Project X Energy Station Workshop Jan 29-30, 2013 – Summary

Pacific Northwest NATIONAL LABORATORY

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Presented at Project X Weekly meeting

February 15, 2013

Workshop Organizers

David Asner, Mary Peterson, David Senor, David Wootan

Patrick Hurh, Shekhar Mishra, Bob Tschirhart, Steve Holmes

Project X Nuclear Energy Station Workshop

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- Fermilab funded PNNL to lead the organization this workshop to test the hypothesis - *Could a Nuclear Energy Station associated with Project X accelerate and enhance the ability to test and evaluate early research concepts for nuclear energy applications?*

- Workshop Objective

  The objective of the workshop is to identify and explore the nuclear energy relevant research and development that would be possible in a Nuclear Energy Station associated with the Project X Linac and identify the design requirements for conducting the research. The U. S. Nuclear Energy mission will always require the use of test reactors but one of the hypotheses is whether a Nuclear Energy Station associated with Project X could accelerate and enhance the ability to test and evaluate early research concepts. This workshop will identify the synergy and benefit that the Project X Linac could bring to the nuclear energy community. The workshop will also cover topics related to design requirements, challenges and trade-offs associated with optimizing a high-power continuous wave linear accelerator target station for nuclear energy research.

Workshop Participants
http://www-ppd.fnal.gov/conf-w/PXES13/Part.PDF

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Project X Energy Station Workshop

January 29 & 30, 2013

Fermi National Accelerator Laboratory - Batavia, IL - USA

Participants List

Updated 01/30/2013

1.	Todd Allen	Idaho National Laboratory	todd.allen@inl.gov
2.	Kavin Ammigan	Fermi National Accelerator Laboratory	ammikav@fnal.gov
3.	Kris Anderson	Fermi National Accelerator Laboratory	kander@fnal.gov
4.	David Asner	Pacific Northwest National Laboratory	david.asner@pnnl.gov
5.	Pushpa Bhat	Fermi National Accelerator Laboratory	bhat@fnal.gov
6.	Mikey Brady Raap	Pacific Northwest National Laboratory	michaele.bradyraap@pnnl.gov
7.	James Cole	Idaho National Laboratory	james.cole@inl.gov
8.	William Corwin	U. S. Department of Energy	william.corwin@nuclear.energy.gov
9.	Mary Anne Cummings	Muons, Inc.	macc@fnal.gov
10.	Lynne Ecker	Brookhaven National Laboratory	lecker@bnl.gov
11.	Tony Gabriel	Scientific Investigation and Development	jkgabrielta@earthlink.net
12.	Yousry Gohar	Argonne National Laboratory	gohar@anl.gov
13.	Frank Goldner	U. S. Department of Energy, Office of Nuclear Energy	frank.goldner@nuclear.energy.gov
14.	Van Graves	Oak Ridge National Laboratory	gravesvb@ornl.gov
15.	Jim Grudzinski	Argonne National Laboratory	jjg@anl.gov
16.	Brian Hartsell	Fermi National Accelerator Laboratory	hartsell@fnal.gov
17.	Steven Hayes	Idaho National Laboratory	steven.hayes@inl.gov
18.	Stuart Henderson	Fermi National Accelerator Laboratory	stuarth@fnal.gov
19.	Steve Holmes	Fermi National Accelerator Laboratory	holmes@fnal.gov
20.	Patrick Hurh	Fermi National Accelerator Laboratory	hurh@fnal.gov
21.	James Hylen	Fermi National Accelerator Laboratory	hylen@fnal.gov
22.	Zhijie Jiao	University of Michigan	zjiao@umich.edu
23.	David Johnson	Fermi National Accelerator Laboratory	dej@fnal.gov
24.	Rolland Johnson	Muons, Inc.	
25.	Kevin Jones	Oak Ridge National Laboratory	joneskw@ornl.gov
26.	Yuri Kamyshkov	University of Tennessee	kamyshkov@utk.edu
27.	Karel Katovsky	Brno University of Technology	katovsky@feec.vutbr.cz
28.	Young-Kee Kim	University of Chicago / Fermi National Accelerator Laboratory	ykkim@fnal.gov
29.	Rick Kurtz	Pacific Northwest National Laboratory	rj.kurtz@pnnl.gov

Page 1

30.	Shekhar Mishra	Fermi National Accelerator Laboratory	mishra@fnal.gov
31.	Nikolai Mokhov	Fermi National Accelerator Laboratory	mokhov@fnal.gov
32.	Mary Peterson	Pacific Northwest National Laboratory	mary.peterson@pnnl.gov
33.	Eric Pitcher	Los Alamos National Laboratory	pitcher@lanl.gov
34.	Vitaly Pronskikh	Fermi National Accelerator Laboratory	vspron@fnal.gov
35.	Claude Reed	Argonne National Laboratory	cbreed@anl.gov
36.	Bernie Riemer	Oak Ridge National Laboratory	riemerbw@ornl.gov
37.	David Senor	Pacific Northwest National Laboratory	david.senor@pnnl.gov
38.	Nikolaos Simos	Brookhaven National Laboratory	simos@bnl.gov
39.	Jim Steimel	Fermi National Accelerator Laboratory	steimel@fnal.gov
40.	Jeff Terry	Illinois Institute of Technology	terryj@iit.edu
41.	Bob Tschirhart	Fermi National Accelerator Laboratory	tsch@fnal.gov
42.	Kamran Vaziri	Fermi National Accelerator Laboratory	vaziri@fnal.gov
43.	Glen Warren	Pacific Northwest National Laboratory	glen.warren@pnnl.gov
44.	David Wootan	Pacific Nortwest National Laboratory	david.wootan@pnnl.gov
45.	Michael Zisman	U. S. Department of Energy	michael.zisman@science.doe.gov

Page 2

- 45 participants
  - Mostly from National Labs ANL, BNL FNAL, INL, LANL, ORNL, PNNL
  - Also DOE-NE, DOE-SC-HEP

Project X Nuclear Energy Station Workshop

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- Workshop organized into two working groups
  - WG1: Proton Beam and Target Design Requirements

    Conveners:
    - Patrick Hurh (FNAL)
    - Bernie Riemer (ORNL)
    - Mikey Brady Raap (PNNL)
  - WG 2: Science and Technology Applications

    Conveners:
    - David Senor (PNNL)
    - Eric Pitcher (LANL)
    - Yousry Gohar (ANL)

Project X Nuclear Energy Station Workshop

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- Keynote Speakers
  - Dr. Frank Goldner (DOE NE)
    - DOE NE R&D Challenges and Roadmap for Addressing
  - Dr. Stuart Henderson (FNAL) – Role of Accelerators
  - Dr. Todd Allen (INL) – Future Needs for Irradiation Testing
- Workshop Goals (before the workshop)
  - Identify and explore possible R&D program for a Nuclear Energy Station
  - Identify associated design requirements ➔ Influence the Project X design
  - Initiate dialog between participants from NE & HEP-accelerator communities with backgrounds in
    - Accelerator-based applications, Nuclear & material science, Isotope production
    - Applications of high intensity proton beams and targets
    - Advanced nuclear reactor concepts, advanced nuclear fuel cycles, light water reactor sustainability, enhanced and accident tolerant fuels
  - DOE NE participation in workshop is critical to determine next steps

PNNL Energy Station Concept

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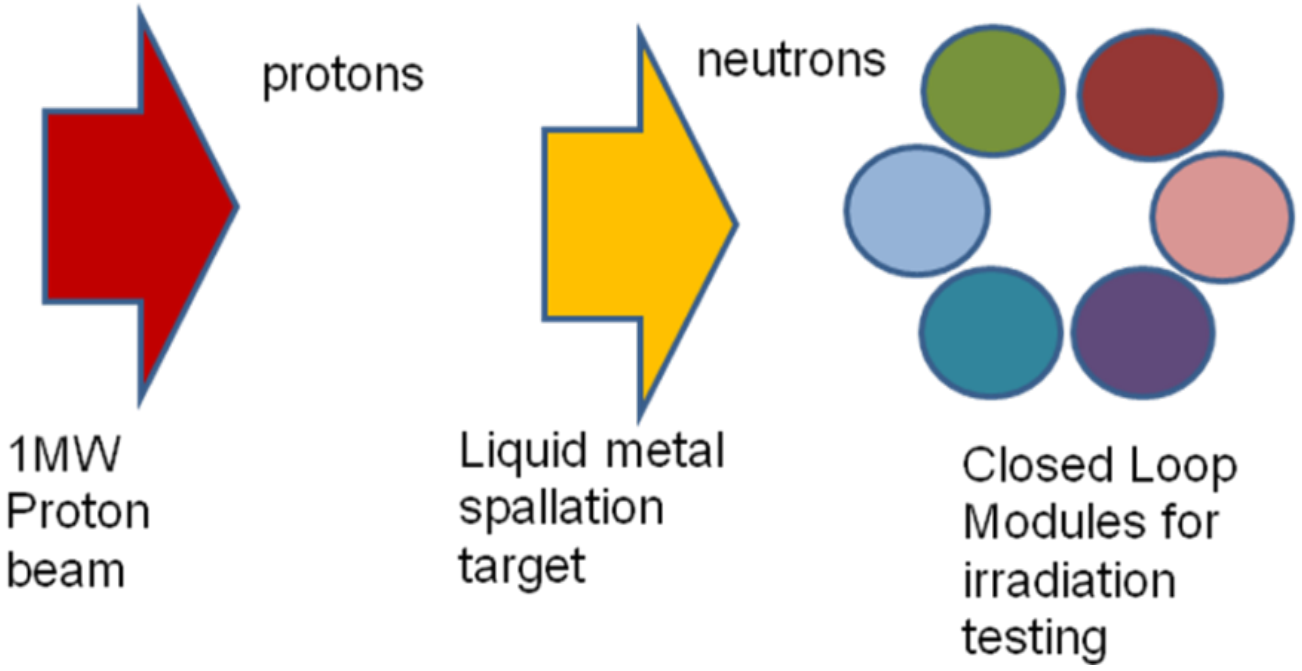
- A new approach utilizing the flexibility of an accelerator neutron source with spectral tailoring coupled with a careful design of a set of independent test loops can provide a flexible neutron test station for DOE NE applications



Project X Energy Station Concept

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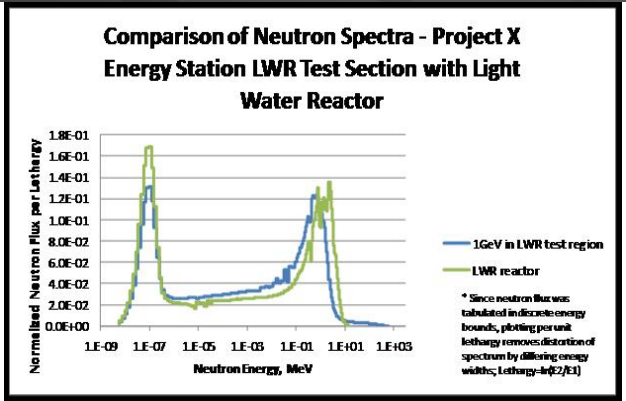
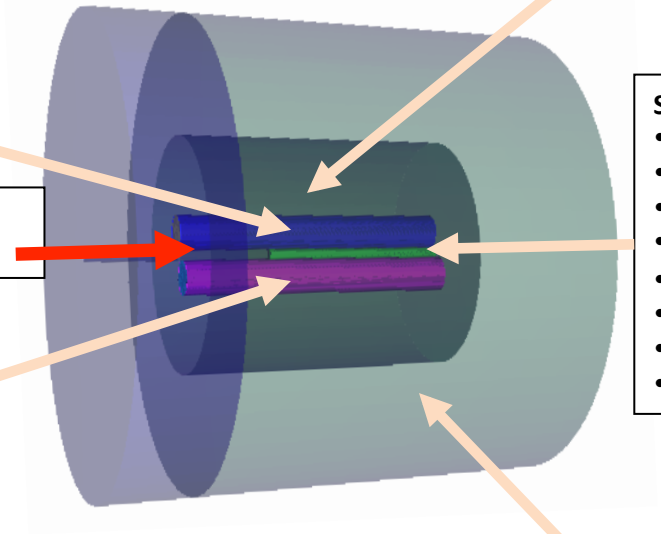


Thermal Spectrum Test Module: LWR, HTGR, MSR

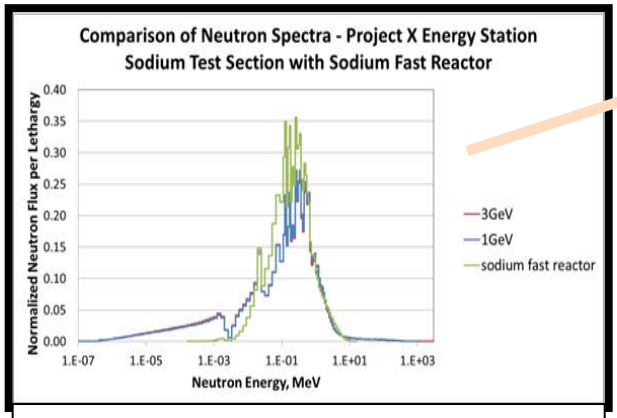
Closed Loop Test Modules
- Removable/replaceable/customizable
- Independent cooling system
- n spectrum/material/temp/pressure to match reactor conditions
- ~30 cm dia

Lead Matrix Test Region
- Solid lead with gas or water cooling
- ~ 2 m diameter, 3 m length
- Low n absorb/ High n scatter
- High n flux/ Fast n spectrum
- Acts as gamma shield



Project X Proton Beam
- 1mA @ 1 GeV (1 MW)

Spallation Target
- Liquid Pb-Bi
- >30 neutrons/proton
- 1 GeV protons penetrate ~50 cm in lead
- Neutrons Similar to fission spectrum
- Samples can be irradiated in proton beam
- Adding W or U can increase n flux density
- Small volume ~ 10 cm dia, 60 cm length
- Cleanup system for spallation products



Fast Spectrum Test Module: SFR, LFR, GFR

Reflector
- Steel/iron/nickel
- High n scatter
- Flattens n flux distribution

Energy Station is Unique Combination of Existing Technologies

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- Proton beam CW - 1 GeV - 1 mA - 1 MW
- Spallation Target:
  - Liquid lead or lead-bismuth release ~30 neutrons/proton
  - Neutron spectrum similar to fission spectrum but with high energy tail
  - Technology has been demonstrate at MEGAPIE
- Test Matrix
  - Solid lead or other (zircalloy) – high scatter, low absorption
  - Maximizes neutron flux, provides space for array of test modules
  - Simple solid block with cooling, holes for test modules
- Closed Loop Test Modules
  - Independently tailored irradiation environments (LWR, HTGR,SFR,LFR)
  - Independent heating/cooling system for each to control temperatures
  - Concept utilized in FFTF (sodium), BOR-60 (sodium, lead), ATR (press. Water)
- Reflector to minimize leakage neutrons

Summary of WG1: Proton Beam & Target Design Requirements

- Did not identify any experimental work outside of that generally required of high intensity target facilities (radiation damage R&D, heat removal R&D, etc.) due to the very pre-conceptual stage of facility development.
- Instead, future work should concentrate on the development of
  - Conceptual target designs that serve both particle physics & nuclear materials
  - Testing program plan for the Energy Station that capitalizes on the unique characteristics of a high intensity accelerator & spallation source
  - Technical requirements to support the proposed testing program plan
- Recommends that work continue to identify synergies between particle physics and nuclear materials research towards development of an integrated target facility design.
  - Require development of a vision for eventual operation of the facility
  - Identifying infrastructure requirements for a megawatt class spallation source physics and nuclear materials irradiation user facility.
- Operational requirements will likely exceed the current knowledge and experience base at Fermilab
  - Must be fully developed and quantified to ensure success of the program.

Summary of WG2: Science and Technology Applications

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- Further consideration of beam on/off issues on both short and long timescales
  - Data exist in the literature, but a review needs to be done to determine which transients have the potential to be problematic due to thermal effects as well as radiation damage effects
  - Further consideration must be given to desired damage rate/sample volume specifications to provide a meaningful irradiation capability
- Neutronics modeling needs to be refined to evaluate dual beam/ rastered beam to optimize flux and flux gradients in maximum usable test volumes
- Vetting technical priority of Project X Energy Station applications via DOE-NE Technical Review Panel
- Submit Facilities White Paper to Fusion Energy Science Advisory Committee (FESAC) – equivalent to HEPAP
  - Deadline February 14

Workshop Summary

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- Project X – stage 1 - could provide ~1 MW of beam dedicated to a spallation neutron source
  - for nuclear materials and fuels research (energy station)
  - or shared with physics mission facility with similar neutron source requirements
- Consensus amongst the participants was that the highest priority fusion energy and nuclear energy mission need relevant to the Project X Energy Station was for irradiation of fusion reactor and fast reactor structural materials.
- Project X Energy Station would have to provide a fusion and fast reactor relevant neutron flux (at least 20 dpa / calendar year) in a reasonable irradiation volume.
- Energy Station could enable the in-situ real-time measurements of various separate-effects phenomena in fuels or materials
  - High value to the modeling and simulation technical community and are
  - More feasible in an accelerator-based system than a reactor.
- Energy Station could satisfy the mission need for integral effects testing of fast reactor fuels, including driver fuel, minor actinide burning fuel, and transmutation of spent fuel.

Key Findings

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- A MW class spallation source for energy station or particle physics missions would generate quantities of radionuclides and will require significant infrastructure and capabilities that Fermilab currently does not possess.
  - Will require an update of the laboratory's Environmental Impact Statement.
  - Irradiation of fuel materials will not require any additional requirements.
  - Hurdles not judged insurmountable, but will require significant effort and attention.
- Thermal stability of test materials:
  - Needs further investigation to quantify the requirements
  - Enable omparison with historic beam trip data.
- Given the reliability and typical maintenance periods for modern superconducting linacs, expected beam interruptions will have an impact on thermal stability - potentially affect microstructure evolution of test materials.
  - Impact can be (partially) mitigated with addition of active heating/cooling systems.
- Pros and cons of liquid and solid targets were discussed extensively
  - agreed that either technology could be made to work
  - Preferred choice will depend on final design requirements.
- General consensus: Single target station for particle physics and energy missions.
  - Sharing neutrons would be better than sharing protons.

Specific actions to further evolve the Project X Energy Station concept

- Develop conceptual target designs that serve both particle physics and nuclear energy missions
- Develop a testing program plan for the Energy Station that capitalizes on the unique characteristics of a high intensity accelerator and spallation source
- Define technical requirements to support the proposed testing program plan
- Compile relevant PXES design parameters to support the high-priority mission needs and provide them to the beam and target designers
- Investigate the beam on/off issues for both short and long time scales.
  - Likely take the form of a literature review to determine which transients have the potential to be problematic due to thermal and radiation damage effects.
- Further consideration must be given to desired damage rate/sample volume specifications to provide a meaningful irradiation capability.
- Neutronics modeling of the notional Project X Energy Station concept needs to be refined to evaluate beam options (e.g. dual or rastered beam) to optimize flux and flux gradients in maximum usable test volumes.

Near term to do list

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1. Develop shared neutron target facility conceptual design (particle physics and nuclear materials irradiation).
2. Define/refine science requirements for the Energy Station
   - nuclear materials (including flux, test volumes, temp./beam stability
   - particle physics (including needed fluence, energy, space, availability)
3. Define operational life cycle for materials irradiations at the PXES
   - addressing issues such as length of irradiations, QA "hand-shake", remote handling requirements, shipping requirements, etc…
4. Organize another workshop to bring together the new work in items 1-3 above.
5. Submit Facilities White Paper to FESAC – submitted on Feb 14
6. Work to get Project X on the NE list for needed facilities
   - Bill Corwin (DOE-NE) and Mary Peterson (PNNL) to discuss with Pete Lyons (NE-1) starting week of Feb 18
7. Complete Workshop Report - before end of February