWR areas to complement new facility.
- Argentina, Brazil, and Poland are not interested in new fast flux US irradiation facility; focused on LWRs.

Assessment of US Irradiation Needs

- Formed Ad Hoc Subcommittee composed of members from Fuel Cycle and Reactor Technology Subcommittees
- Invited over 20 organizations from industry (reactor/fuel vendors, designers, and developers) and government (NRC, NR, NNSA, DoC, DoD, etc.) to a meeting to discuss irradiation needs
  - Speakers: GA, Westinghouse, Terrestrial, GE-Hitachi, Lightbridge, EPRI, Oklo, Elysium Inc, Terrapower
  - Other industry/government participants: NR, ORNL, ANL, LANL, Southern Company, NEI, US NRC, US DOE
- Also received written input from Terrapower, Westinghouse, AREVA, and ARC.

US Irradiation Need Findings

- A new domestic fast flux test reactor could address several missions:
  - Fast reactor fuel and materials irradiations;
  - Accelerated materials damage irradiations;
  - Full-length fuel assembly /large component/advanced instrumentation performance irradiations;
  - Domestic capability (avoiding export control issues, limited irradiation time, etc.)
- Desired traits to accomplish these missions include:
  - Fast flux (~5E14 to 1E16 n/cm^2-s, E > 0.1 MeV)/higher dpa (> 6 dpa/yr);
  - Large test volume (> 10 liters and > 1 meter length);
  - Loops with coolants used in non-LWR concepts;
  - Advanced real-time instrumentation and trained staff comparable to that in international test reactors;
  - High reliability/availability;
  - Operational as soon as possible (in order to meet the schedule proposed by some advanced reactor vendors).

US Irradiation Need Findings (continued)

- Some vendors indicate that a new test reactor is not essential for deploying their advanced reactor design. Backup plans include:
  - Relying on data from a non-US test reactor
  - Obtaining data from existing US facilities (e.g., ATR)
- Most participants indicated that a new domestic test reactor is still useful for longer term needs (e.g., using higher dpa to identify performance issues before they occur in a reactor, larger test volumes for fuel assemblies and large components, etc.) .

US Irradiation Need Recommendation

- DOE-NE should proceed with the preparation of a mission need/CD-0 document (as specified in DOE Order 413.3B) that summarizes:
  - Test reactor capability gap
  - Why current facilities are not sufficient to address the gap
  - Why a new fast test reactor supports the DOE-NE strategic plan
  - DOE's overall R&D program for advanced reactor concepts.

International Irradiation Needs Assessment

- Completed by NEAC International Subcommittee
- Sent out 47 Information Request Letters
- Invited over 31 organizations 24 countries
- Written responses received from 13 organizations:
  - Japan (JAEA)
  - Korea (KAERI)
  - UK (NNL)
  - Norway (OECD Halden)
  - Brazil (CNEN)
  - China (CINE)
  - Argentina (CNEA)
  - Poland (NCNR)
  - India (BARC)
  - European Commission (JRC)
  - Ukraine (NSC)
  - Germany (INET)
  - Czech Republic (UJV Rez)
  - Canada, Australia, & Belgium indicated they would respond in near future

International Irradiation Needs Findings

- **There are several missions that a US fast flux test reactor could provide.**
- **Desired irradiation capabilities include:**
  - Fast flux (~5E14 to 1E16 n/cm^2-s, E > 0.1 MeV)
  - Large test volume (> 10 liters with > 1 meter length) with temperature control and enhanced instrumentation (at least comparable to JOYO).
  - Loops with coolants used in non-LWR concepts (helium, sodium, lead, and lead-bismuth)
  - Coolant temperature capabilities: ≈700 °C for sodium and ≈1,500 °C for helium
  - Advanced real-time instrumentation and trained staff available in non US test reactors
  - High reliability/availability
  - Fuels to be tested are $(U,Pu)O_2$, (U,Pu)C, (U,Pu)N, $(Th,U)O_2$, and TRU

International Irradiation Needs Recommendation

- Complete assessment of international irradiation facilities as additional input is received
- Send out reminder requests to those international organizations that have not responded to the previous information requests
- Engage in more detailed dialog through DOE representatives with those international organizations that currently have advanced test reactors (e.g., Japan and China) to determine the detailed testing capabilities and availability of their facilities for potential use by US companies
- Based on potential emerging policy changes by the new administration, consider engaging organizations in Russia and India to determine if their existing advanced test reactors could be available for US companies needing irradiation services

Path Forward

- Update preliminary draft report findings and recommendations based on input obtained at December 2016 NEAC meeting;
- By December 31, 2016, post Draft Report, "Assessment of User Needs for Irradiation Testing" on NEAC website:

  http://www.energy.gov/ne/services/nuclear-energy-advisory-committee
- Comments on draft report due January 15, 2017. Final report will be issued soon thereafter.

Acknowledgements

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