Accelerator Driven System Target Requirements and R&D

Stuart Henderson
Fermilab
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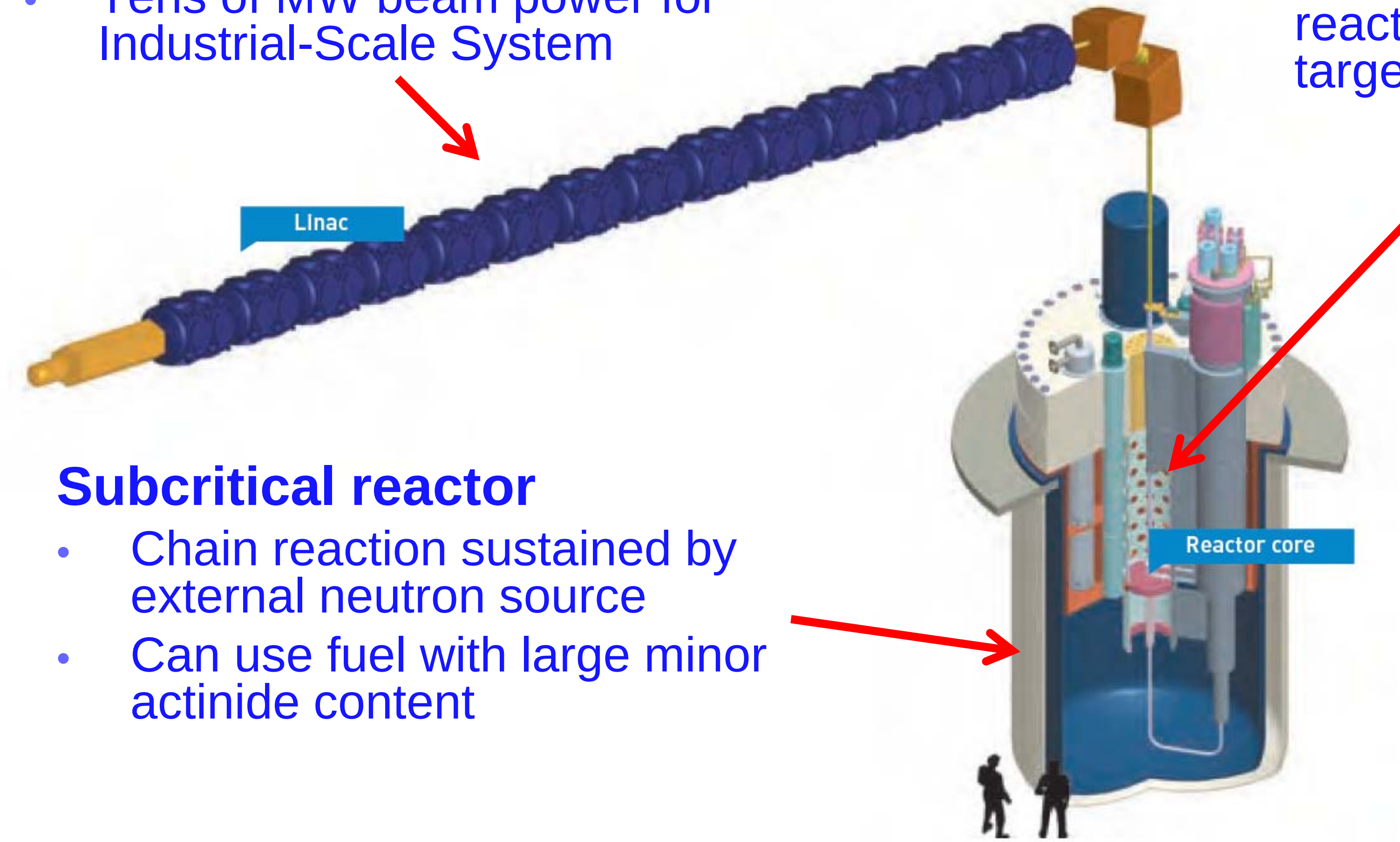
Accelerator Driven Systems



High-power, highly reliable proton accelerator

- ~1 GeV beam energy
- ~1 MW of beam power for demonstration
- Tens of MW beam power for Industrial-Scale System

Spallation neutron target system

- Provides external source of neutrons through spallation reaction on heavy metal target

Subcritical reactor

- Chain reaction sustained by external neutron source
- Can use fuel with large minor actinide content

Accelerator Challenges: Requirements

- Accelerators for ADS applications require
- Proton beam energy in the ~GeV range
  - Efficient production of spallation neutrons
  - Energy well-matched to subcritical core design
  - Minimize capital cost (lower energy increases source requirements)
- Continuous-wave beam in the > 10 MW regime
  - High power is required for industrial scale systems to justify large capital expense
- Low beamloss fractions to allow hands-on maintenance of accelerator components
- Reliability ranging from very high to extremely high
- Availability typical of modern nuclear plants

The “DOE ADS Whitepaper”

The White Paper

- In June 2010 DOE Office of Science tasked a Working Group with producing a White Paper assessing accelerator and target technology for Accelerator-Driven Systems (ADS)
- The White Paper was intended to make a hard-nosed assessment, addressing
  - the technical requirements for ADS
  - the current status and readiness of accelerator and spallation target technology
  - the R&D necessary to meet the requirements
- …and to answer two underlying questions:
  - Do the advances that have been made in Accelerator Technology in the last 10-15 years change the practicality of ADS for processing waste and generating electricity?
  - Is the technology to the point where a demonstration program is warranted?

The White Paper

"Accelerator and Target Technology for Accelerator Driven Transmutation and Energy Production"

http://www.science.doe.gov/hep/files/pdfs/ADSWhitePaperFinal.pdf

- Hamid Aït Abderrahim, SCK-CEN
- John Galambos, ORNL
- Yousry Gohar, ANL
- Stuart Henderson*, FNAL
- George Lawrence, LANL, retired
- Tom McManamy, ORNL
- Alex Mueller, CNRS-IN2P3
- Sergei Nagaitsev, FNAL
- Jerry Nolen, ANL
- Eric Pitcher*, LANL
- Bob Rimmer, TJNAF
- Richard Sheffield, LANL
- Mike Todosow, BNL

*Co-chairs

Range of Missions for Accelerator Driven Systems

Transmutation Demonstration and Experimentation

- Accelerator sub-critical reactor coupling
- ADS technology and components
- M.A./Th fuel studies

Industrial-Scale Transmutation

- Transmutation of M.A. or Am fuel
- Convert process heat to another form of energy

Industrial-Scale Power Generation w/ Energy Storage

- Deliver power to the grid
- Burn MA (or Th) fuel
- Incorporate energy storage to mitigate long interruptions

Industrial-Scale Power Generation w/o Energy Storage

- Deliver power to the grid
- Burn MA (or Th) fuel

Time, Beam-Trip Requirements, Accelerator Complexity, Cost

Range of Parameters for ADS

	Transmutation Demonstration	Industrial Scale Transmutation	Industrial Scale Power Generation with Energy Storage	Industrial Scale Power Generation without Energy Storage
Beam Power	1-2 MW	10-75 MW	10-75 MW	10-75 MW
Beam Energy	0.5-3 GeV	1-2 GeV	1-2 GeV	1-2 GeV
Beam Time Structure	CW/pulsed (?)	CW	CW	CW
Beam trips (t < 1 sec)	N/A	< 25000/year	<25000/year	<25000/year
Beam trips (1 < t < 10 sec)	< 2500/year	< 2500/year	<2500/year	<2500/year
Beam trips (10 s < t < 5 min)	< 2500/year	< 2500/year	< 2500/year	< 250/year
Beam trips (t > 5 min)	< 50/year	< 50/year	< 50/year	< 3/year
Availability	> 50%	> 70%	> 80%	> 85%

Accelerator Technology – Existing Parameter Sets

	Transmutation Demonstration (MYRRHA [5])	Industrial Scale Facility driving single subcritical core (EFIT [10])	Industrial Scale Facility driving multiple subcritical cores (ATW [11])
Beam Energy [GeV]	0.6	0.8	1.0
Beam Power [MW]	1.5	16	45
Beam current [mA]	2.5	20	45
Uncontrolled Beamloss	< 1 W/m	< 1 W/m	< 1 W/m
Fractional beamloss at full energy (ppm/m)	< 0.7	< 0.06	< 0.02

Target Systems- Requirements

- Maximize the number of neutrons *escaping* from the target per proton incident on it.
- Accommodate high deposited power density (~1 MW/liter).
- Relative to the subcritical core, contribute in an insignificant way to the dose received by workers and the public under design basis accident scenarios.
- Operate reliably for more than six months between target replacements.
- Be capable of being replaced within a reasonable (about one week) maintenance period.

Target Systems – Technology Choices

- Solid target options, which consist of a solid material in the form of rods, spheres, or plates to produce the neutrons, and coolant flowing between the elements for heat removal.
- Liquid target options where a flowing liquid metal (LM) acts both as the source of neutrons and the heat removal media.

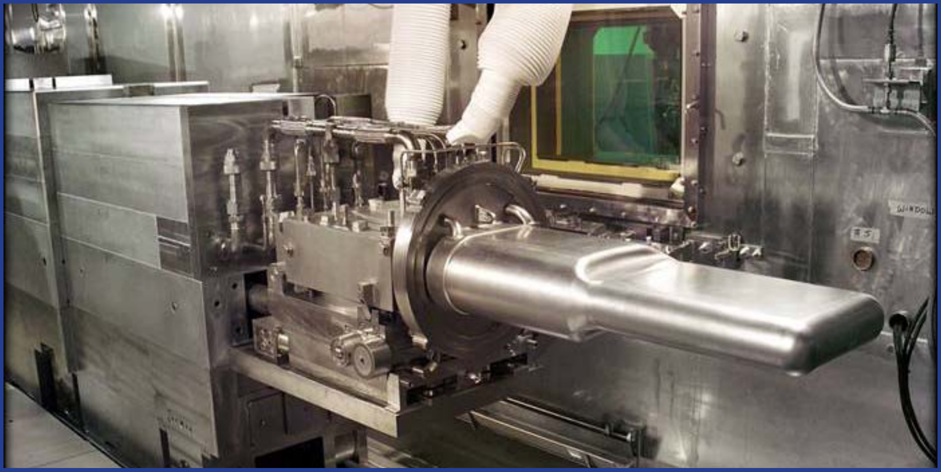
Target Technology Design Issues

- Neutronics
  - Maximizing the neutrons/proton emerging from the target
  - trade-offs between engineering, materials, safety, operational, and cost considerations.
- Thermal Hydraulics
  - Heat Removal from target and window
  - Design considerations include material compatibility, safety, radiation damage, remote handling and required reliability.
- Safety
  - Adequate cooling
  - Maintaining structural integrity
  - Manage/contain radioactive inventory
  - Accommodate accelerator induced transients

Target Technology Design Issues, cont’d

- Target Lifetime
  - Limitations from radiation-induced degradation of mechanical properties
  - Corrosion and erosion from coolant (oxygen control in LBE to avoid corrosion)
- Accelerator/Target Interface
  - Beam profile control and measurement
  - Equipment protection for off-normal events
- Maintenance and Remote Handling

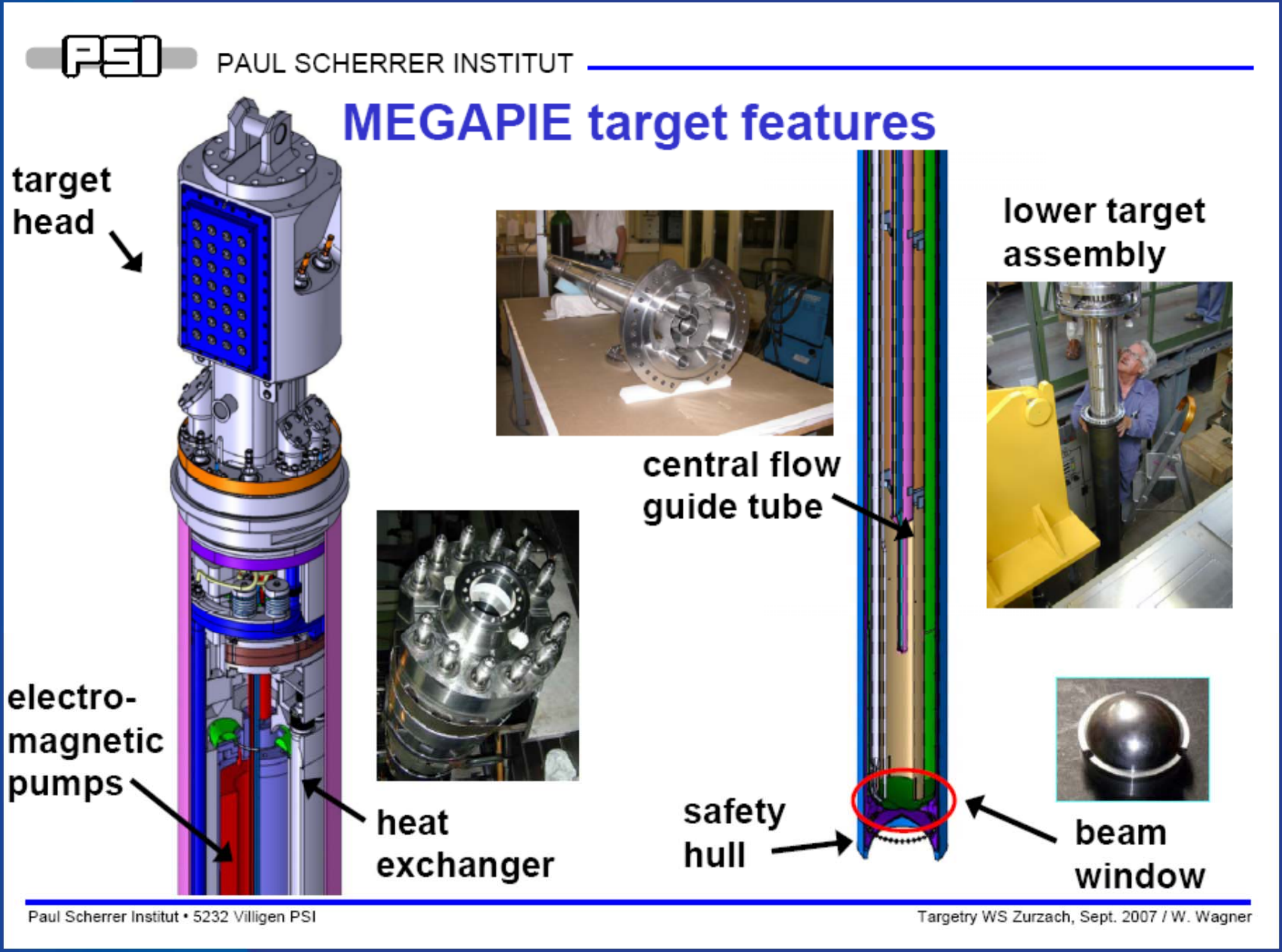
State of the Art: Operating MW-class Target Systems



- Solid-target
  - SINQ at PSI (~1.2 MW “DC” beam)
- Liquid Hg
  - Spallation Neutron Source (1.1 MW pulsed)
  - Japan Proton Accelerator Research Complex (0.3 MW pulsed)
- Pb-Bi Eutectic target
  - MEGAPIE at PSI (0.8 MW)
- Spallation targets for ADS application well above 1 MW will likely use heavy liquid metal cooling to achieve compact designs.
  - The only example of lead or LBE cooling for high power is the Russian LBE submarine reactors which were designed for approximately 150 MW.

Liquid Metal Target Design – Pb-Bi

T. McManamy



PAUL SCHERRER INSTITUT

MEGAPIE target features

target head

central flow guide tube

lower target assembly

electro-magnetic pumps

heat exchanger

safety hull

beam window

Paul Scherrer Institut • 5232 Villigen PSI

Targetry WS Zurzach, Sept. 2007 / W. Wagner

- ~1 year test with Lead Bismuth Eutectic - “steady state”
- Very good neutronic performance obtained and overall the test was successful
- Target was too expensive for normal operation and did have some operational problems
- PIE and initial sectioning in progress (ICANS XIX)

Lead Bismuth Eutectic Design considerations

T. McManamy

- High average density gives good neutron production
  - (44.5wt%Pb+55.5wt%Bi) ~1.04 x 10^4 kg/m3 @ 450K
- High melting temperature (125 C) requires systems to prevent freezing in piping
- ^{210}Po is produced which decays by α and is a biological hazard which must be contained
- Liquid metal corrosion is a serious issue with steels and usually requires control of the oxygen content within a narrow range
- 150 MW reactors using LBE have been used for Russian submarines

Finding #12

Spallation target technology has been demonstrated at the 1-MW level, sufficient to meet the "Transmutation Demonstration" mission.

R&D Needs for Target Technology

Liquid Metal Targets

- Oxygen control in an LBE environment. A number of out-of-beam LBE loops with oxygen control exist today that can be used to further develop appropriate operating conditions that limit corrosion of steels in contact with LBE. This testing should be augmented by one or more long-term in-beam tests.
- Polonium release from LBE. To support safety analyses, measure Po release fractions from LBE as a function of LBE temperature and concentration of trace contaminants.
- LBE cleanup chemistry. To limit corrosion of steels in contact with LBE, develop LBE cleanup chemistry techniques.
- Plate out of spallation products throughout the circulating LM system (piping, heat exchanger(s), filters) is likely with an LM target. The impact on personnel dose and ways to ensure RAMI (Reliability, Availability, Maintainability and Inspectability) and ways to mitigate adverse consequences should be explored.
- Develop criteria, verified by testing, required for safe and reliable operation of a windowless (LBE) liquid target.

R&D Needs for Target Technology

Solid Targets

- While LM targets have several benefits in high power density compact applications, the potential of solid targets to satisfy mission requirements should not be ignored. **The principal benefit of a solid target is that the radioactive spallation products are generally confined to the solid target material and are localized in the target proper.** The radioactivity in the primary coolant will depend on the coolant utilized and the design of the primary coolant loop, but should be significantly less of an issue than for LM targets.
- Solid target options should be evaluated and their performance and ES&H characteristics compared to those of LM targets. Carrying along a solid target option at the early stages of ADS conceptual design, if warranted by the comparative studies suggested above can reduce programmatic risk.

R&D Needs for Target Technology

Independent of Target Type (Liquid or Solid)

- Materials irradiations. Extend the irradiated materials database to include ADS environmental conditions (elevated temperature, contact with liquid metal, fatigue) and structural materials relevant to ADS applications.
- Subscale heat transfer and flow testing at operating temperatures.
- Full scale testing at operating temperatures.
- Off normal testing of safety systems
    - Leak containment – thermal shock on structures
    - Decay heat removal – natural convection testing may be needed
- Component testing under operating and off normal conditions.
- Remote handling development testing for components.
- Develop higher frequency (10-100 kHz), redundant/fail-safe raster power supplies and magnets with telescopic image magnification (2-4x) for uniform circular beam spots.
- Develop real-time, non-destructive beam imaging for 10-100 mA – e.g. residual gas fluorescence imaging.
- Develop through large-scale simulations detailed criteria for beam-trip recovery scenarios to minimize damage to liquid target and solid or liquid fuel containment vessels.
- Examine issues associated with integral cooling of the target and the sub-critical blanket via a single loop.
- Address interface issues of the target with the accelerator and sub-critical blanket

Finding #13

With appropriate scaling at each step along a technology demonstration path, there are no obstacles foreseen that would preclude the deployment of spallation targets at a power level (10 to 30 MW) needed to meet the application of ADS at an industrial scale.

ADS Activities: Recent Past and Ongoing

- There is no ADS program in the United States
- However, there are a number of developments over the last decade that are highly relevant to the topic
  - High-power CW front-end system development (LANL LEDA)
  - Construction, Commissioning and Operation of the world’s highest power pulsed accelerator and liquid metal target system (Spallation Neutron Source)
- These developments bring ADS feasibility forward

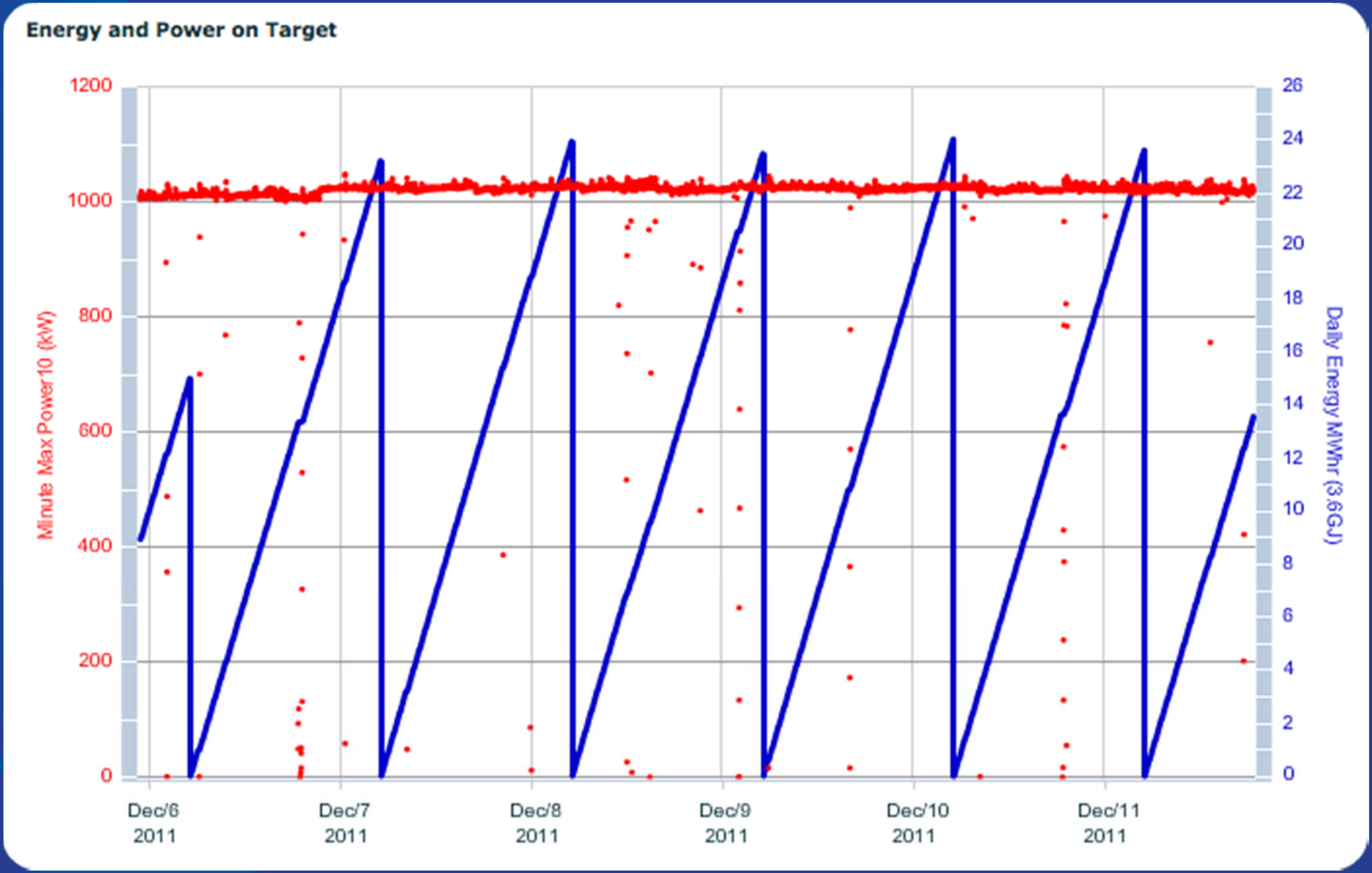
ADS-Relevant Technology Development of the Last 10-15 Years

- Spallation Neutron Source: Modern, ***MW-class high power proton accelerators*** based on superconducting technology ***exist and operate with acceptable beam loss rates***
- ***Superconducting radiofrequency structures*** have been built to cover a broad range of particle velocities (from v/c=0.04 to 1). Use of SRF offers potential for achieving high reliability


SNS Superconducting Linac

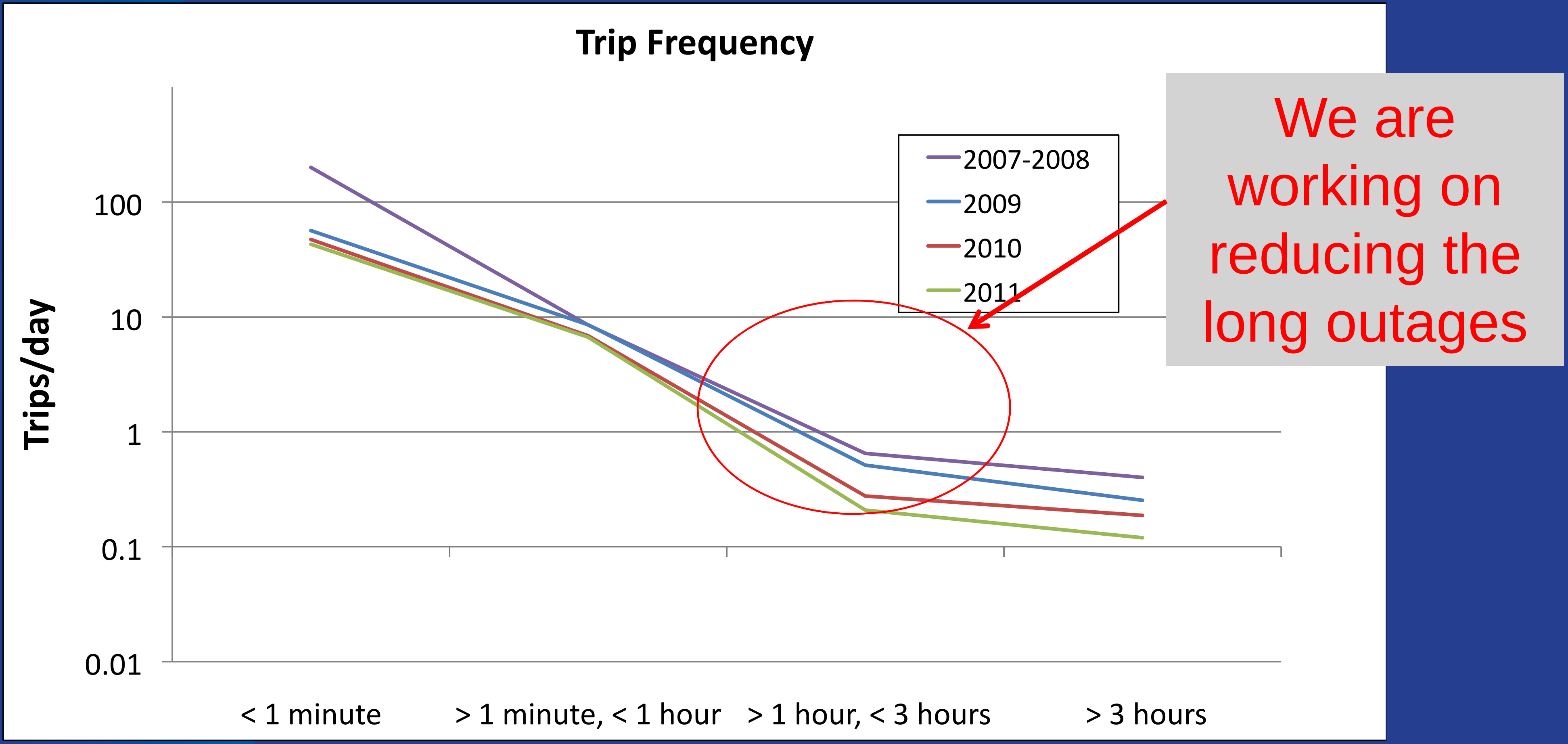
S. Henderson

Performance of SNS, a MW-class Proton Linear Accelerator



Trip Rates at SNS

Courtesy J. Galambos

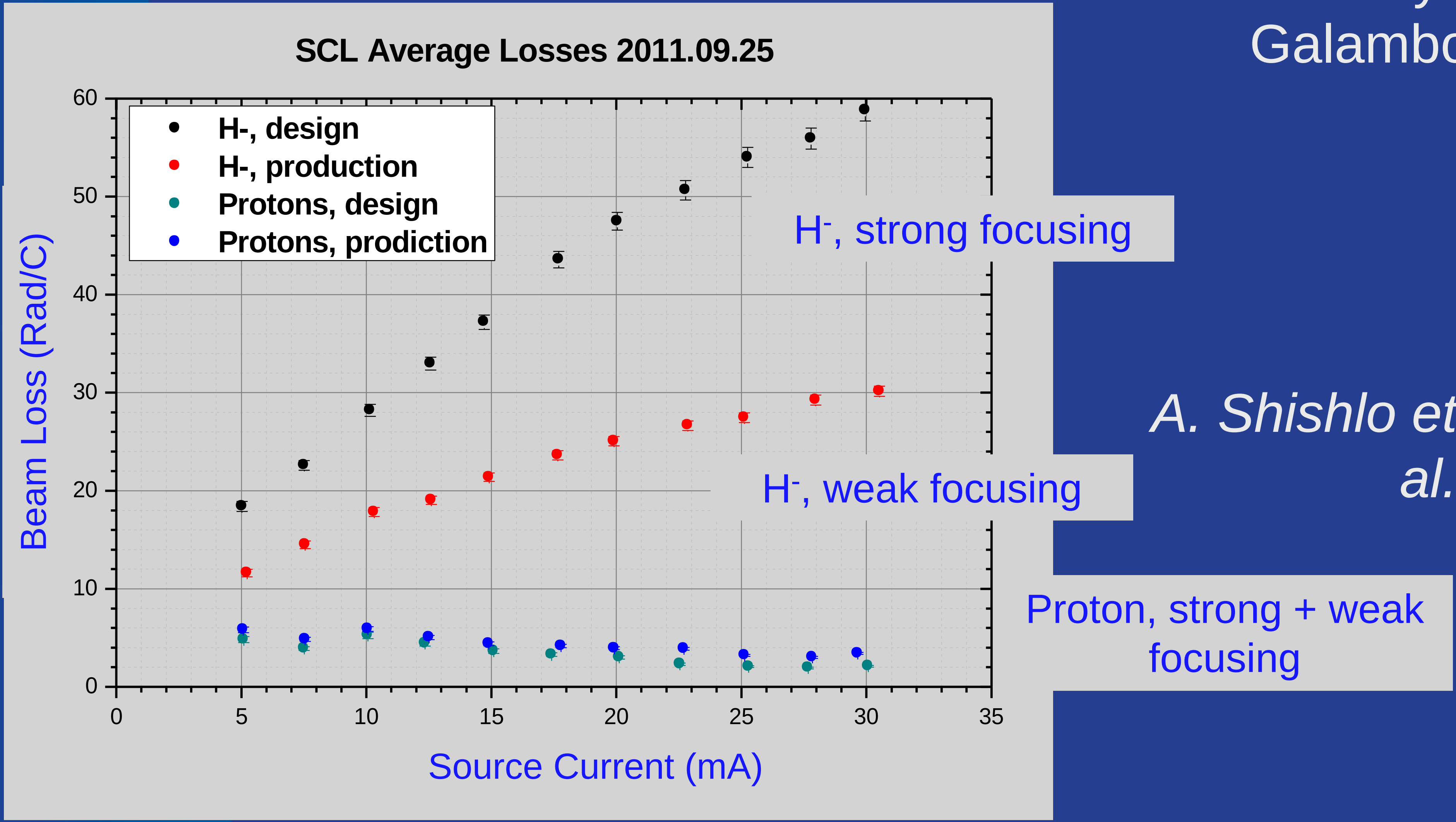


We are working on reducing the long outages

- SNS is focusing on reducing long outages – which affect our customer
  - Short trips are not a driver of downtime, and have received relatively little attention
- SNS was not designed for very low trip rates

Proton Beam Loss is much lower than H$^-$

Courtesy J. Galambos

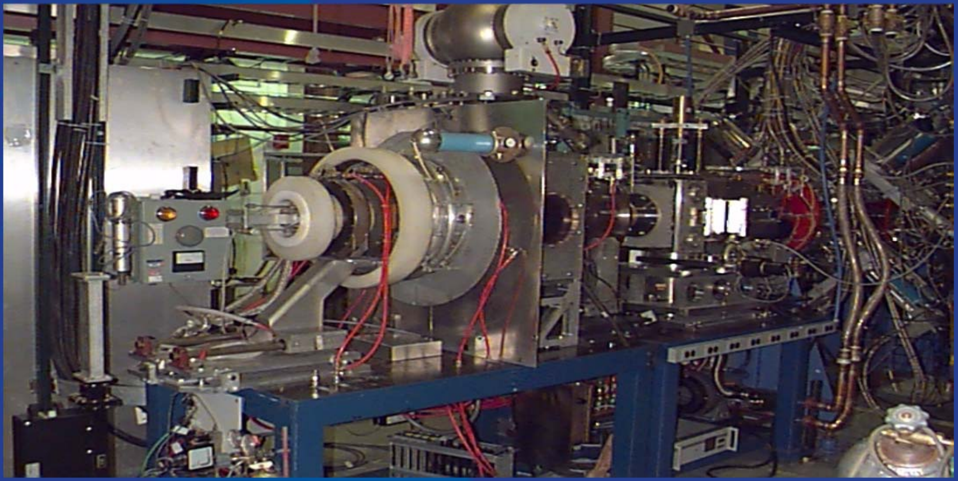


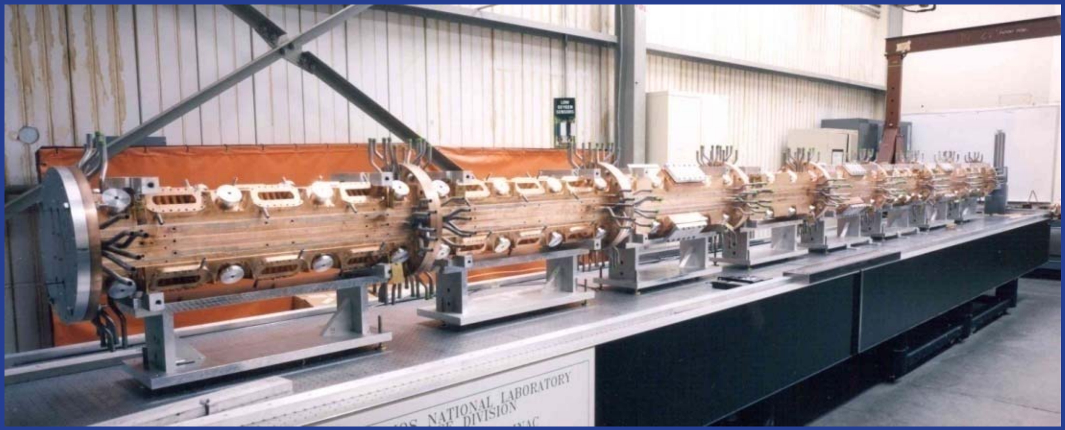
A. Shishlo et al.

- Measured beam loss in the SNS linac is much lower for protons than for H$^-$
    - Trends are consistent with “Intra-beam stripping”
    - Good news for ADS !

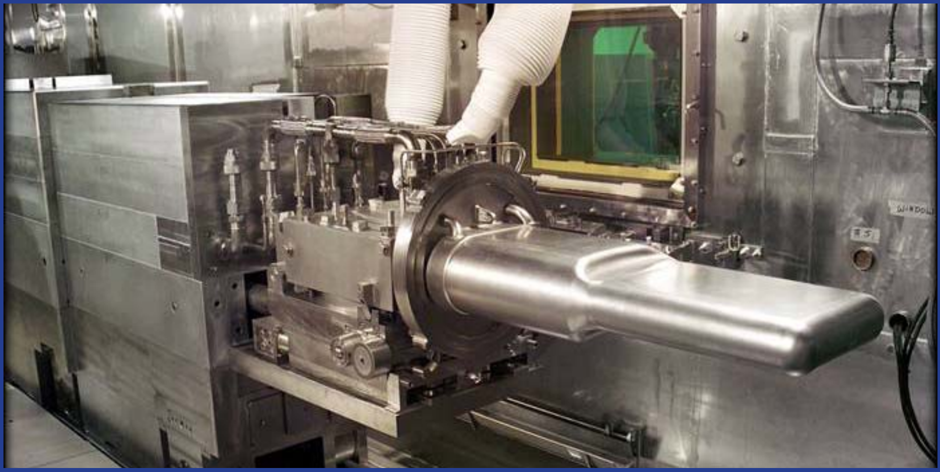
Front-End System Technology: Low-Energy Demonstration Accelerator (LEDA)

- Full power performance demonstrated for a limited operating period.
  - 20 hours at 100 mA CW
  - 110 hours at > 90 mA CW
- RMS beam emittances measured; reasonable agreement with simulation
- No long-term operations for reliability/availability evaluation.
- HPRF system performed well, but no long-term window tests.





State of the Art: Operating MW-class Target Systems



- Solid-target
    - SINQ at PSI (~1.2 MW “DC” beam)
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- Spallation targets for ADS application well above 1 MW will likely use heavy liquid metal cooling to achieve compact designs.
    - The only example of lead or LBE cooling for high power is the Russian LBE submarine reactors which were designed for approximately 150 MW.

Accelerator Reliability

- More than any other requirement, the maximum allowable beam trip frequency has been the most problematic, and in many ways has been perceived as a “show-stopper”
- Conventional wisdom held that beam trips had to be limited to a few per year to avoid thermal stress and fatigue on the reactor structures, the target and fuel elements

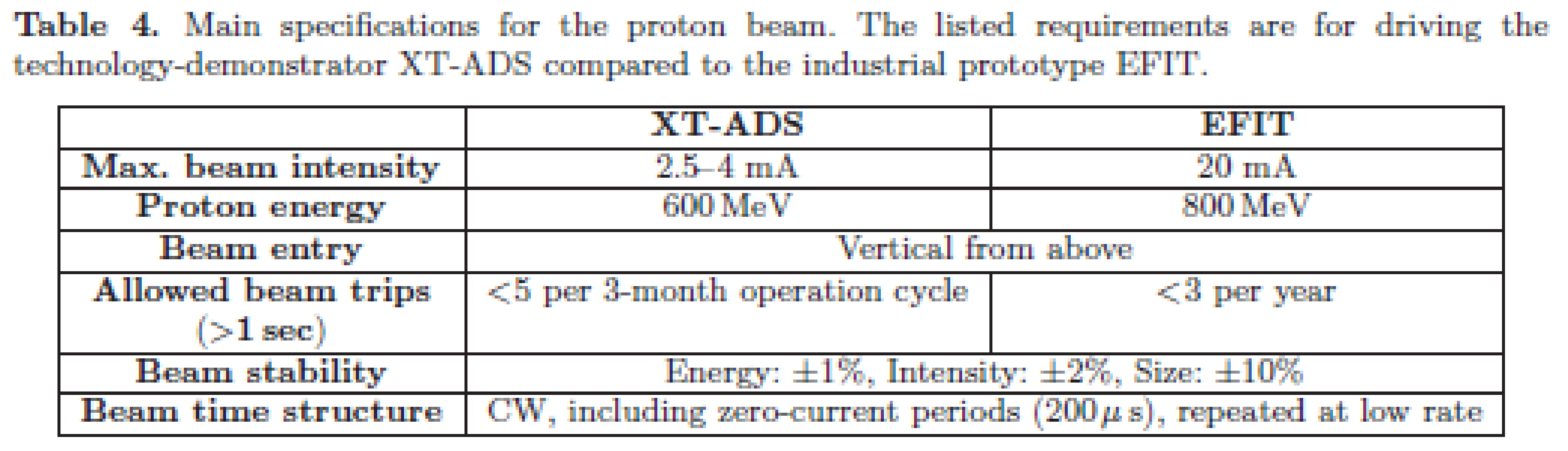

Table 4. Main specifications for the proton beam. The listed requirements are for driving the technology-demonstrator XT-ADS compared to the industrial prototype EFIT.

	XT-ADS	**EFIT**
Max. beam intensity	2.5–4 mA	20 mA
Proton energy	600 MeV	800 MeV
Beam entry	Vertical from above	
Allowed beam trips (>1 sec)	<5 per 3-month operation cycle	<3 per year
Beam stability	Energy: ±1%, Intensity: ±2%, Size: ±10%	
Beam time structure	CW, including zero-current periods (200 μ s), repeated at low rate	

Recent Developments Re: Beam Trip Requirements

- Three analyses based on transient response of reactor components using modern FEA methods are in good agreement: JAEA, MYRRHA and Argonne National Laboratory
- These new analyses result in ~2 order of magnitude relaxation of requirements for “short” trips and ~1 order of magnitude relaxation for “long” trips
- Updated Beam-Trip Rate requirements, while still very challenging, appear manageable with i) modern linac architecture, ii) appropriate redundancy and iii) utilization of reliability engineering principles
- More work is required to bring these components together with high reliability at > 10 times the beam power of today’s accelerators, but “getting from here to there” is achievable

ADS Technology Readiness Assessment

		Transmutation Demonstration	Industrial-Scale Transmutation	Power Generation
Front-End System	Performance	🟩	🟩	🟩
	Reliability	🟨	🟨	🟥
Accelerating System	RF Structure Development and Performance	🟩	🟩	🟩
	Linac Cost Optimization	🟩	🟨	🟨
	Reliability	🟨	🟨	🟨
RF Plant	Performance	🟩	🟩	🟩
	Cost Optimization	🟩	🟨	🟨
	Reliability	🟨	🟨	🟥
Beam Delivery	Performance	🟩	🟩	🟩
Target Systems	Performance	🟩	🟨	🟨
	Reliability	🟨	🟨	🟨
Instrumentation and Control	Performance	🟩	🟨	🟨
Beam Dynamics	Emittance/halo growth/beamloss	🟩	🟨	🟨
	Lattice design	🟩	🟨	🟨
Reliability	Rapid SCL Fault Recovery	🟨	🟥	🟥
	System Reliability Engineering Analysis	🟨	🟥	🟥

Green: “ready”, Yellow: “may be ready, but demonstration or further analysis is required”, Red: “more development is required”.

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Key Findings from the White Paper Working Group Report

1. There are active programs in many countries, although not in the U.S., to develop, demonstrate and exploit accelerator-driven systems technology for nuclear waste transmutation and power generation.
2. Accelerator-driven sub-critical systems offer the potential for safely burning fuels which are difficult to incorporate in critical systems, for example fuel without uranium or thorium.
3. Accelerator driven subcritical systems can be utilized to efficiently burn minor actinide waste.
4. Accelerator driven subcritical systems can be utilized to generate power from thorium-based fuels
5. The missions for ADS technology lend themselves to a technology development, demonstration and deployment strategy in which successively complex missions build upon technical developments of the preceding mission.

Key Findings from the White Paper Working Group Report

6. Recent detailed analyses of thermal transients in the subcritical core lead to beam trip requirements that are much less stringent than previously thought; while allowed trip rates for commercial power production remain at a few long interruptions per year, relevant permissible trip rates for the transmutation mission lie in the range of many thousands of trips per year with duration greater than one second.
7. For the tens of MW beam power required for most industrial-scale ADS concepts, superconducting linear accelerator technology has the greatest potential to deliver the required performance.
8. One of the most challenging technical aspects of any ADS accelerator system, the Front-End Injector, has demonstrated performance levels that meet the requirements for industrial-scale systems, although reliability at these levels has not yet been proven.

Key Findings from the White Paper Working Group Report

9. Superconducting radio-frequency accelerating structures appropriate for the acceleration of tens of MW of beam power have been designed, built and tested; some structure types are in routinely operating accelerator facilities.
10. Ten to one-hundred fold improvement in long-duration beam trip rates relative to those achieved in routine operation of existing high power proton accelerators is necessary to meet industrial-scale ADS application requirements.
11. The technology available to accelerator designers and builders of today is substantially different from, and superior to, that which was utilized in early ADS studies, in particular in the design which was considered in the 1996 National Research Council report.
12. Spallation target technology has been demonstrated at the 1-MW level, sufficient to meet the “Transmutation Demonstration” mission.

Key Findings from the White Paper Working Group Report

13. With appropriate scaling at each step along a technology demonstration path, there are no obstacles foreseen that would preclude the deployment of spallation targets at a power level (10 to 30 MW) needed to meet the application of ADS at an industrial scale.
14. Technology is sufficiently well developed to meet the requirements of an ADS demonstration facility; some development is required for demonstrating and increasing overall system reliability.
15. For *Industrial-Scale Transmutation* requiring tens of MW of beam power many of the key technologies have been demonstrated, including front-end systems and accelerating systems, but demonstration of other components, improved beam quality and halo control, and demonstration of highly-reliable sub-systems is required.

Activities in the US with connections to ADS (there is no US ADS Program)

Project X and potential for ADS

- A demonstration facility that couples a subcritical assembly to a high-power accelerator requires 1-2 MW beam power in the GeV range
- The 3 GeV Project X CW Linac has many of the elements of a prototypical ADS Linac
  - Beam power will range from 3 to 12 MW
  - Energy in the 1-2 GeV range is considered optimal, so provision is retained for delivering a beam energy less than 3 GeV
- The Project X CW Linac is ideally suited to power a demonstration facility with focus on:
  - Target system and subcritical assembly technology development and demonstration
  - Demonstration of transmutation technologies and support for fuel studies
  - Materials irradiation
  - High reliability component development, fault tolerant linac and rapid fault recovery development
- In Collaboration with Argonne have begun to formulate an experimental program on Pb-Bi spallation target characteristics and transmutation experiments

US Activities (Stuart's Summary)

- Argonne activities (more from Y. Gohar)
  - Experimental neutron source based one electron linac
  - Study physics and develop control meth for future ADS using Zero power systems
  - Three-year study to develop ADS concept for disposal of SNF from US light water reactor fleet
- JLAB/Virginia activities:
  - CLEAN Proposal for CEBAF to rebuild a section of linac to demonstrate very high reliability
  - A consortium of Virginia Universities, Industrial partners, and JLab has been established to develop US leadership in ADS R&D while preparing to host an ADS facility in Virginia
    - Goal - pursue funding for an electron accelerator coupled to a small, non-critical reactor core to study cross-sections and reaction rates

US Activities

- ORNL activities:
  - Evaluation of second target station as an irradiation facility
- LANL activities:
  - Materials Test Station proposal to serve the irradiation community
- BNL activities:
  - Interest but no activities yet
- Texas A&M University (P. McIntyre)
  - Subcritical Fission Technology Center
  - Developing a concept for a multi-beam flux-coupled cyclotron providing multi-MW beams

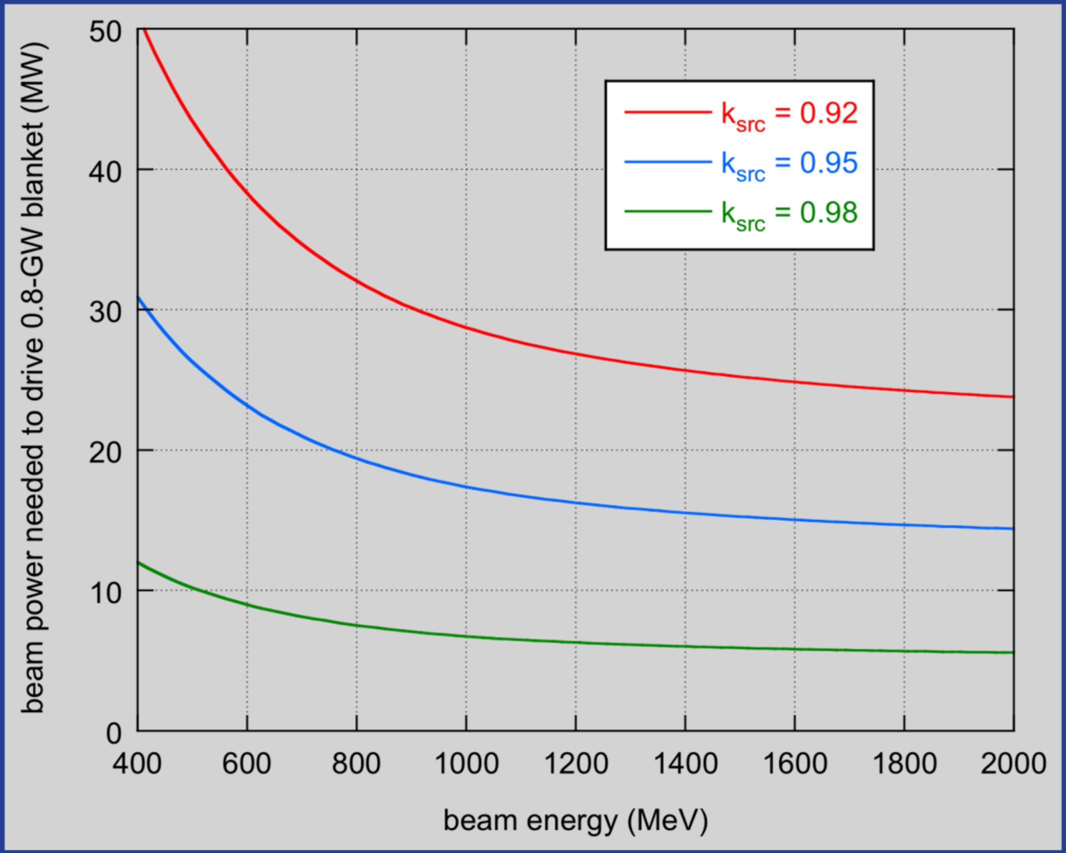
Finally

- There is a growing grass-roots effort to put ADS back on the radar screen in this country
- Many people are working at the lab level to generate interest
- What is lacking now is interest from the funding agency to restart a healthy program
- Nevertheless, there are many activities that bear directly on ADS technology and readiness for deployment
- A strengthened effort between UK-US on these important topics is welcomed and could be very helpful in making the case for ADS

ADS System Level Requirements

Accelerator and Target requirements are challenging

- High proton beam power
- Low beam loss to allow hands-on maintenance of the accelerator
- High wall-plug to beam power efficiency
- Accommodate high deposited power density (~1 MW/liter) in the target.



- Beam Trip Frequency: thermal stress and fatigue in reactor structural elements and fuel assembly sets stringent requirements on accelerator reliability
- High System Availability is required for a commercial system

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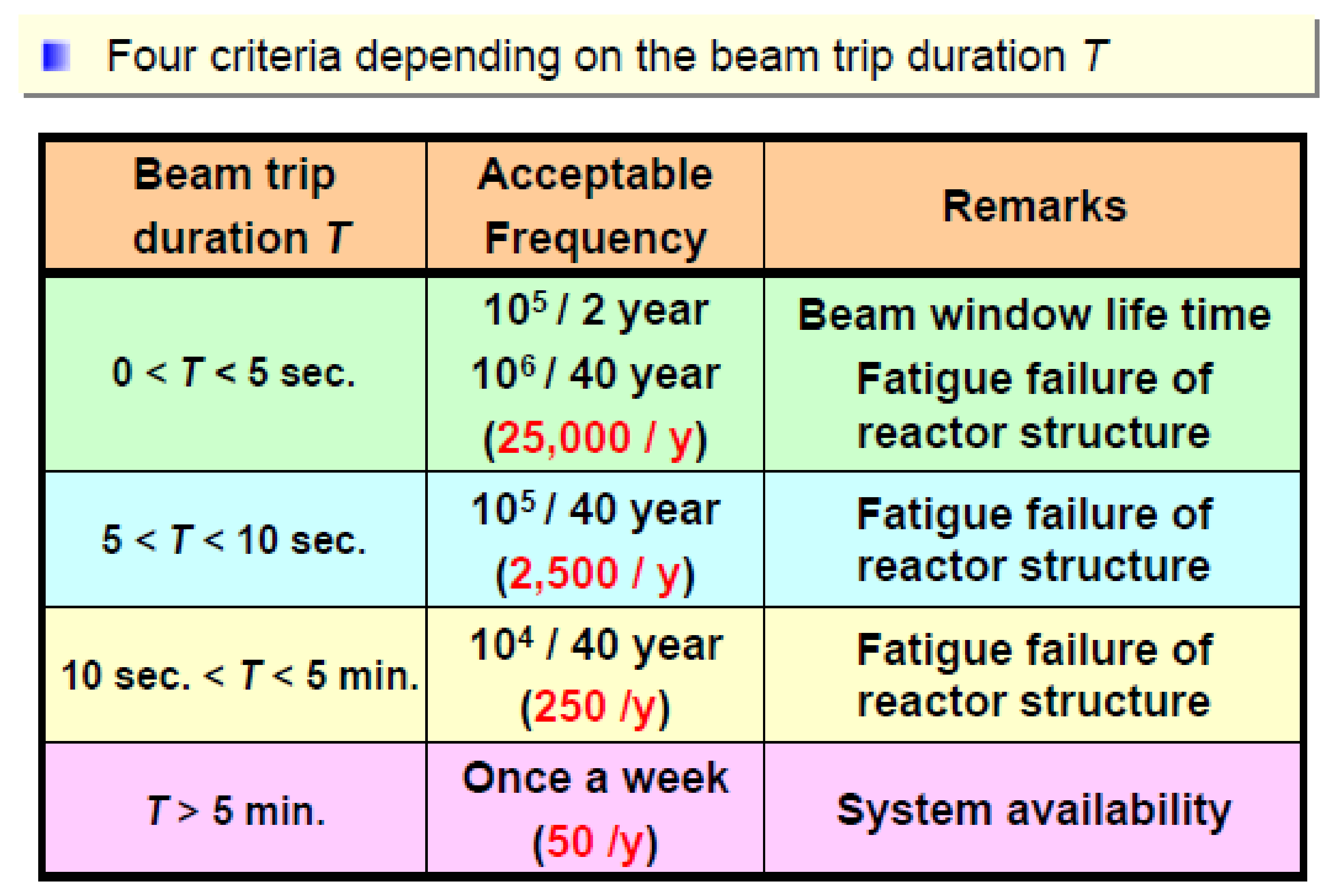
Recent Beam Trip Duration Analyses

- There are three analyses based on transient response of reactor components using modern FEA methods: JAEA, MYRRHA and Argonne
- These analyses show relatively good agreement

JAEA Analysis: H. Takei et. al., Proc. 5th OECD/NEA HPPA

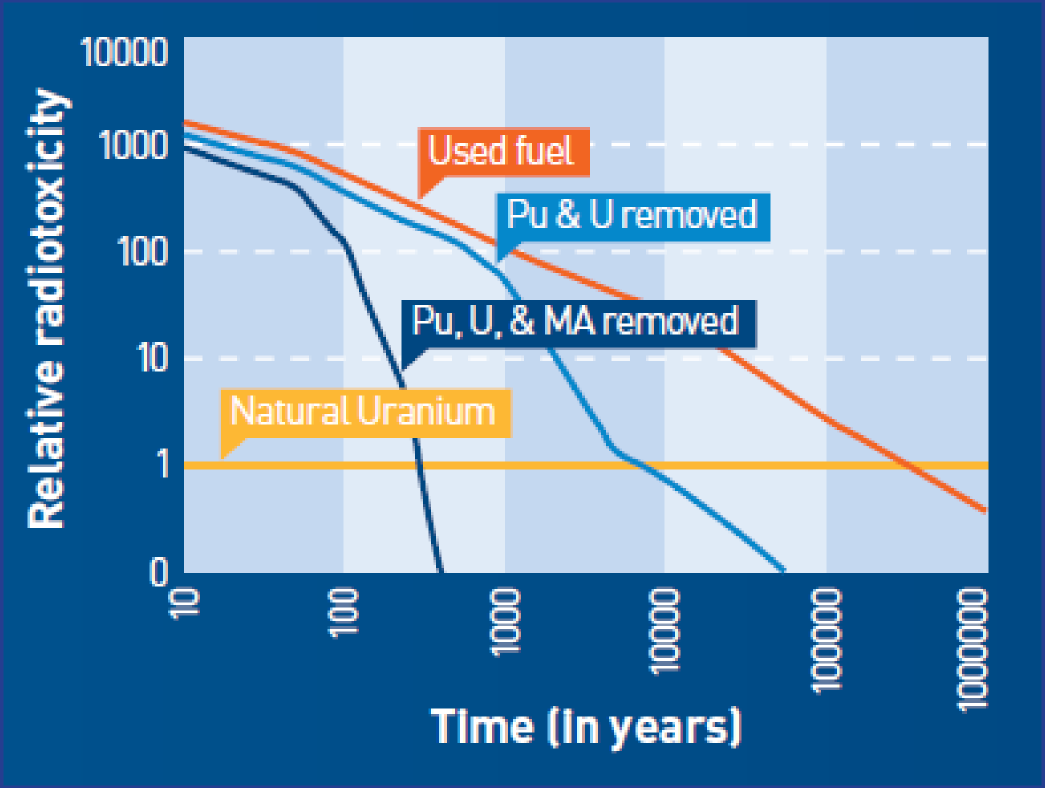


- Four criteria depending on the beam trip duration *T*

Beam trip duration *T*	Acceptable Frequency	Remarks
0 < *T* < 5 sec.	10^5 / 2 year 10^6 / 40 year (25,000 / y)	Beam window life time Fatigue failure of reactor structure
5 < *T* < 10 sec.	10^5 / 40 year (2,500 / y)	Fatigue failure of reactor structure
10 sec. < *T* < 5 min.	10^4 / 40 year (250 /y)	Fatigue failure of reactor structure
T > 5 min.	Once a week (50 /y)	System availability

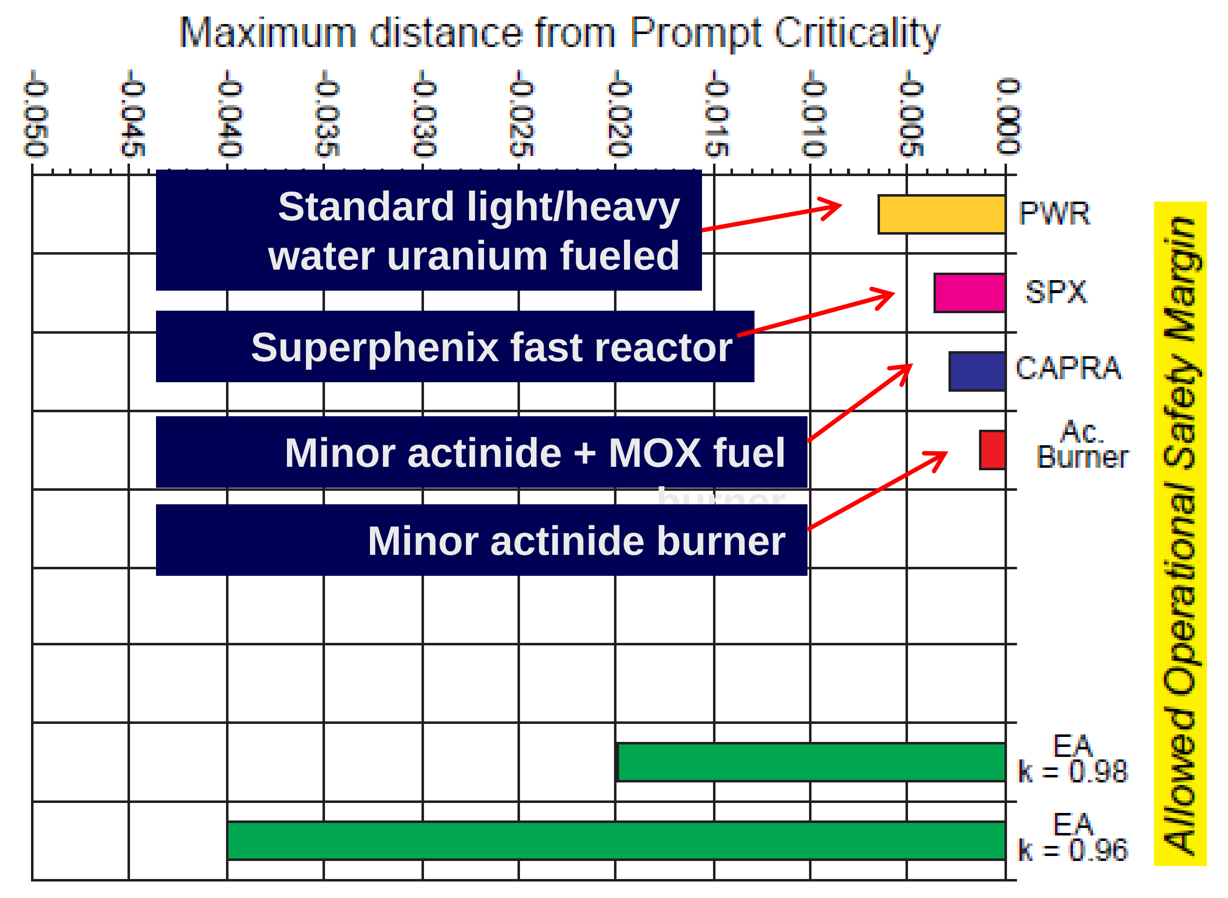
Applications of Accelerator Driven Systems Technology

- Accelerator Driven Systems may be employed to address several missions, including:
  - Transmuting selected isotopes present in nuclear waste (e.g., actinides, fission products) to reduce the burden these isotopes place on geologic repositories.
  - Generating electricity and/or process heat.
  - Producing fissile materials for subsequent use in critical or sub-critical systems by irradiating fertile elements.



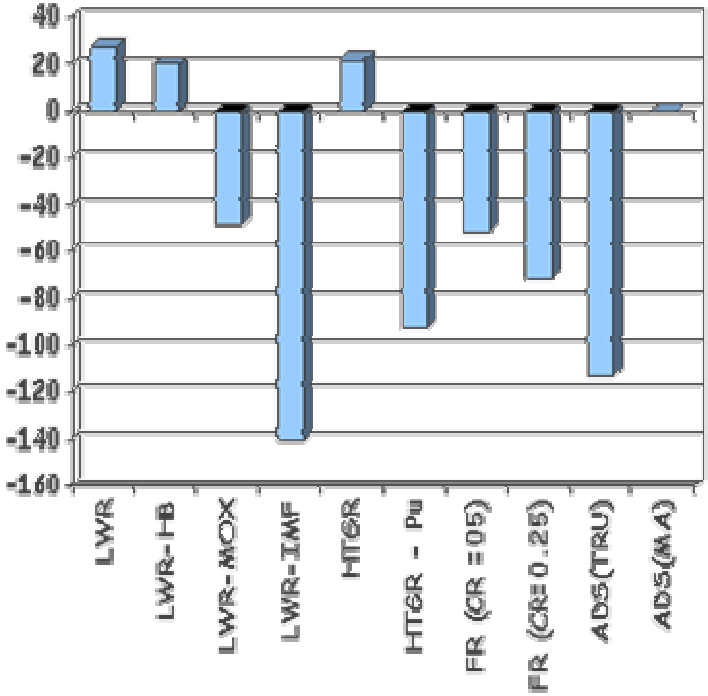
Advantages of ADS

- Greater flexibility with respect to Fuel Composition:
    - ADS are ideally suited to burning fuels which are problematic from the standpoint of critical reactor operation, namely, fuels that would degrade neutronic characteristics of the critical core to unacceptable levels due to small delayed neutron fractions and short neutron lifetimes, such as minor actinide fuel.
    - Additionally, ADS allows the use of non-fissile fuels (e.g. Th) without the incorporation of U or Pu into fresh fuel.
- Potentially enhanced safety:
    - External neutron source is eliminated when the beam is terminated

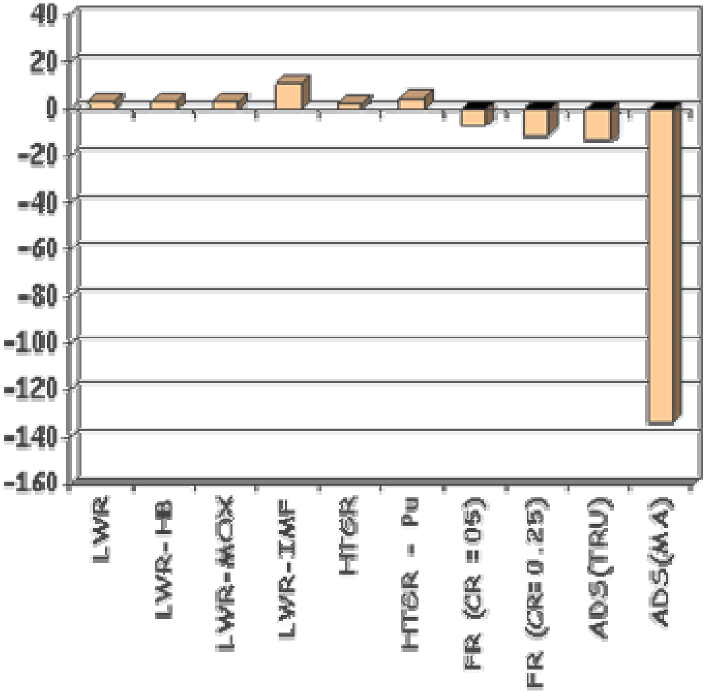


M. Cappiello, “The Potential Role of ADS in the U.S.”

The ADS is most efficient at Minor Actinide Transmutation



Pu Production Rate (grams / GWh)



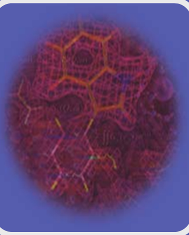
MA Production Rate (grams / GWh)

Project X as a National Resource with Application Beyond HEP

Project-X Beyond HEP

- We recognize that a multi-MW high energy proton accelerator is a national resource, with potential application that goes beyond particle physics
- Such facilities are sufficiently expensive that the U.S. will not invest in multiple facilities with duplicative capabilities
- We are engaging the potential user communities for utilization of high power proton beams beyond HEP
- We would like to explore your interests and ideas for potential uses of such a facility

Applications of High Power Proton Accelerators

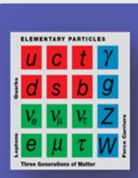


Materials Science

- Neutron Sources
- Muon Sources

Energy & Environment

- Materials Irradiation
- Accelerator Driven Systems

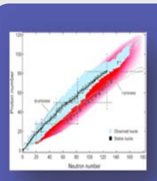


Particle Physics

- Proton Drivers for HEP

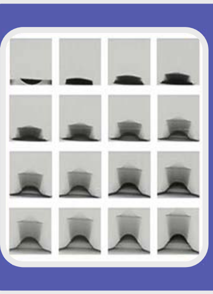
Medicine

- Isotope production



Nuclear Physics

- High-power ISOL
- Neutron, nuclear EDMs

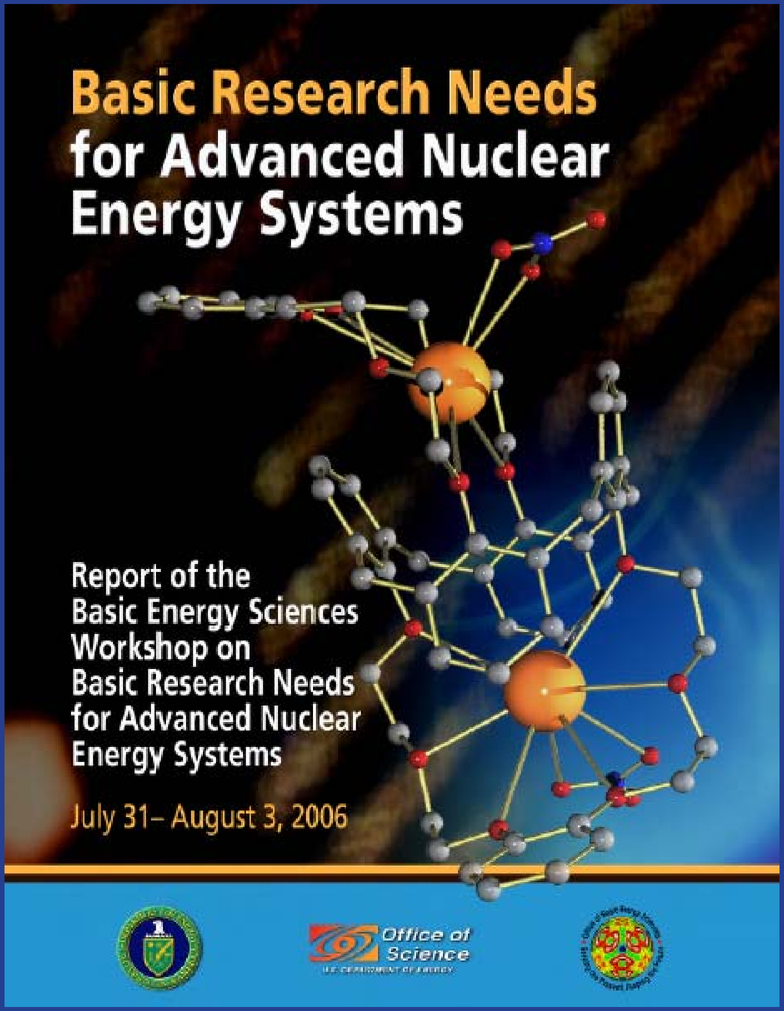


National Security

- Proton Radiography

National Needs in Advanced Energy Systems are Articulated in Numerous Recent Reports

- DOE/BES Report: Basic Research Needs for Advanced Nuclear Energy Systems
  - *“The fundamental challenge is to understand and control chemical and physical phenomena…from femto-seconds to millennia, at temperatures to 1000 C,* ***and for radiation doses to hundreds of displacements per atom.*** *This is a scientific challenge of enormous proportions, with broad implications in the materials science and chemistry of complex systems”*



Basic Research Needs
for Advanced Nuclear
Energy Systems

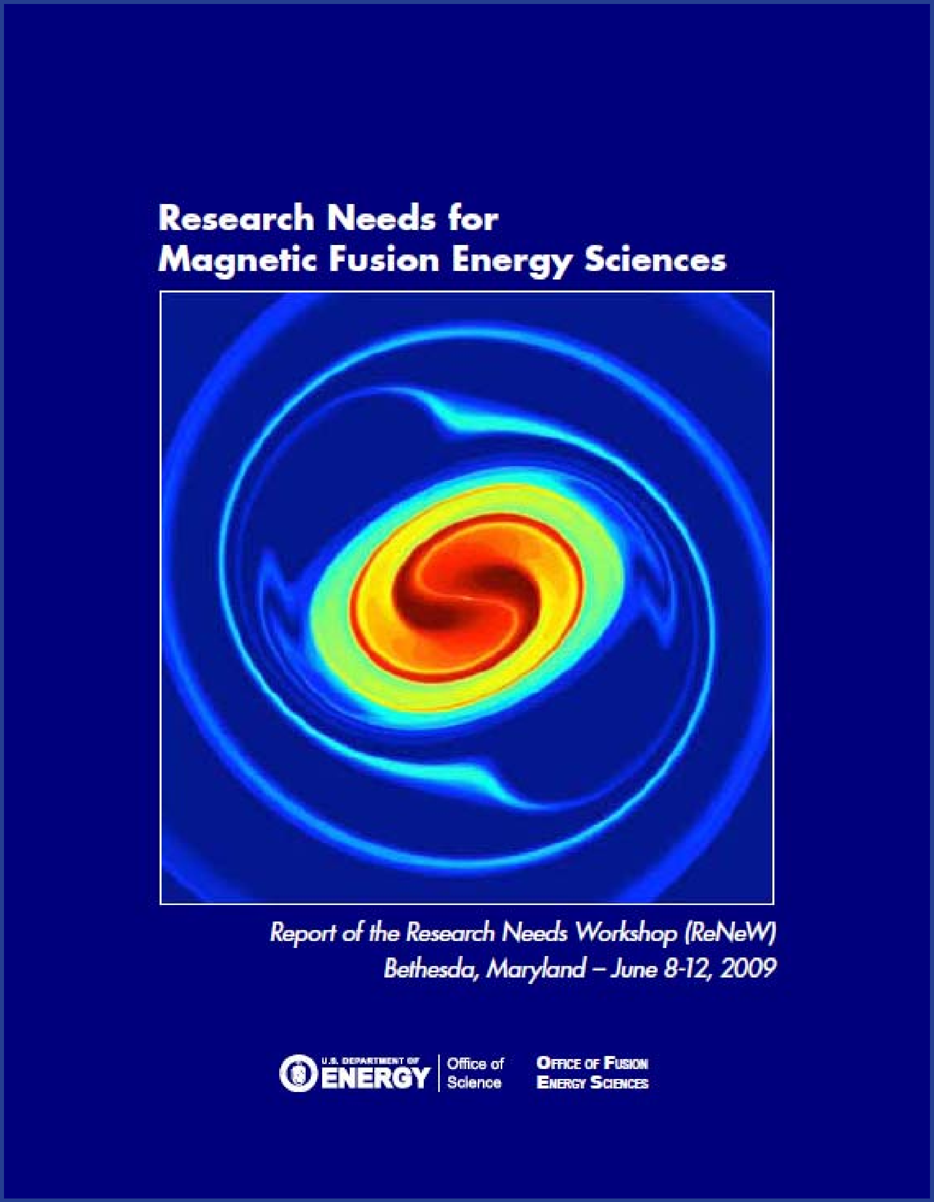
Report of the
Basic Energy Sciences
Workshop on
Basic Research Needs
for Advanced Nuclear
Energy Systems

July 31– August 3, 2006

Office of Science

National Needs in Advanced Energy Systems are Articulated in Numerous Recent Reports

- DOE/FES Report: Research Needs for Magnetic Fusion Energy Sciences
  - Thrust: Develop the material science and technology needed to harness fusion power
  - *"Establish a fusion-relevant neutron source to enable accelerated evaluations of the effects of radiation-induced damage to materials"*



Research Needs for
Magnetic Fusion Energy Sciences

Report of the Research Needs Workshop (ReNeW)
Bethesda, Maryland – June 8-12, 2009

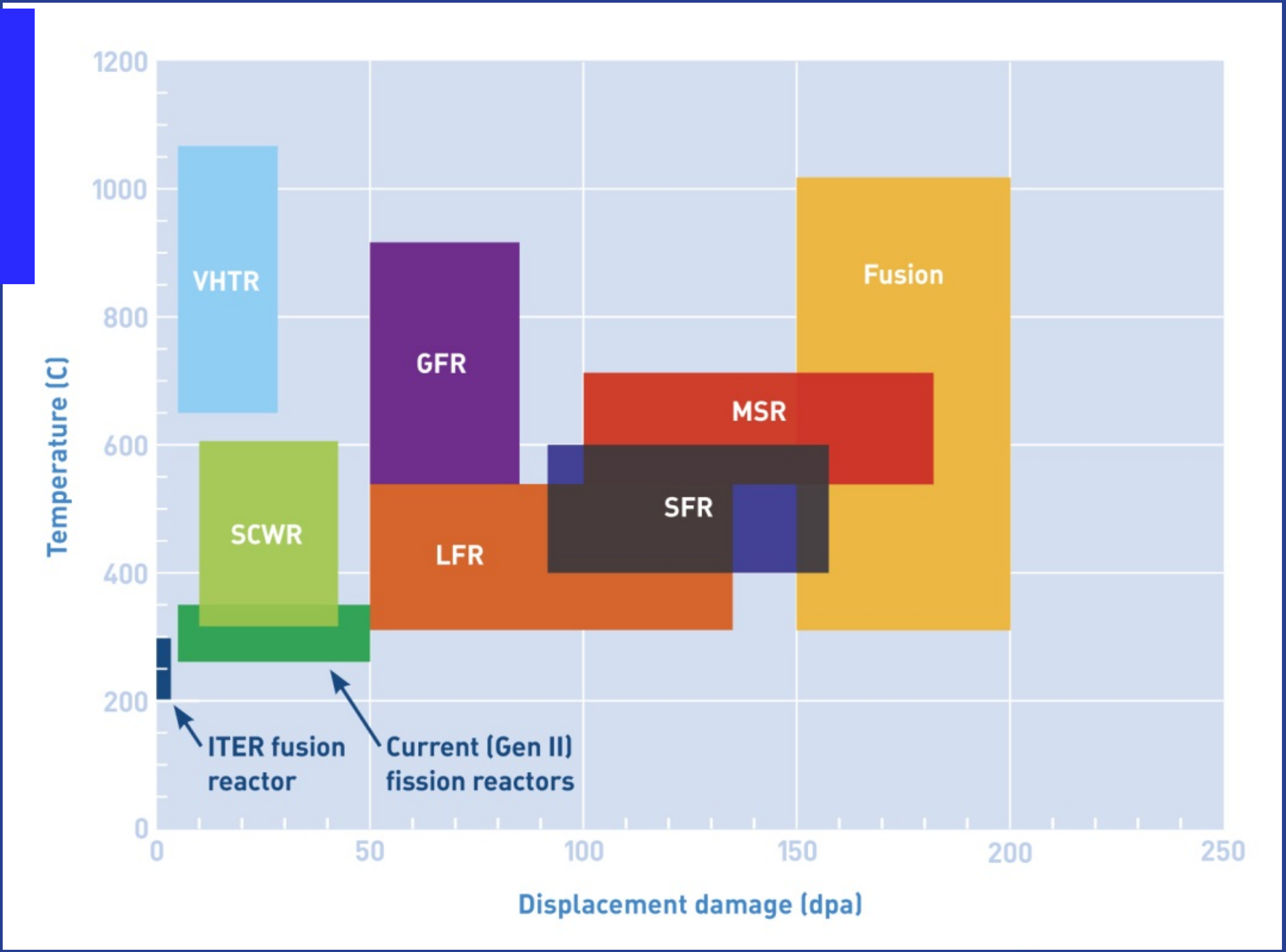
U.S. DEPARTMENT OF ENERGY | Office of Science
Office of Fusion Energy Sciences

Applications of Accelerators: Materials Irradiation

- Materials for next generation fission reactors or fusion devices need an order of magnitude greater radiation resistance than those in use today

Zinkle and Busby, Materials Today 12 (2009) 12.

Fission reactors include very-high-temperature reactors (VHTR), supercritical water-cooled reactors (SCWR), gas-cooled fast reactors (GFR), lead-cooled fast reactors (LFR), sodium-cooled fast reactors (SFR), and molten-salt reactors (MSR).



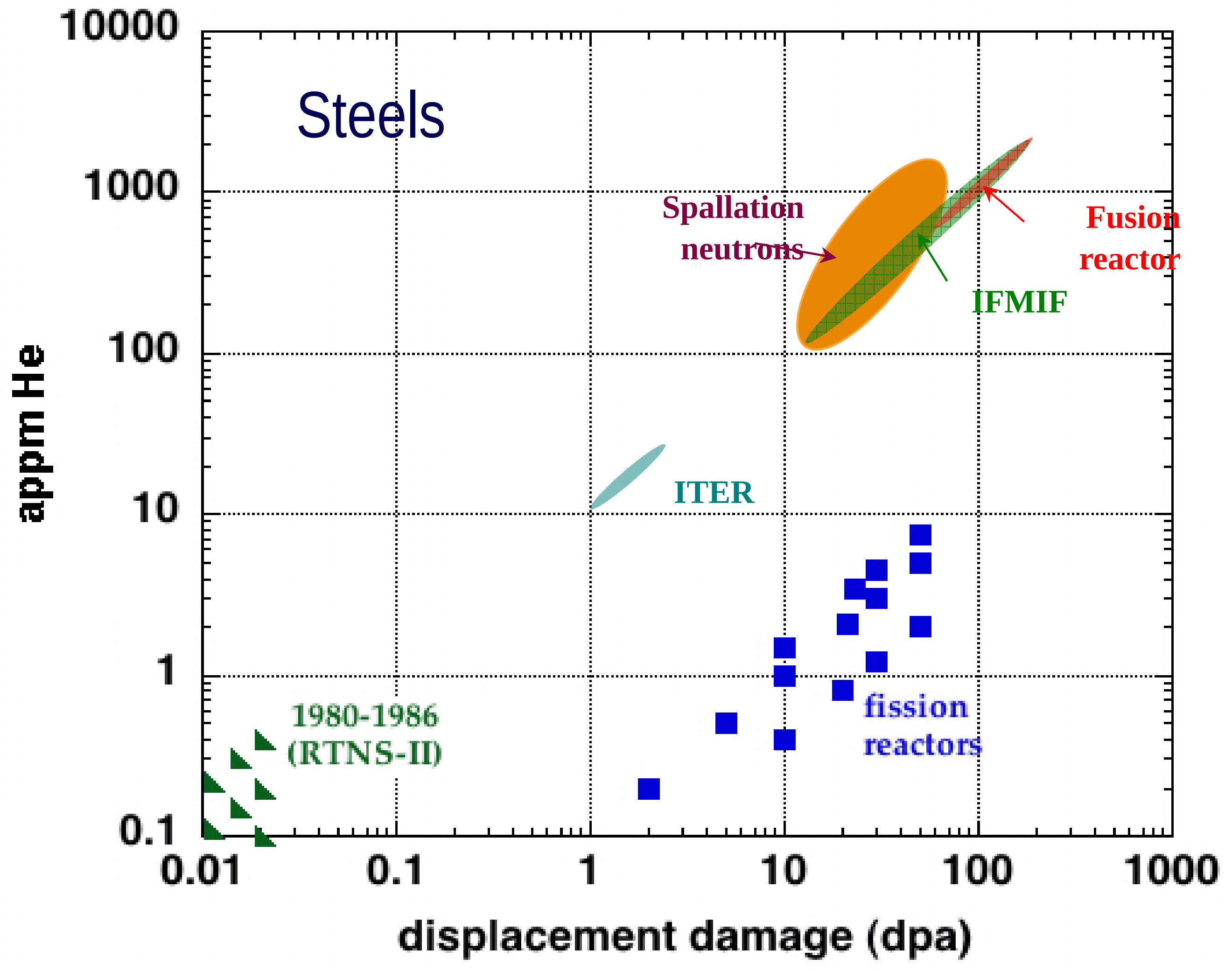
Applications of Accelerators: Materials Irradiation

- Irradiation with energetic particles leads to atomic displacements
    - Atomic displacements leads to microstructural evolution, which results in substantial mechanical and physical property changes.
- Damage regime can be reached by accelerator-driven sources
- Very aggressive accelerator parameters are required to reach 20-40 dpa/yr
    - IFMIF: 250 mA x 40 MeV deuteron accelerator (10 MW beam power) using d-Li stripping
    - MW-class spallation neutron source

Courtesy R. Kurtz, PNNL

Materials Irradiation

- Suitable irradiation sources are a critical need for future fission/fusion materials development
- **A MW-class proton beam driving a target designed for high neutron flux can meet this need**



Fermilab

Recent Developments

- DOE Symposium and Workshop on Accelerators for America's Future
- DOE/Office of Science recently commissioned an assessment of "*Accelerator and Target Technology for Accelerator Driven Transmutation and Energy Production*"
  - http://www.science.doe.gov/hep/files/pdfs/ADSWhitePaperFinal.pdf
- Summary: Substantial technology developments of the last 10-15 years make an ADS demonstration facility feasible, and go a long way toward demonstrating the technology required for an industrial-scale system.
- Briefing to Secretary Chu on ADS