Nuclear Energy Topics at July's INPC 2010

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FCR&D
Nuclear Physics WG
Santa Fe, NM
November 4-5, 2010

LBNL and Tech Source Inc.






Program Overview

	Sunday July 4	Monday July 5		Tuesday July 6		Wednesday July 7	Thursday July 8	Friday July 9
7:30		Registration Chan GPL		Registration Chan GPL		Registration Chan GPL	Registration Chan GPL	Registration Chan GPL
8:00				Plenary *Chan Centre*		Plenary *Chan Centre*	Plenary *Chan Centre*	
8:30		Opening Remarks Plenary *Chan Centre*	Exhibit Setup LSC Atrium					Plenary *Chan Centre*
9:00								
9:30								
10:00								
10:30		Break		Break		Break	Break	
11:00		Plenary *Chan Centre*		Plenary *Chan Centre*		Plenary *Chan Centre*	Plenary *Chan Centre*	Break
11:30								Plenary *Chan Centre*
12:00	Registration *Chan Centre*					IUPAP Award Session (13:20)Finish		
12:30		Lunch		Lunch (Student Lecture)			Lunch (Student Lecture)	Closing Remarks (13:15)Finish
13:00								
13:30								
14:00		Parallel Sessions *LSC & FSC*	Exhibits *LSC Atrium*	Parallel Sessions *LSC & FSC*	Exhibits *LSC Atrium*		Parallel Sessions *LSC & FSC*	
14:30	Reception *Chan Centre*							
15:00								
15:30		Break 15:35 - 16:10		Break 15:35 - 16:10			Break 15:35 - 16:10	
16:00	Public Lecture *Chan Centre*							
16:30								
17:00								TRIUMF Tour

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Plenary Program

Wednesday July 7 2010

Session 5: New Facilities and Instrumentation
Chairs: M. Borge (Spain)
R. Tribble (USA)

08:00-08:30	S. Nagamiya (J-PARC) *Overview Hadron Facilities*
08:30-09:00	B. Fulton (University of York) *Present and Future RIB Facilities*
09:00-9:30	J. Jowett (CERN) *Facilities for the Energy Frontier of Nuclear Physics*
9:30-10:00	N. Smith (SNOLAB) *Developments in Underground Facilities*

Session 6: Applications and Interdisciplinary Research
Chairs: B. Jonson (Sweden)
M. Pfutzner (Poland)

10:00-10:30	D. Dean (DOE) *Energy Future and Nuclear Physics*
10:30-11:00	Coffee
11:00-11:30	S. Kailas (Bhabha Atomic Research Centre) *Sub-critical Thorium Reactors Developments*
11:30-12:00	A. MacFarlane (UBC) *New Applications of Beta Detected NMR in the Study of Condensed Matter at the Nanoscale*

Day \ Room	LSC 2	LSC 3		LSC 1410		FSC 1005		FSC 1221		FSC 1001		FSC 1003		LSC 1510
Monday	NS1	NS7		SM1		NR1		NA1		HS1		NI1		NF1
14:00	**Hjorth-Jensen**	**Scheit**	14:00	**Mischke**	14:00	**Fonseca**	14:00	**Arcones**	14:00	**Badelek**	14:00	**Schaedel**	14:00	**Saunders**
14:25	Faestermann	Kruecken	14:25	**Heckel**	14:25	Stephan	14:25	**Wanajo**	14:25	Kaiser	14:25	**Morita**	14:25	**Ruth**
14:40	Ferreira	Yordanov			14:40	Bacca			14:40	Marchand				
14:55	Cederwall	Tshoo	14:50	Malbrunot	14:55	Sagara	14:50	Kajino	14:55	Karatsu	14:50	**Nitsche**	14:50	Herlert
15:10	Barrett	Charlwood	15:05	Lynch	15:10	Maeda	15:05	Kusakabe					15:05	Fox
15:25	Boutachkov	Al Falou	15:20	Saathoff	15:25	Lekala	15:20	Otsuki	15:10	**Richards**	15:15	**Schumann**	15:20	Papadakis
15:40-16:10	Coffee													
	NS2	NS8		SM2		NR2		NA2		HS2		NI2		NF2
16:10	**van Duppen**	**Bracco**	16:10	**Cirigliano**	16:10	**Thoennessen**	16:10	**Sonnabend**	16:10	**Meziani**	16:10	**Gaulin**	16:10	**Page**
16:35	Chamoli	Orce	16:35	Finlay	16:35	Ma	16:35	Liu	16:35	Doria	16:35	**Prokscha**	16:35	Uesaka
16:50	Coraggio	Savran	16:50	Liu	16:50	Di Pietro	16:50	Sfienti	16:50	Antognini			16:50	Shimizu
17:05	Gottardo	Volya	17:05	Murata	17:05	Kanungo	17:05	Rogers	17:05	Versteegen	17:00	**Lynn**	17:05	Sinha
17:20	Orlandini	Hyldegaard	17:20	Kim	17:20	Sparenberg	17:20	Pain					17:20	Blumenfeld
17:35	Holt	Tonchev	17:35	Ban	17:35	Sakaguchi	17:35	Togano	17:20	**Hemmert**	17:25	**Lacy**	17:35	Hackman
Tuesday	NS3	NS9		SM3		NR3		NR5		NN1		HN1		NI3
14:00	**Duguet**	**Ettenauer**	14:00	**Carey**	14:00	**Ogata**	14:00	**Rodrigues**	14:00	**Poves**	14:00	**Gal**	14:00	**Mayer**
14:25	Barbieri	Zhou	14:25	Kuno	14:25	**T. Nakamura**	14:25	Aichelin	14:25	**Heeger**	14:25	**Weise**	14:25	**Schroeder**
14:40	Ichikawa	Myo	14:40	Fujiwara			14:40	Tripathi						
14:55	Smirnova	Vigezzi	14:55	Gray	14:50	Madurga Flores	14:55	Cugnon	14:50	Fynbo	14:50	**Zmeskal**	14:50	Stocki
15:10	Bürger	Cavallaro	15:10	Gorelov	15:05	Chau	15:10	Ray	15:05	Mueller			15:05	Kretschmer
15:25	Kwiatkowski	Papadimitriou	15:25	Wauters	15:20	Crespo	15:25	Cai	15:20	Ransome	15:15	**Hayano**	15:20	Colonna
15:40-16:10	Coffee													
	NS4	NS10		HD1		NR4		NA3		NN2		HN2		NF3
16:10	**Egido**	**Greenlees**	16:10	**Casalderrey Solana**	16:10	**Cizewski**	16:10	**Brune**	16:10	**Fiorini**	16:10	**Millener**	16:10	**Savard**
16:35	Huyse	Berryman	16:35	Fernandez-Fraile	16:35	**Nunes**	16:35	Tagliente	16:35	Mackay	16:35	**Rios Huguet**	16:35	Lee
16:50	Heenen	Csige	16:50	David			16:50	Von Neumann-Cosel	16:50	Mosel			16:50	Gwinner
17:05	Miki	Bastin	17:05	Galatyuk	17:00	Carbone	17:05	Ishikawa	17:05	Wang	17:00	**Schadmand**	17:05	Hong
17:20	Petri	Karwowski	17:20	Linnyk	17:15	Guimaraes	17:20	Jiang	17:20	Brunner			17:20	Lebois
17:35	Liang	Wilson	17:35	Zhang	17:30	Furumoto	17:35	Pereira	17:35	Meierhofer	17:25	**Filippi**	17:35	Lewitowicz
Thursday	NS5	NS11		HD2		NR6		NA4		HS3		HN3		NF4
14:00	**Rykaczewski**	**Afanasjev**	14:00	**Hemmick**	14:00	**Nishio**	14:00	**Hebeler**	14:00	**Distler**	14:00	**Grabmayr**	14:00	**Strieder**
14:25	Jungclaus	Herfurth	14:25	Tatsumi	14:25	Dressler	14:25	**Li**	14:25	Myers	14:25	**Oset**	14:25	Lauss
14:40	Baroni	Tamii	14:40	Linnyk	14:40	Barbui			14:40	S. Nakamura			14:40	Nagy
14:55	Galindo-Uribarri	Kay	14:55	Stroebele	14:55	Hamilton	14:50	Maruyama	14:55	Lin	14:50	Pomerantz	14:55	Lauer
15:10	Nakatsukasa	Howard	15:10	Roehrich	15:10	Andrade-Segundo	15:05	Bandyopadhyay			15:05	Tolos	15:10	Masuda
15:25	Petrovici	Heusler	15:25	Aamodt	15:25	Hussein	15:20	Shen	15:10	**Platter**	15:20	Mosel	15:25	Neveling
15:40-16:10	Coffee													
	NS6	NS12		HD3		NR7		NA5		HS4		HN4		NF5
16:10	**Carpenter**	**Gaggeler**	16:10	**Schenke**	16:10	**Greco**	16:10	**Brown**	16:10	**Kumano**	16:10	**Reinhold**	16:10	**Noble**
16:35	Toivanen	S.N. Nakamura	16:35	Aichelin	16:35	Yennello	16:35	**Gasques**	16:35	**McKeown**	16:35	Suzuki	16:35	Sugitate
16:50	Watanabe	Alcorta	16:50	Stachel	16:50	Papa					16:50	Bufalino	16:50	H. Takahashi
17:05	Zhu	Kubo	17:05	Kunde	17:05	Kumar	17:00	Suzuki	17:00	**Bettoni**	17:05	Hashimoto	17:05	T. Takahashi
17:20	Leoni	Chudoba	17:20	Nouicer	17:20	Verde	17:15	Bandyopadhyay			17:20	Nakazawa	17:20	Shirotori
17:35	Iwasaki	Wang	17:35	Steinberg	17:35	Gauthier	17:30	Ha	17:25	**Kinney**	17:35	Umeya	17:35	Suzuki

Building

FSC Forest Sciences Centre
LSC Life Sciences Centre

Session

HD Hot and Dense QCD
HN Hadrons in Nuclei
HS Hadron Structure
NA Nuclear Astrophysics
NF New Facilities and Instrumentation
NI Nuclear Applications and Interdisciplinary Research
NN Neutrinos and Nuclei
NR Nuclear Reactions
NS Nuclear Structure
SM Standard Model Tests and Fundamental Symmetries

Science and Innovation:

U.S. Department of Energy

David J. Dean
Senior Advisor
Office of the Under Secretary for Science
Department of Energy

INPC
July, 2010

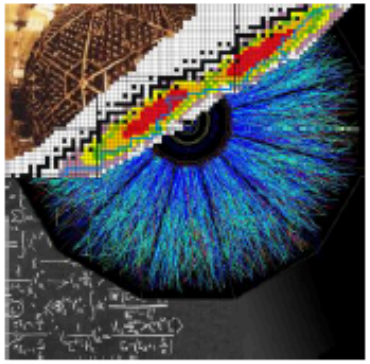
What is the U.S. policy framework?

- President Barack Obama
  - "So we have a choice to make. We can remain one of the world's leading importers of foreign oil, or we can make the investments that would allow us to become the world's leading exporter of renewable energy. We can let climate change continue to go unchecked, or we can help stop it. We can let the jobs of tomorrow be created abroad, or we can create those jobs right here in America and lay the foundation for lasting prosperity."
  - "Whether it is improving our health or harnessing clean energy, protecting our security or succeeding in the global economy, our future depends on reaffirming America's role as the world's engine of scientific discovery and technological innovation"

DOE priorities that meet the President's challenge

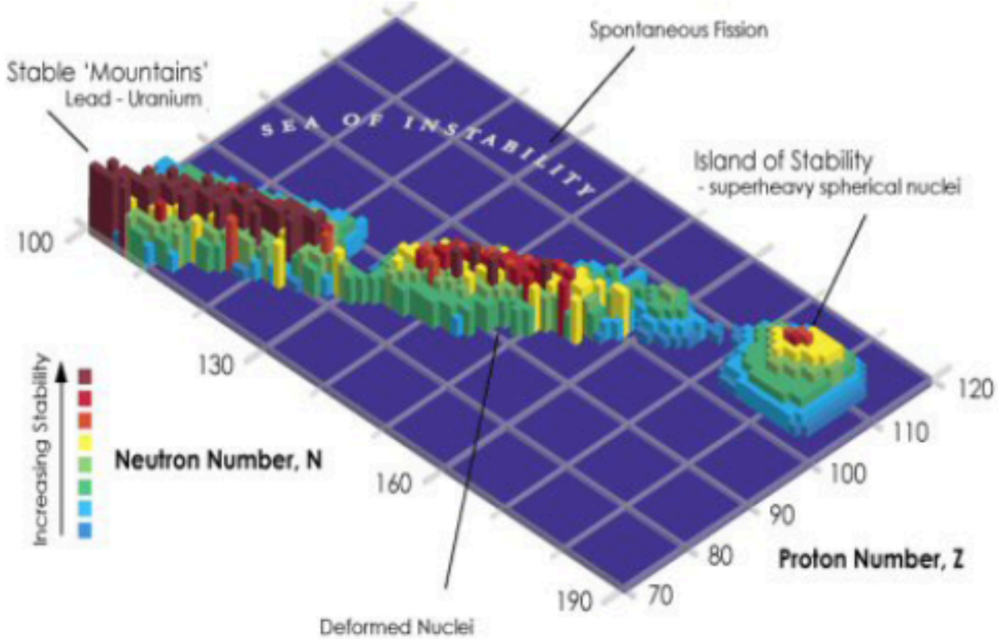
- Sustain **basic research,** discovery and mission driven
- Catalyze a transformation of the national/global **energy system**
- Enhance **nuclear security**
- Contribute to **US competitiveness** and jobs

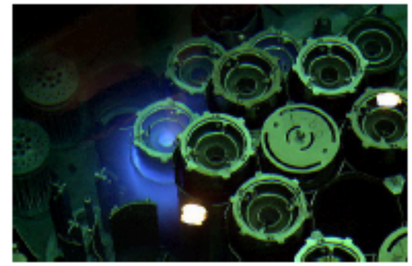
Outline of talk

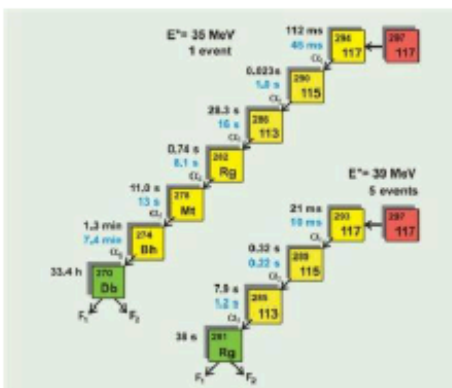


I. Scientific Discovery in Nuclear Physics
II. Simulation: Nuclear Physics Examples
III. Energy and the Environment
IV. Innovation and Competitiveness through Simulations

Scientific Discovery: Element 117







ORNL, LLNL, Vanderbilt, Dubna

Phys. Rev. Lett. **104**, 142502 (2010)

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7

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DOE provides extreme scale computing today: 15 years of world leadership

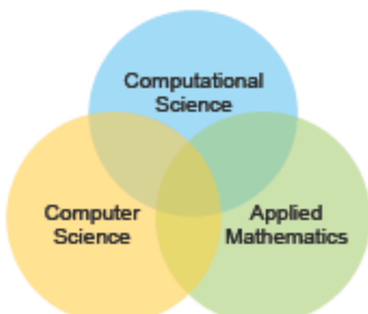
The Office Of
Advanced Scientific Computing Research

NNSA
Advanced Simulation and Computing

Top 500 list, June 2010

Machine	Place	Speed (max)	On list Since
Jaguar	ORNL	1.75 PF	2009 (1)
Roadrunner	LANL	1.04 PF	2009 (3)
Dawn	LLNL	0.478 PF	2007 (8)
BG/P	ANL	0.458 PF	2007 (9)
Red Sky (NREL)	SNL	0.434 PF	2010 (10)
Red Storm	LLNL	0.416 PF	2009 (12)
NERSC	BNL	0.266 PF	2008 (18)

INCITE: 2.5x oversubscribed



ASC and ASCR *provide much more than machines*:
- Applications (Computational Science)
- Algorithms (Applied Mathematics)
- Systems (Computer Science)
- Integration (SciDAC, Campaigns)

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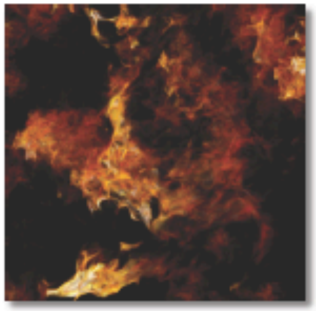
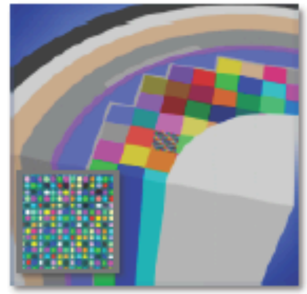
Simulations have come of age in Science and National Security



Turbulence

Understanding the statistical geometry of turbulent dispersion of pollutants in the environment.

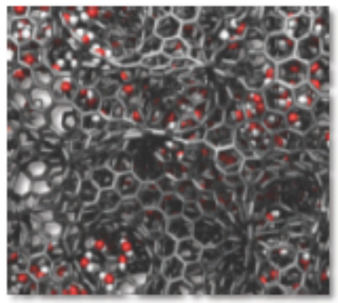


Nuclear Energy

High-fidelity predictive simulation tools for the design of next-generation nuclear reactors to safely increase operating margins.

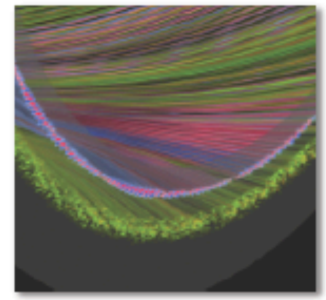
Energy Storage

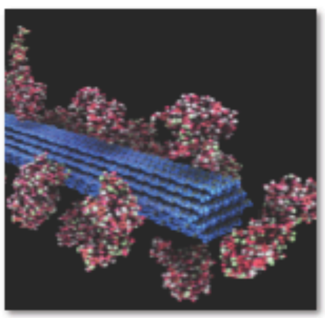
Understanding the storage and flow of energy in next-generation nanostructured carbon tube supercapacitors



Fusion Energy

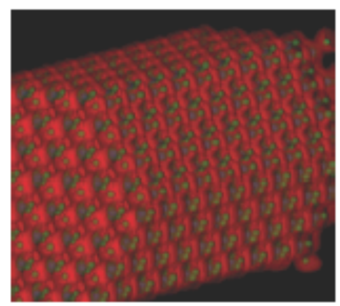
Substantial progress in the understanding of anomalous electron energy loss in the National Spherical Torus Experiment (NSTX).





Biofuels

A comprehensive simulation model of lignocellulosic biomass to understand the bottleneck to sustainable and economical ethanol production.



Nano Science

Understanding the atomic and electronic properties of nanostructures in next-generation photovoltaic solar cell materials.

All known sustained petascale science applications to date have been run on OLCF system

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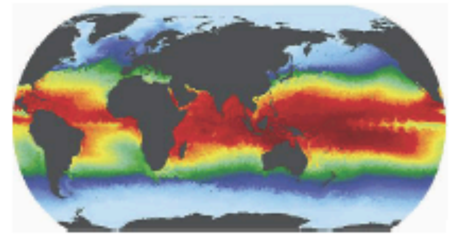
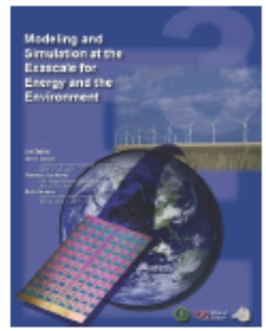
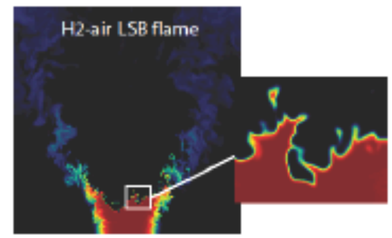
Simulation has become an important means toward innovation in science and national security: Extreme Scale Workshops

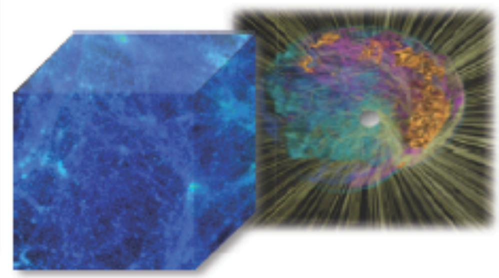
- Town Hall Meetings April-June 2007
- Scientific Grand Challenges Workshops November 2008 – October 2009
  - Climate Science (11/08)
  - High Energy Physics (12/08)
  - Nuclear Physics (1/09),
  - Fusion Energy (3/09),
  - Nuclear Energy (5/09) (with NE)
  - Biology (8/09)
  - Material Science and Chemistry (8/09),
  - National Security (10/09) (with NNSA)
- Cross-cutting workshops
  - Architecture and Technology (12/09)
  - Architecture, Applied Mathematics and Computer Science (2/10)
- Meetings with industry (8/09, 11/09)
- External Panels
  - ASCAC Exascale Charge (FACA)
  - Trivelpiece Panel







MISSION IMPERATIVES



FUNDAMENTAL SCIENCE

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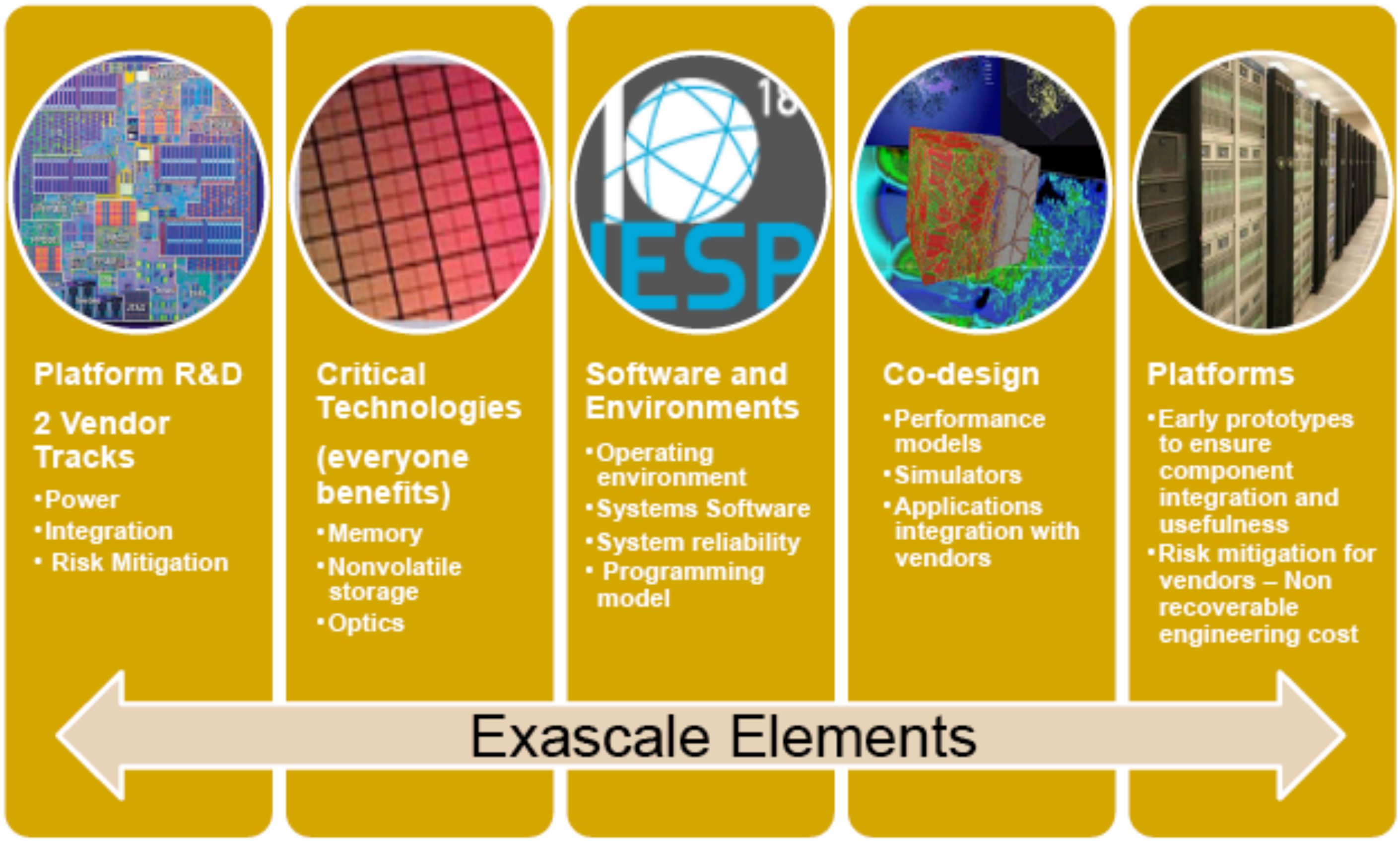
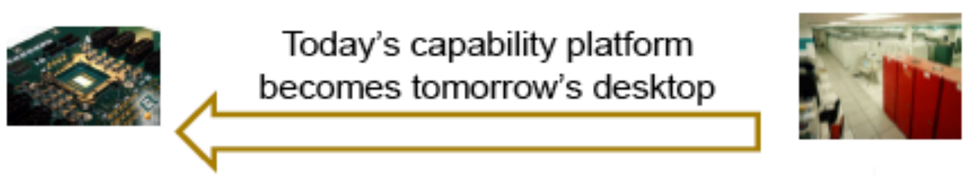
Exascale Program Elements





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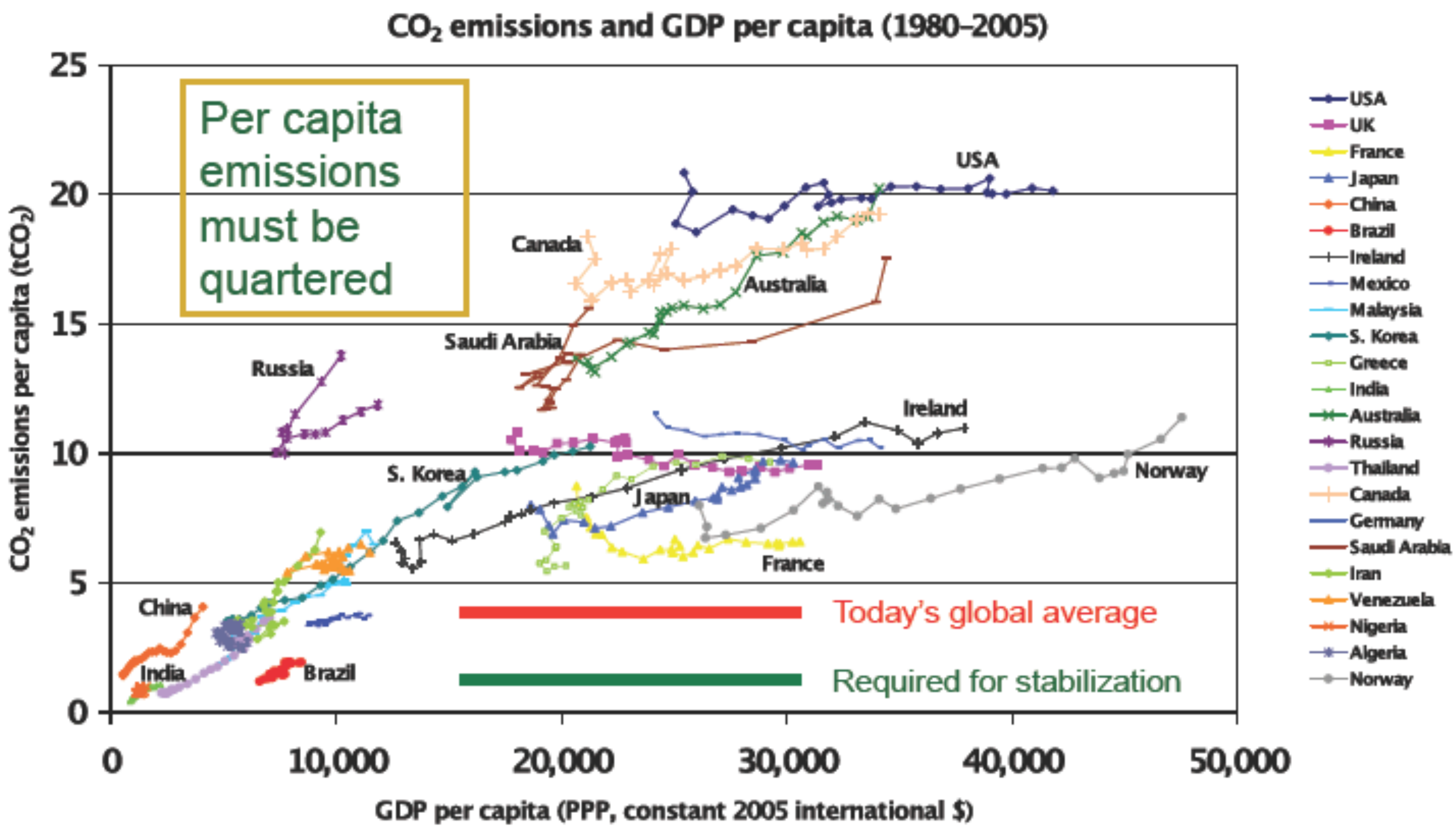
CO_2 emissions and GDP per capita



Source: DOE EIA database (2008)
Russia data 1992-2005, Germany data 1991-2005

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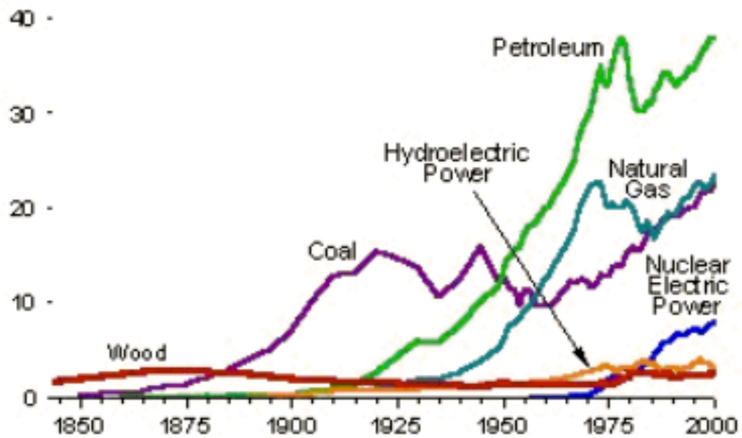
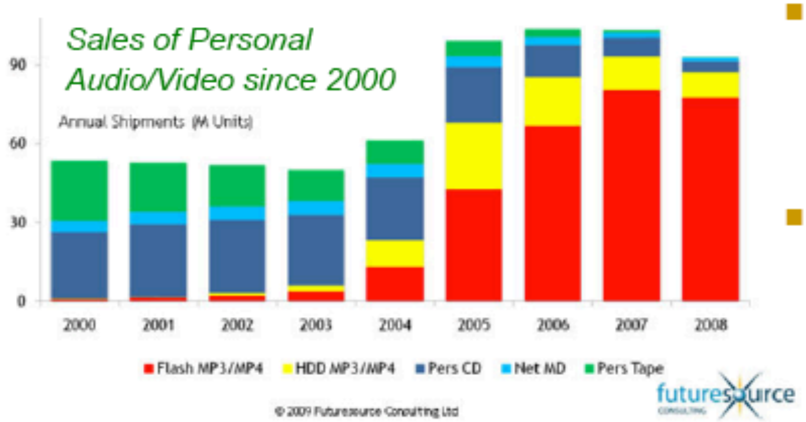
What about Innovation?

U.S. Energy Supply since 1850



Source: EIA

- Ubiquity – consider economic, social and political costs
- Longevity – Stock of existing assets
- Scale – large capital assets and access to existing infrastructure
- Incumbency – New technologies compete on cost



- Demand structural features allow rapid learning
  - Multiple units
  - Smaller capital cost
  - More rapid turnover
- Demand responds to the right signals
  - Perceived price
  - Standards
  - Behavior

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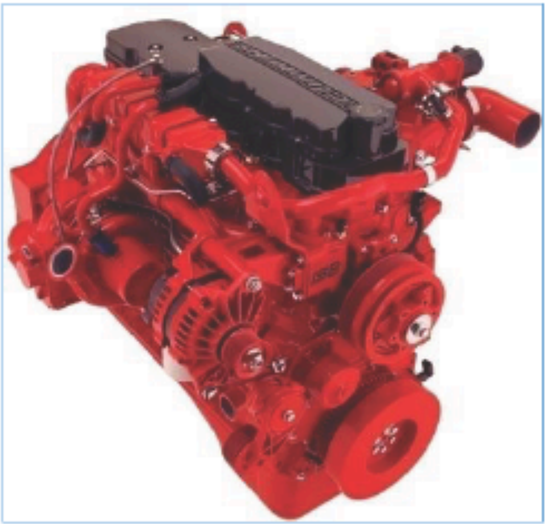
The US must accelerate innovation to remain competitive: Examples



Cummins achieved a milestone in engine design by bringing a diesel engine, the 2007 ISB 6.7 liter, to market solely with computer modeling and analysis tools. The only testing was after-the-fact to confirm performance. Cummins achieved a reduction in development time and cost (estimated to be about 10 to 15% for this first effort). As important, they realized a more robust design, improved mileage, and met all environmental and customer constraints.

Goodyear's Assurance® Triple Tred all-weather tire was its first product designed using predictive modeling simulation tools developed in conjunction with Sandia National Laboratories. This tire and the subsequent products utilizing advanced modeling capabilities resulted in a factor of three reduction in product development time and led to record profits for Goodyear.

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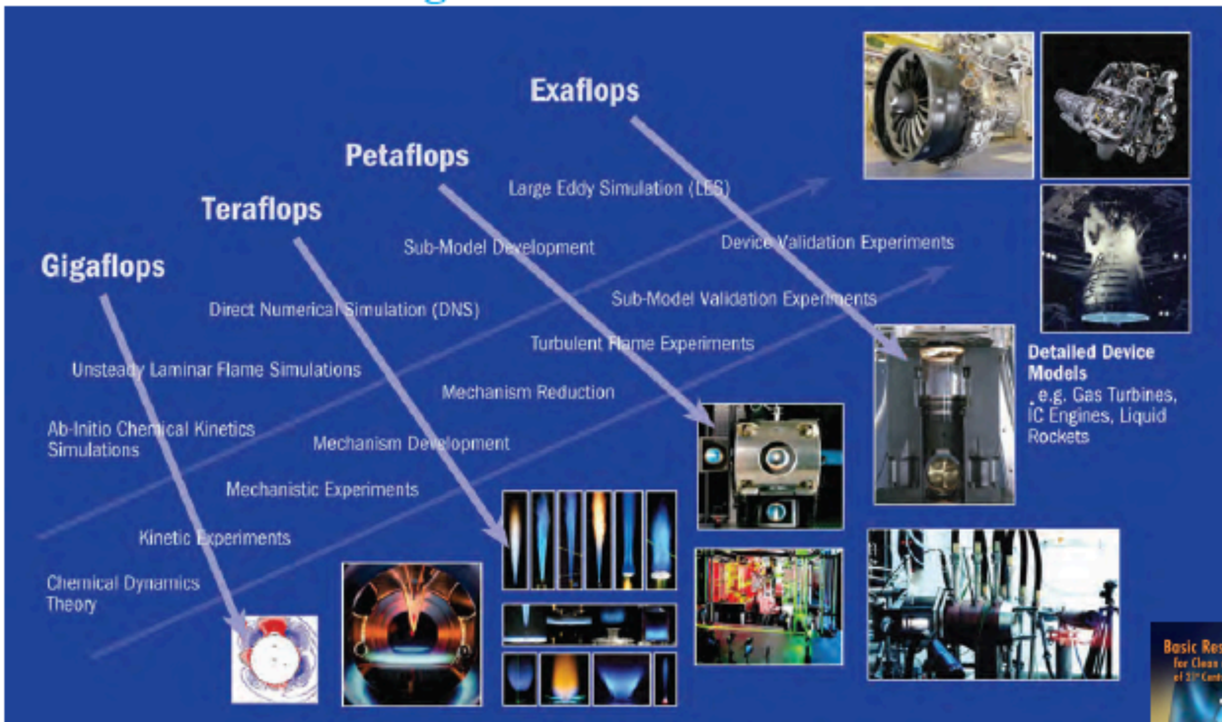
Simulation combines HPC with experiments and observations: Combustion – accelerating innovation



Develop a validated, predictive, multiscale, combustion modeling capability that can optimize the design and operation of evolving fuels in advanced engines and power plants.

Thousands of design iterations – each corresponding to a high-fidelity multiscale simulation –would accelerate optimization and implementation of new technologies.

CASL vision: Create a virtual reactor (VR) for *predictive* simulation of LWRs

Leverage

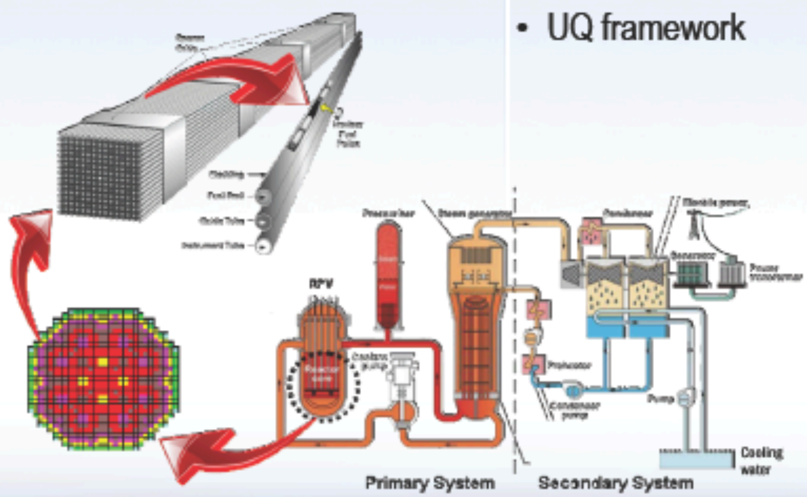
- Current state-of-the-art neutronics, thermal-fluid, structural, and fuel performance applications
- Existing systems and safety analysis simulation tools

Develop

- New requirements-driven physical models
- Efficient, tightly-coupled multi-scale/ multi-physics algorithms and software with quantifiable accuracy
- Improved systems and safety analysis tools
- UQ framework

Deliver

- An unprecedented predictive simulation tool for simulation of physical reactors
- Architected for platform portability ranging from desktops to DOE's leadership-class and advanced architecture systems (large user base)
- Validation basis against 60% of existing U.S. reactor fleet (PWRs), using data from TVA reactors
- Base M&S LWR capability



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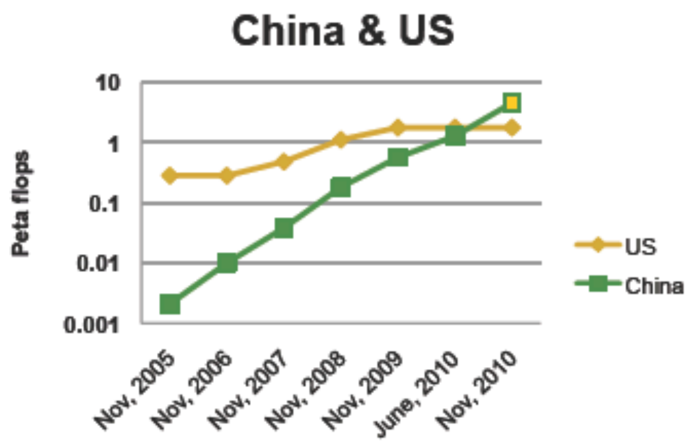
Competitiveness: Example from Computing



- US leads today in HPC
- China is pursuing HPC vigorously;
- By November, 2010:
  - 3-6 PF machine Chinese integrated from US accelerators by November
  - 1 PF full Chinese machine
  - China likely #1 on the Top 500 list in November

- US Companies involved in HPC

> **"The United States led the world's economies in the 20th century because we led the world in innovation. Today, the competition is keener; the challenge is tougher; and that is why innovation is more important than ever. It is the key to good, new jobs for the 21st century." --*President Barack Obama, August 5, 2009***

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Simulation – the ability to predict

- US must lead in innovation and high-end manufacturing to be competitive in a global economy
  - New technologies, optimal designs, shorter design cycles, faster transition to scale
  - Optimizing complex systems for efficiency, reliability, security
- Simulation has become an important means toward these goals in science and national security
  - Methodology combining HPC with models, experiments, data
  - US best in world, but others moving rapidly
- For-profit sector has lagged in applying simulation
  - Only a hand-full of Fortune 50 companies
  - In-house capabilities usually lag national laboratories, academia
- Two-pronged initiative to more fully exploit simulation
  - Make simulation a unique asset for US industry
    - Transfer current capabilities, create workforce, software, hardware
  - Advance simulation through Exascale computation

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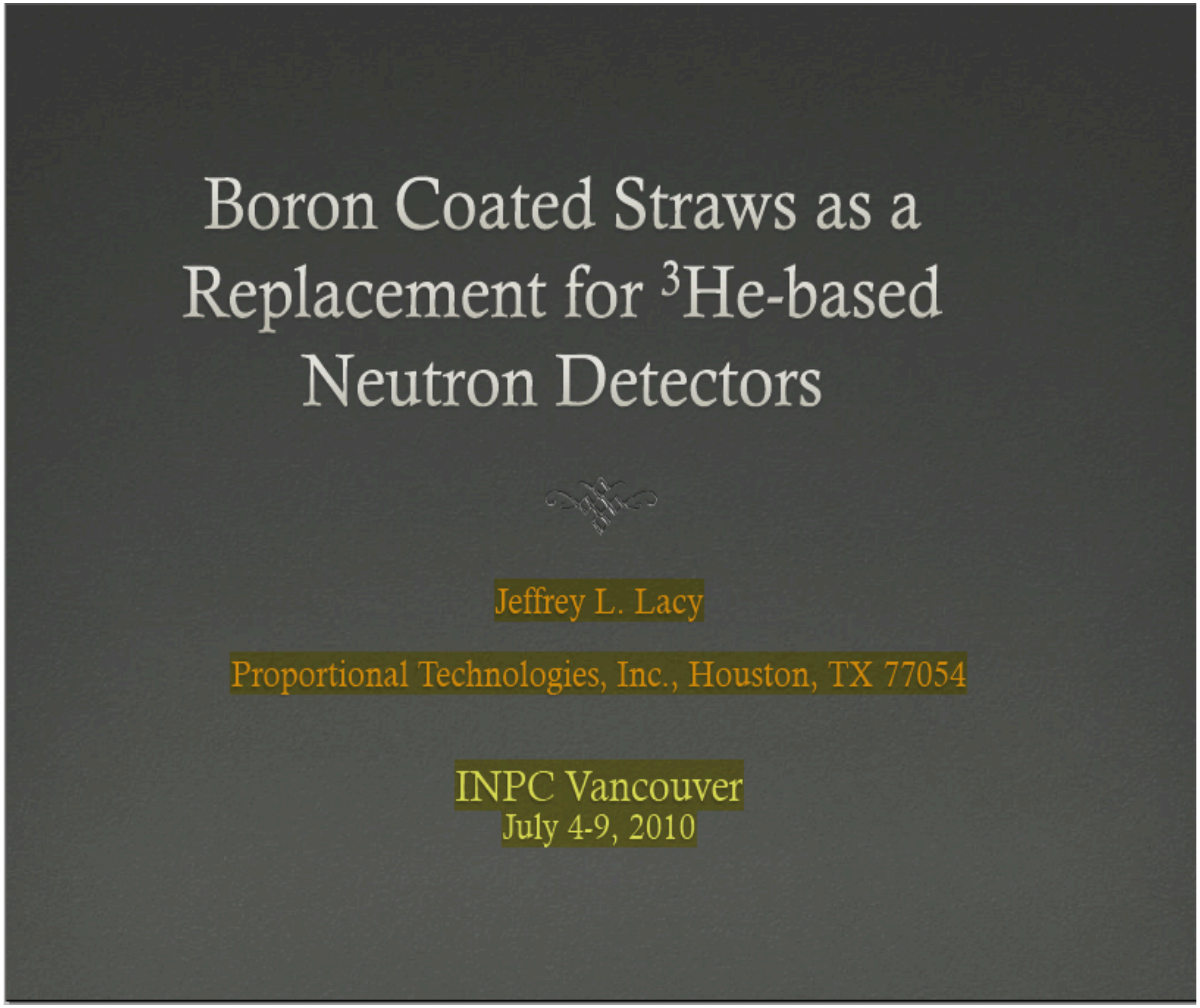

Boron Coated Straws as a Replacement for ^{3}He-based Neutron Detectors
Jeffrey L. Lacy
Proportional Technologies, Inc., Houston, TX 77054
INPC Vancouver
July 4-9, 2010

The need for ^{3}He-replacement technologies

World ^{3}He Applications	World demand (2009-2014):
neutron scattering *125 kliters needed from 2009-2015	~20 kliters/yr
security applications (US)	~22 kliters/yr
industrial, medical (US)	~8 kliters/yr
safeguards (fission counters)	~20 kliters/yr
DEMAND *TOTAL*:	~70 kliters/year

World ^{3}He supply (2009-2014): in the short term ^{3}He is only available from the US and Russia; the global supply total during this period as reported by the ^{3}He supply crisis meeting, Munich July 2009 is SUPPLY TOTAL ~20 kliter/year.

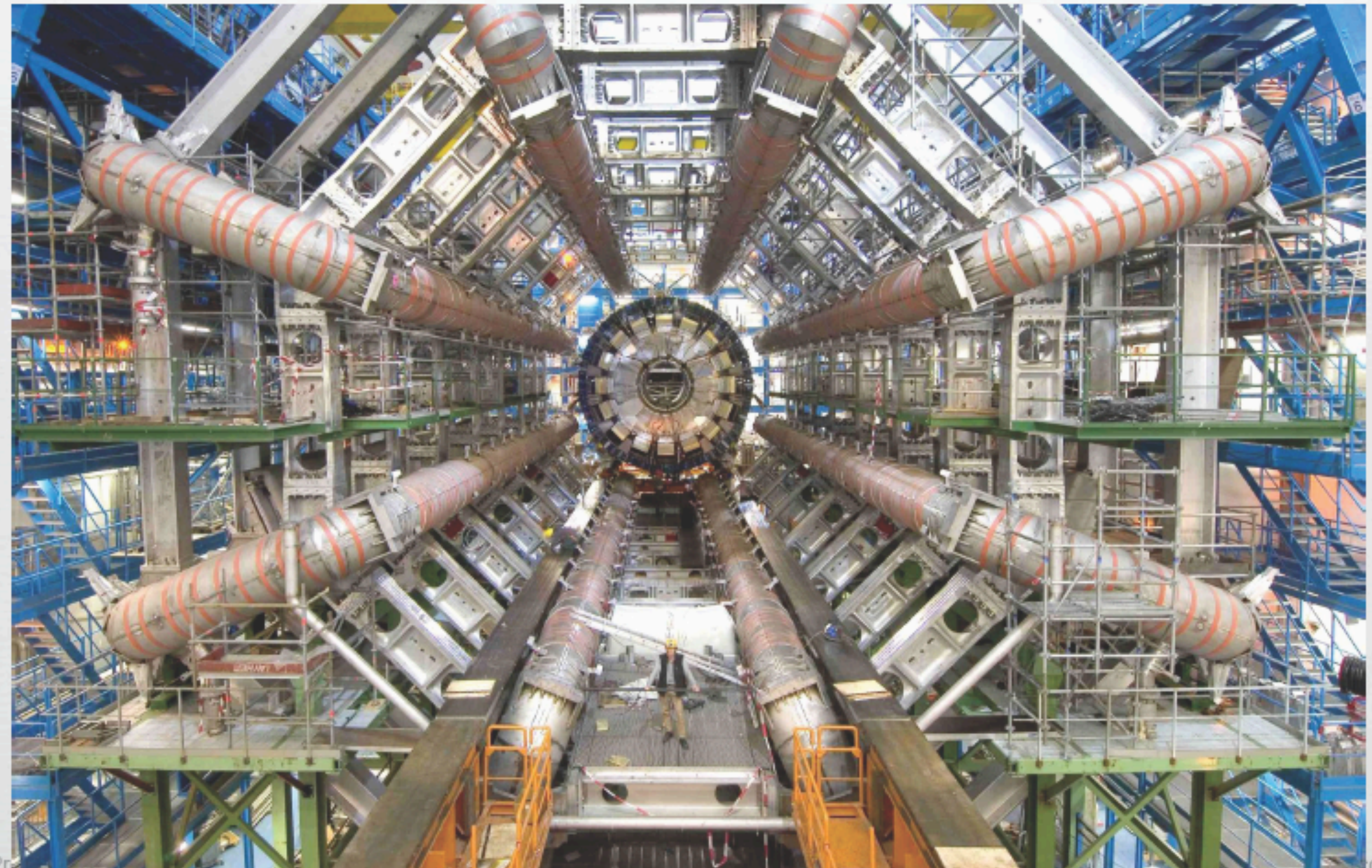
World Short Fall → 50 kliters/year

Sources

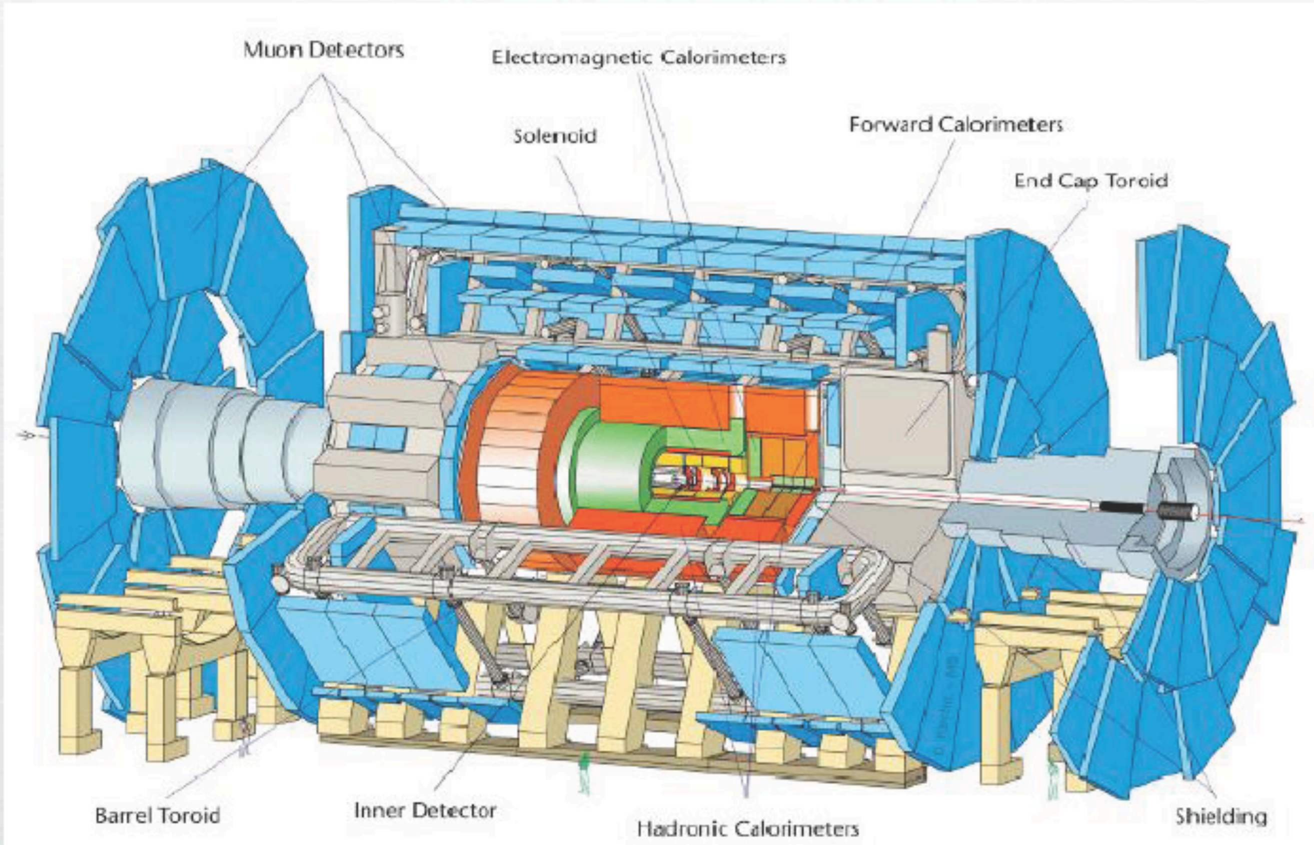
- Helium detector expert group, *"The ^{3}Helium supply crisis and alternative techniques to ^{3}Helium based neutron detectors for neutron scattering applications"*. proc. of meeting held at FRM II, Munich, July 2009.
- "Helium-3 Issues and Alternatives Workshop", Savannah River National Laboratory, June 2009.
- R. L. Kouzes, *"The ^{3}He supply problem"*, PNNL report 18388, April 2009.

CERN ATLAS

(under construction 2005)



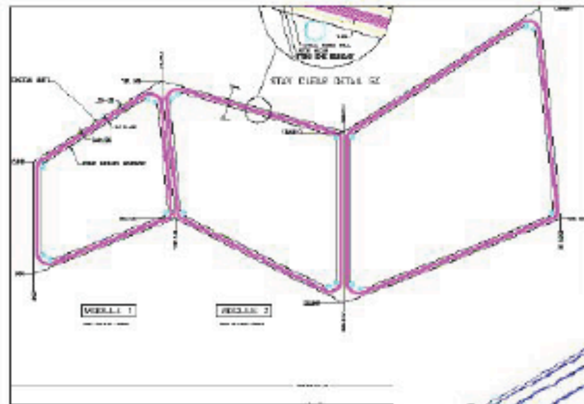
ATLAS

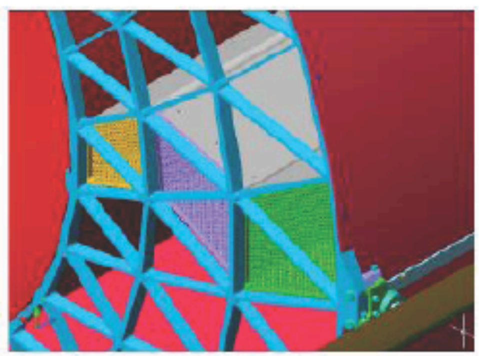

Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

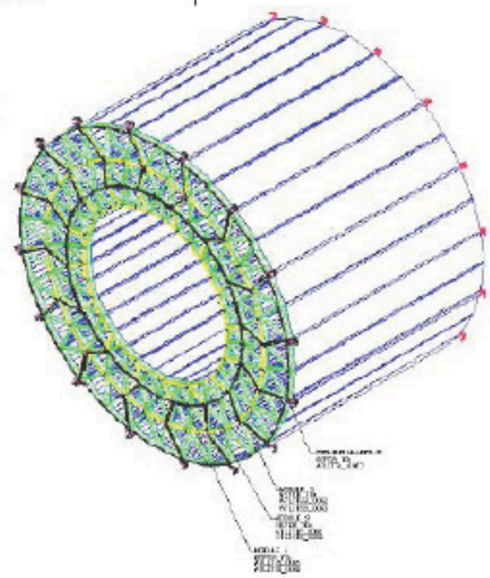
Barrel detector

Type 1 32 * 329 straws
=10528
Type 2 32* 520 straws
=16640
Type 3 32* 793 straws
=25376

52544 total straws



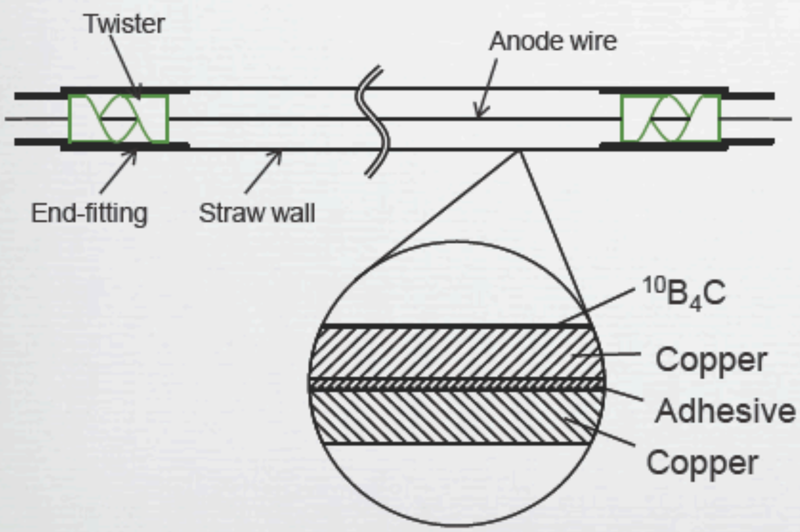




LBNL and Tech Source Inc.

Boron-coated Straw Detectors

$$^{10}B + n \longrightarrow \begin{cases} ^{7}Li + \alpha & 2.79\ \text{MeV} \\ ^{7}Li^{*} + \alpha & 2.31\ \text{MeV} \end{cases}$$



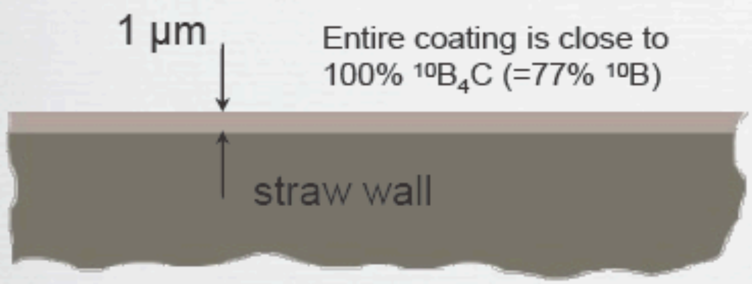
Proportional Technologies, Inc.   INPC 2010, July 5, Vancouver

LBNL and Tech Source Inc.

Coating techniques

Physical Vapor Deposition

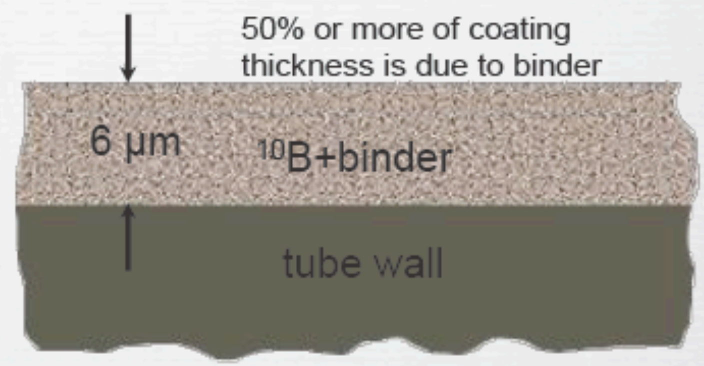
in Boron-Coated Straw (BCS)



- *Example: for* 1 µm of $^{10}B_4C$ (equivalent to 0.18 mg/cm^2 of ^{10}B), the escape efficiency for the $^{10}B(n,\alpha)$ reaction products is 78%

Spray painting

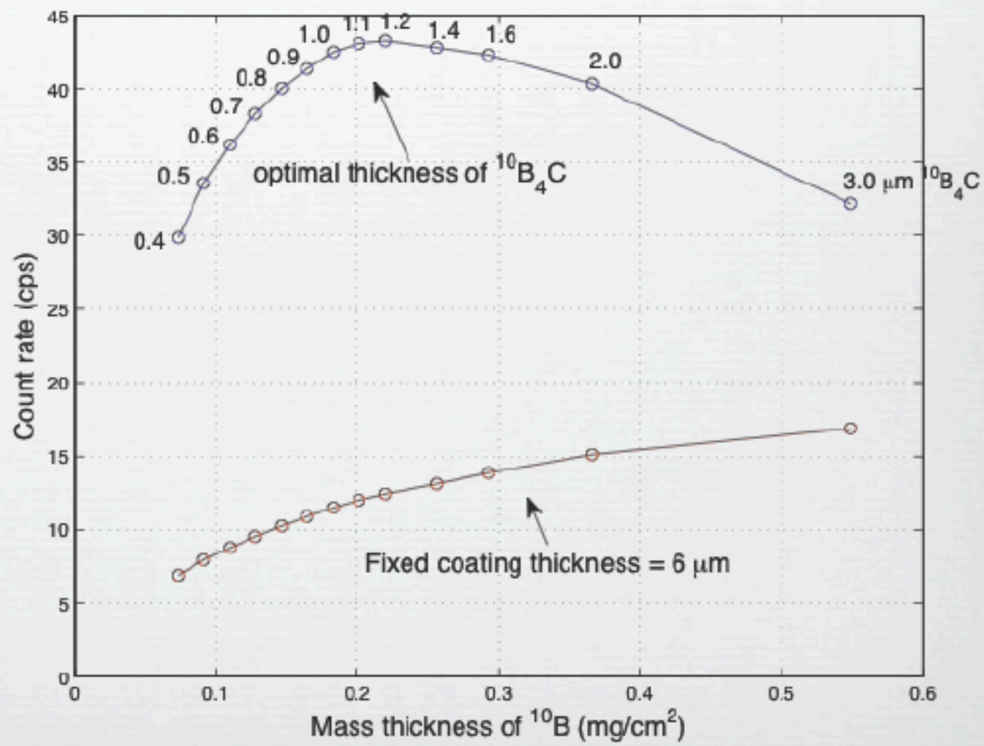
in Boron-Lined Counter (BLC)



- *Example:* escape efficiency for 6 µm coating is 21%

Coating techniques

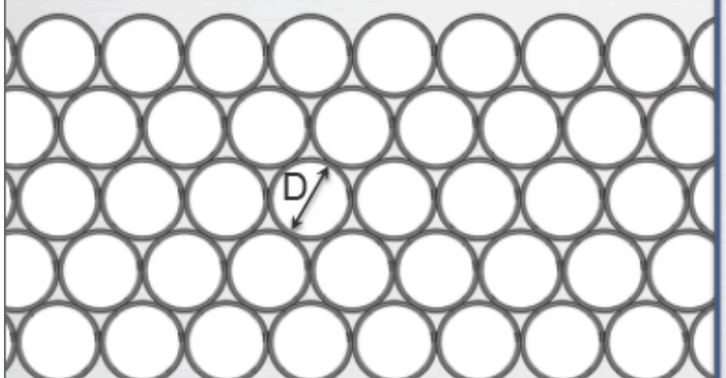
- Straw detectors coated with the optimal thickness of $^{10}B_4C$ have the maximum possible escape efficiency
- Conventional boron-lined counters have thicker coatings, due to the addition of binders, resulting in very low escape efficiency.



Detection efficiency of dense array

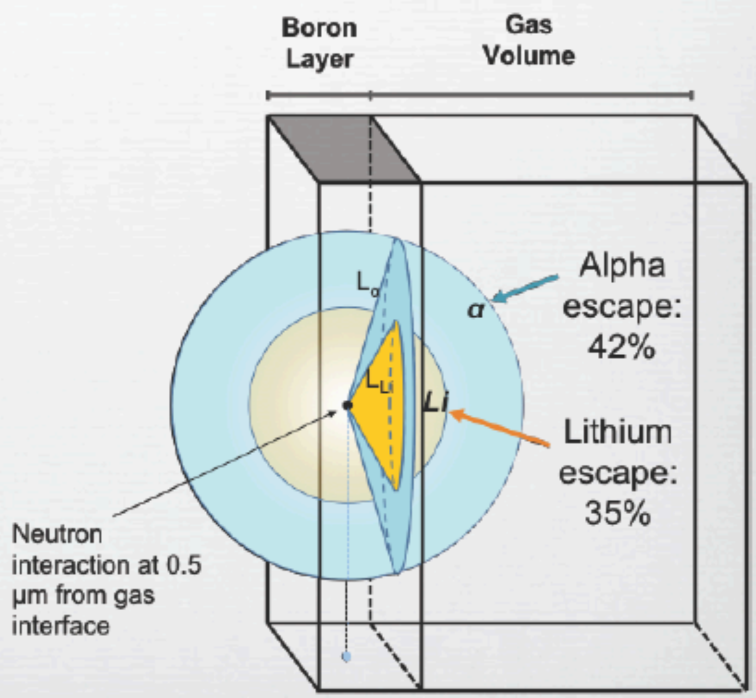
Effective density of ^{10}B in straw array

$$\rho_e \approx \frac{\pi d}{0.866D}\frac{40}{52}\rho$$



For d=1 μm; D=4 mm ➔ ρ_e=1.7 mg/cm^3

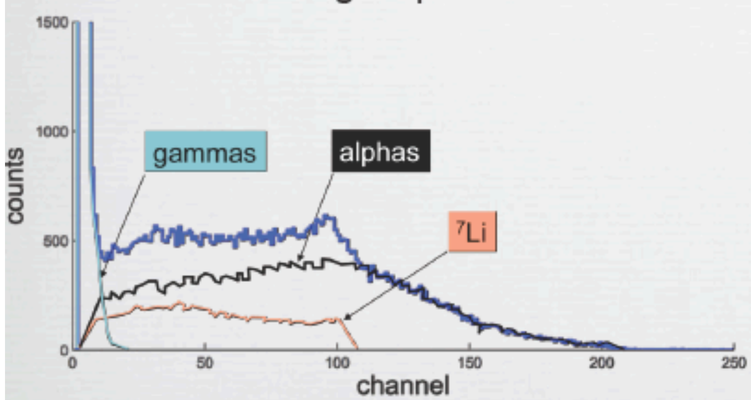
Wall escape



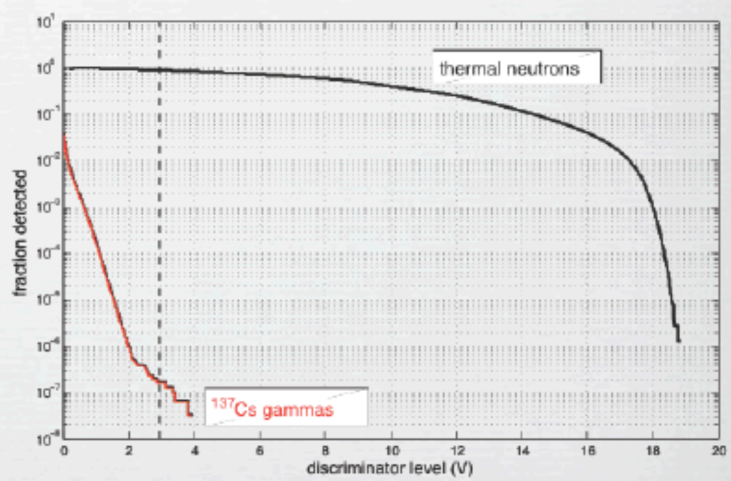
Gamma rejection

Energy loss to ionization
- Alphas in argon gas: 200 keV/mm
- Electrons in argon gas: 0.25 keV/mm

Pulse height spectra



Gamma rejection



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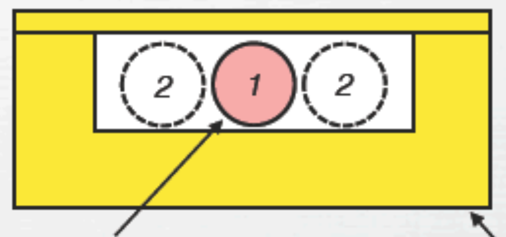
Radiation Portal Monitor (RPM) ^{3}He Replacement

Typical RPM installation with 4 panels - over 1500 installed ~70,000 liters ^{3}He

<u>^{3}He-based RPM</u>

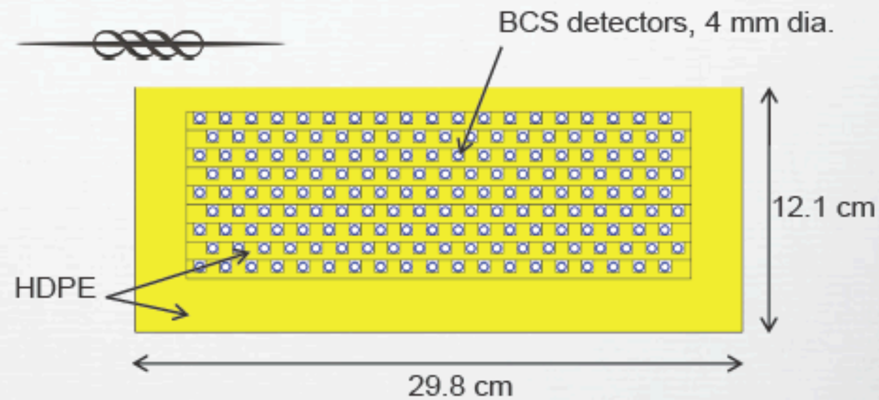


Count rate for a ^{252}Cf source at 2 m, emitting 20,000 n/s :

- 1 ^{3}He tubes – 22 cps
- 2 ^{3}He tubes – 32 cps

Straw-based RPM

- A moderator block formed by bonding together long slabs of HDPE
- Long square grooves machined into each slab, to accommodate up to 171 straw detectors.
- Straws - 4 mm in diameter and 200 cm long



LBNL and Tech Source Inc.

Replacing ^{3}He in RPMs

• Because of their small size, straw detectors can be distributed with high granularity in the converter providing much more efficient detection than large, pressurized ^{3}He tubes.

• As a result, the sensitivity equivalency for RPMs is significantly improved, compared to the moderator-free case (for which 1 liter ^{3}He = 34.5 m of straw):

1 RPM panel (11.4 liters of ^{3}He) = 160 meters of 4 mm straws§

1 liter of ^{3}He = 14 meters of 4 mm straws§

§ coated with 1 μm of $^{10}B_4C$

^{10}B Resource Requirement for Existing RPM Replacement

• Current RPM deployments :	70,000 liters of ^{3}He
• Required length of straws :	980,000 meters
• Required amount of $^{10}B_4C$:	29 kg
• Commercial production of ^{10}B :	10,000 kg annually

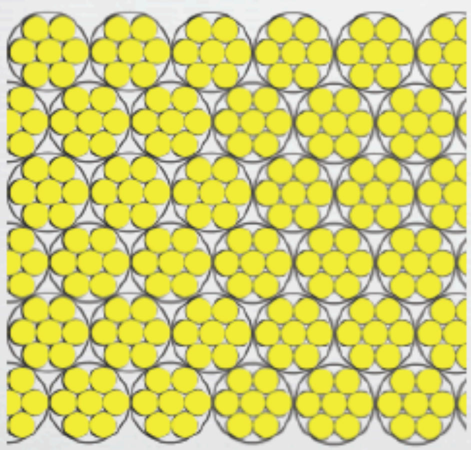
• Current cost of $^{10}B_4C$ material in 4 mm straw§ :	\$1.40 per meter
• Current cost of finished 4 mm straw§:	\$100 per meter
• Current cost to replace single RPM panel : (11.4 liters of ^{3}He)	\$16,000
• Current cost of straw-based RPM installation with 4 panels (2 panels on either side of drive-through lane) :	\$64,000

§ coated with 1 µm of $^{10}B_4C$

Large Inelastic Neutron Scattering Detector Replacement

- The ILL Grenoble detector shown below right contains **2700 liters** of ^{3}He
- For replacement with 8 mm straw detectors, 46,575 m of straw are needed
- These 8 mm straw detectors can be 3 m long each, and packed in bundles of 7, inside 1" OD tubes, as shown below left
- The required configuration is **~6 layers** of these 1" tubes, with **394 tubes** in each layer

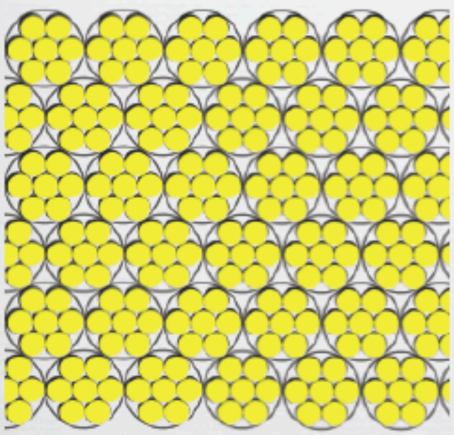
Straw-based replacement

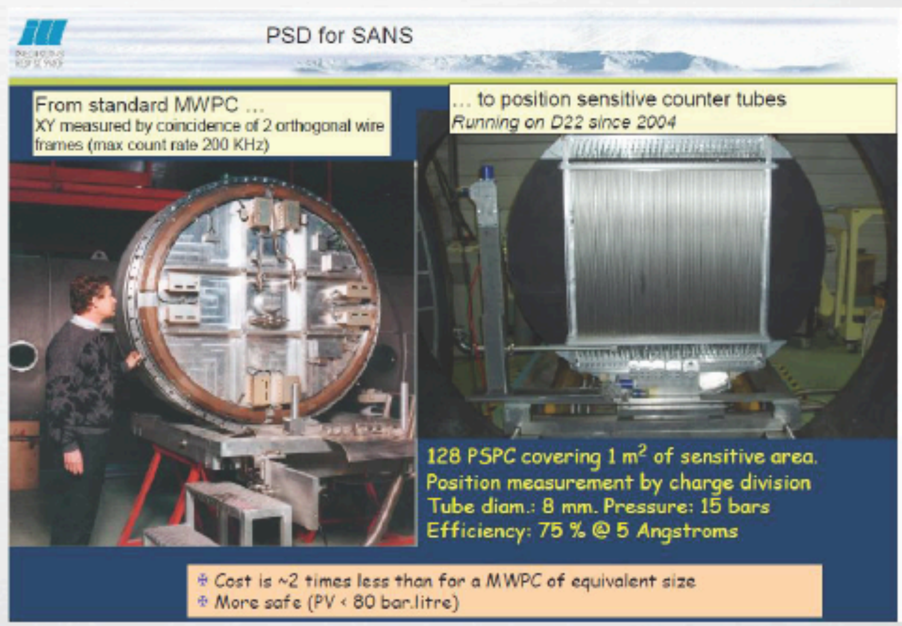


Small Angle Neutron Scattering SANS Detector Replacement

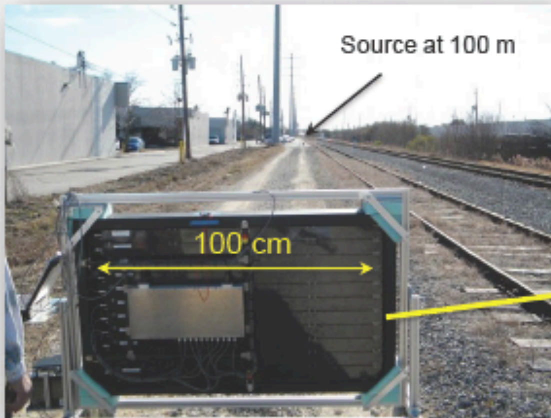
- The 1 x 1 m^2 SANS detectors shown on the right contain **~96.5 liters** of ^3He
- For replacement with 8 mm straw detectors, 1665 m of straw are needed
- Using the 1" OD bundles, the required configuration is **~6 layers**, with **39 tubes** in each layer.

Straw-based replacement

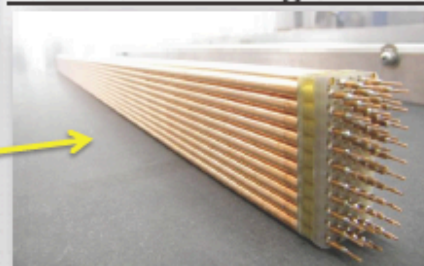




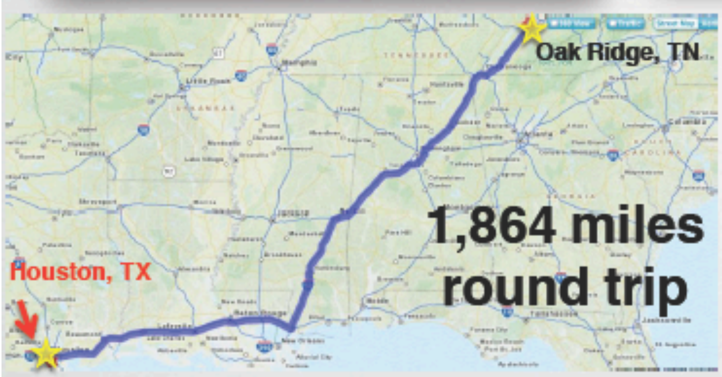
Replacement of ^{3}He in Portable Field Applications

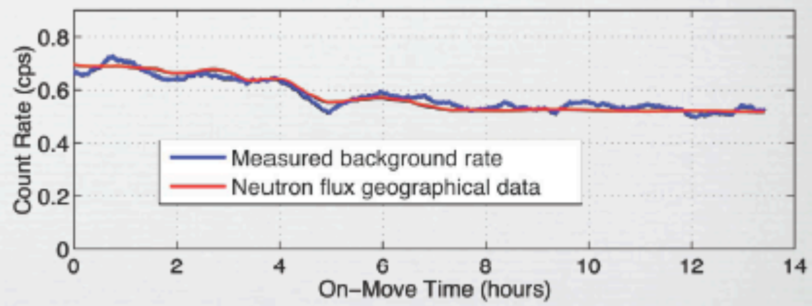


50-straw module, with 100 cm long straws



- Eleven detectors
  – 550 total straws
- High sensitivity
- Low weight
- Rugged
- High shock and vibration resistance





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Conclusion

- The Boron-coated straw (BCS) detector is a relatively mature technology that offers an exceptionally robust, low cost solution to ^{3}He replacement.
- Because of its simplicity and maturity, neutron straws offer a short cycle time to full scale deployment.
- The BCS detector not only offers a replacement solution but promises to improve performance in the largest scale neutron detection applications.

Fission Cross-Sections of Minor Actinides for Advanced Reactor Systems: New Data from n_TOF (CERN)

International Nuclear Physics Conference 2010 Vancouver INPC

n_TOF

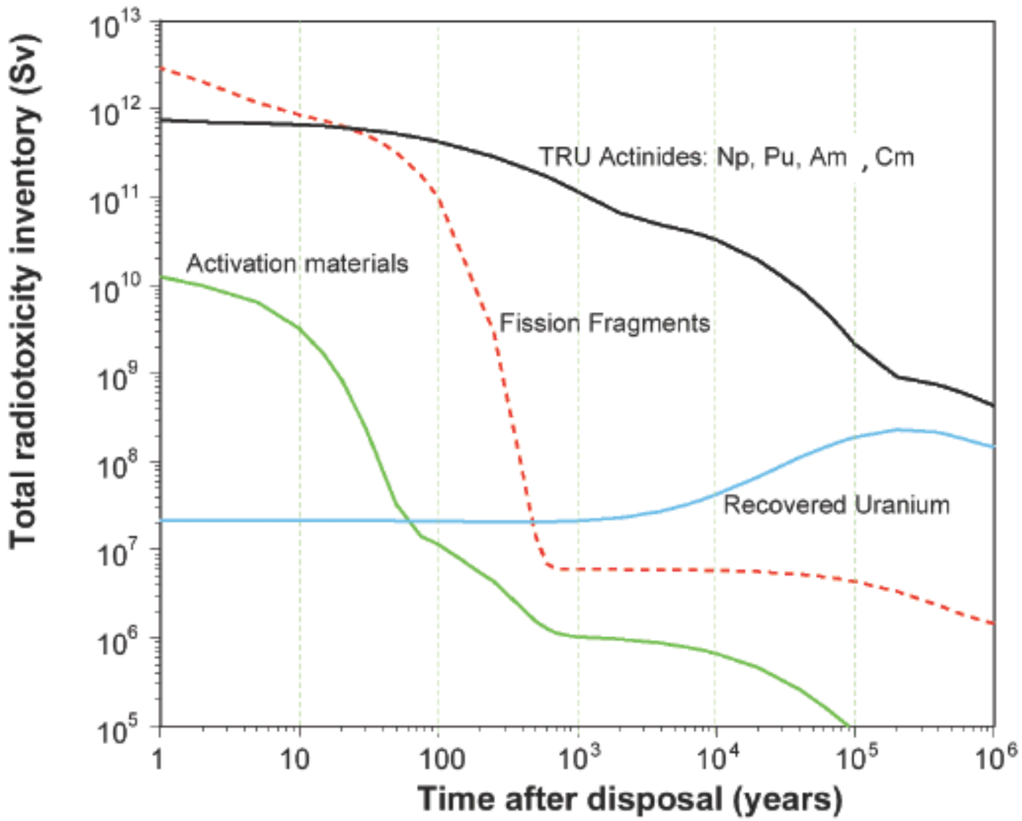
Giuseppe Tagliente

n_TOF collaboration

giuseppe.tagliente@ba.infn.it

INFN ISTITUTO NAZIONALE DI FISICA NUCLEARE

The actinide problem



Main problem in the nuclear waste are the **transuranic actinides:** Pu and MA (Np, Am, Cm,...)

- 1.5% in mass but give the biggest contribution to **radiotoxicity** and heat after 100 y
- problem persists for more than **10^5 y**
- some isotopes are **fissionable** (proliferation and criticality concern).

At present, only solution to the high radiotoxicity nuclear waste is **geological repositories**

Actinide burning in Gen IV reactors

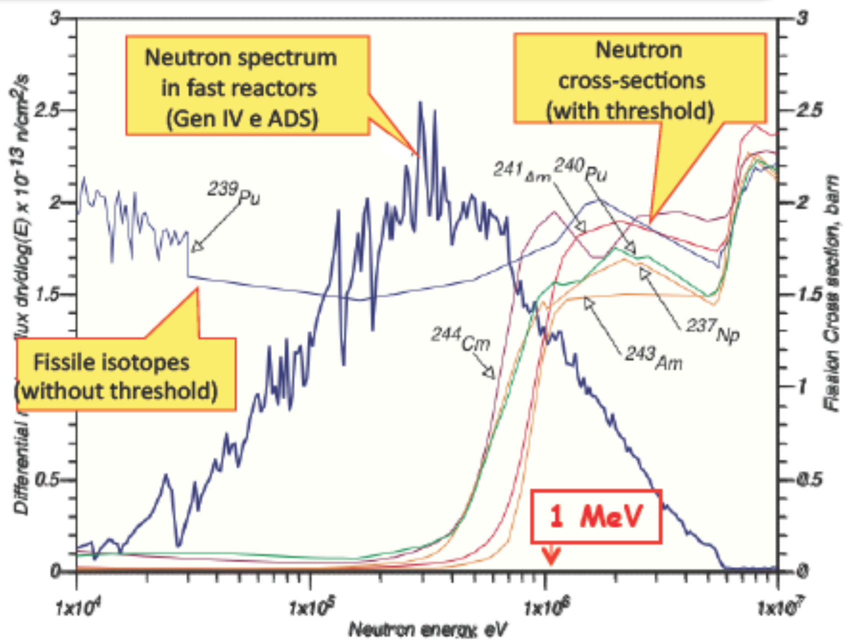
The **innovation** of Gen IV reactors consists in the possibility to produce energy by burning **Pu** and minor actinides **Np, Am, Cm**.

Most minor actinides present a **fission threshold** (~ 1 MeV).

To burn nuclear waste, it is necessary to use **fast reactors** or ADS.

Gen IV **fast breeder reactors** (SFR, GFR and LFR) would fulfill a closed fuel cycle, thus:

- maximizing the use of U resources
- minimizing waste



The development of Gen IV **fast reactors** requires accurate nuclear data (minimize design uncertainty and optimize safety parameters)

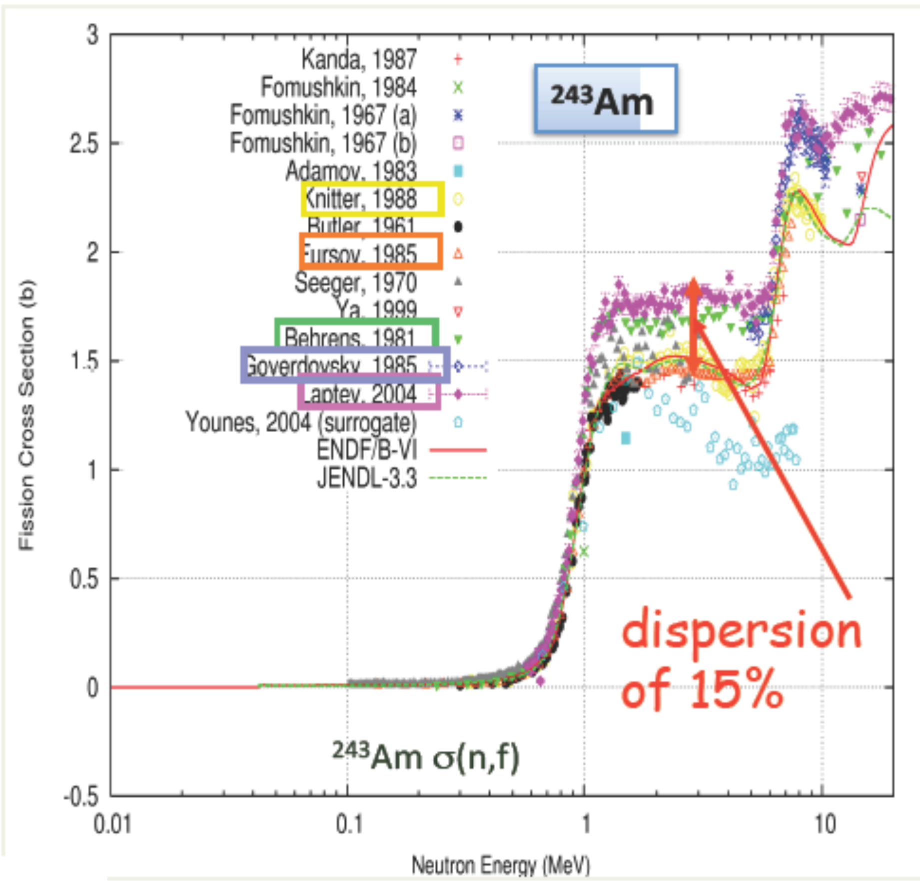
Table 1. Summary Target Accuracies for Fast Reactors

		Energy Range	Current Accuracy (%)	Target Accuracy (%)
U238	inel	0.5 ÷6.1 MeV	10 ÷ 20	2 ÷ 3
	capt	2.04 ÷24.8 keV	3 ÷ 9	1.5 ÷ 2
Pu241	fiss	454. eV ÷1.35 MeV	8 ÷ 20	2 ÷ 5
Pu239	capt	2.04 ÷498 keV	7 ÷ 15	4 ÷ 7
Pu240	fiss	0.498 ÷1.35 MeV	6	1 ÷ 3
Pu242	fiss	0.498 ÷2.23 MeV	19 ÷ 21	3 ÷5
Pu238	fiss	0.183 ÷1.35 MeV	17	3 ÷5
Am242m	fiss	67.4 keV ÷1.35 MeV	17	3 ÷4
Am241	fiss	2.23 ÷6.07 MeV	9	2
Am243	fiss	0.498 ÷6.07 MeV	12	3
Cm244	fiss	0.498 ÷1.35 MeV	50	5
Cm245	Fiss	67.4 ÷183 keV	47	7
Fe56	Inel	0.498 ÷2.23 MeV	16 ÷ 25	3 ÷ 6
Na23	inel	0.498 ÷1.35 MeV	28	4 ÷10
Pb206	inel	1.35 ÷2.23 MeV	14	3
Pb207	Inel	0.498 ÷1.35 MeV	11	3
Si28	inel	1.35 ÷6.07 MeV	14 ÷ 50	3 ÷ 6
	capt	6.07 ÷19.6 MeV	53	6

Necessary to reduce uncertaintied to ~3-7 % for most Pu isotopes and Minor Actinides, in the energy range from a few keV to several MeV

Source: Aliberti, Palmiotti, Salvatores, NEMEA-4 workshop, Prague 2007

An example: ^{243}Am(n,f)



Several cross section measurements already exist (between 1960 and 2004).

Results discrepant by 15 % !!

Accurate new data needed to clarify this important cross section.

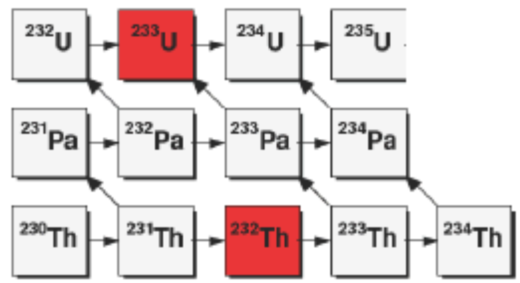
The need of new data on actinides

NEA/WPEC-26 (ISBN 978-92-64-99053-1)

The overall list of requirements is rather long:

- capture cross sections of ^{235,238}U, ^{237}Np, $^{238\text{-}242}$Pu, ^{241,242m,243}Am, ^{244}Cm
- fission cross sections of ^{234}U, ^{237}Np, $^{238,240\text{-}242}$Pu, ^{241,242m,243}Am, $^{242\text{-}246}$Cm

Accurate data also needed on some **Th, Pa and U** isotopes involved in the Th/U fuel cycle.



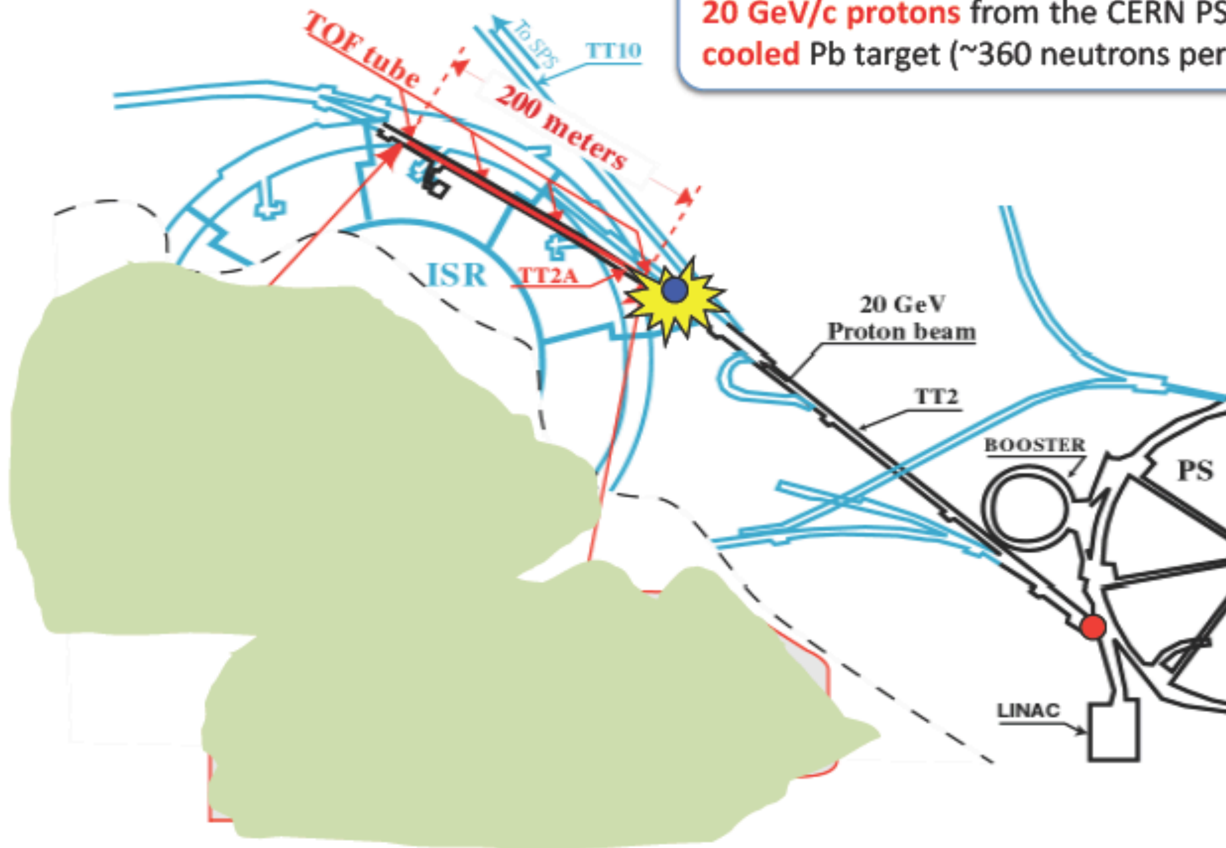
Research on high precision nuclear data for advanced reactors supported by **FP VII EURATOM** (Fission-2009-2.3.2)

In Europe, neutron measurements going at two major facilities:

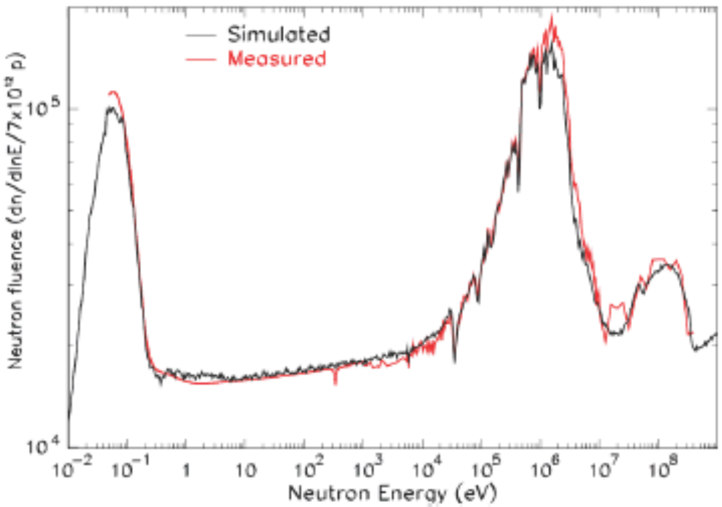
n_TOF (CERN, Geneva) **and GELINA** (JRC-Geel, Belgium)

The n_TOF facility at CERN

n_TOF is a **spallation** neutron source based on **20 GeV/c protons** from the CERN PS on a **water-cooled** Pb target (~360 neutrons per proton).



The n_TOF facility



Main features of the n_TOF neutron beam (measuring station at 200 m):

- high **instantaneous flux** *10^5 n/cm²/pulse*
- wide energy **spectrum** *25 meV<E_n<1GeV*
- low **repetition** rate *< 0.8 Hz*
- good energy **resolution** *$\Delta E/E = 10^{-4}$*

Neutron beam + state-of-the-art detectors and acquisition systems make n_TOF UNIQUE for:

- measuring **radioactive isotopes**, in particular **actinides**
- identifying and studying **resonances** (at energies higher than before)
- extending **energy range** for fission (up to 1 GeV !).

The experimental activity at n_TOF

Capture

^{151}Sm

$^{204,206,207,208}Pb$, ^{209}Bi

$^{24,25,26}Mg$

$^{90,91,92,94,96}Zr$, ^{93}Zr

$^{186,187,188}Os$, ^{139}La

^{232}Th, $^{233,234}U$

^{237}Np, ^{240}Pu, ^{243}Am

Fission

$^{233,234,235,236,238}U$

^{232}Th, ^{209}Bi

^{237}Np

$^{241,243}Am$, ^{245}Cm

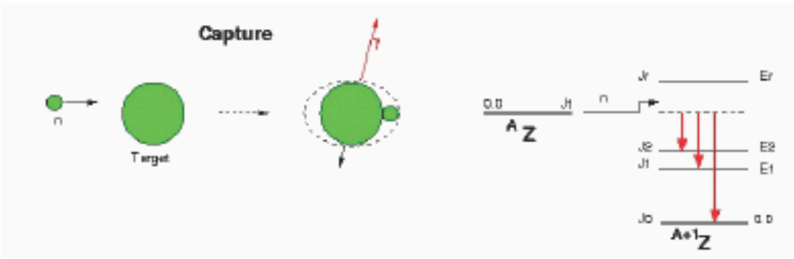
n_TOF Collaboration (120 Researchers from 40 European Institutes)

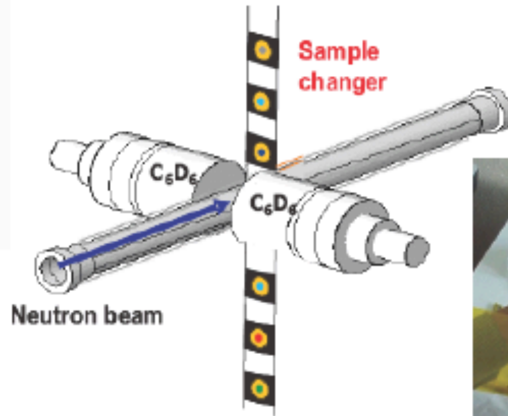
CERN	
Technische Universitat Wien	Austria
IRMM EC-Joint Research Center, Geel	Belgium
IN2P3-Orsay, IN2P3-Strasbourg, CEA-Saclay	France
FZK – Karlsruhe	Germany
Univ. of Athens, Ioannina, Demokritos	Greece
INFN Bari, Bologna, LNL, Trieste ENEA – Bologna	Italy
ITN Lisbon	Portugal
INR – Dubna, IPPE – Obninsk	Russian Fed.
CIEMAT, Univ. of Valencia, Santiago de Compostela, University of Cataluna, Sevilla	Spain
University of Basel	Switzerland
IFIN	Rumania
Univ. Of Manchester, Univ. Of York	Great Britain

EC Contracts

FP5: n-TOF-ND-ADS FP6: EUROTRANS FP7: ANDES

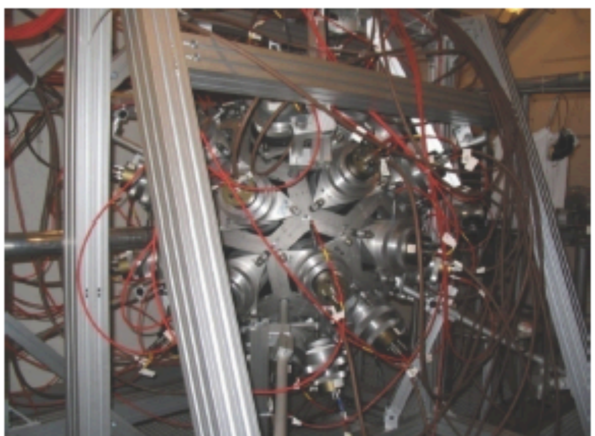
The experimental setup: capture reactions





Capture reactions are measured by detecting γ-rays emitted in deexcitation. At n_TOF used two systems: C_6D_6 and TAC

C_6D_6: scintillator detectors characterized by very low neutron sensitivity (but low efficiency)

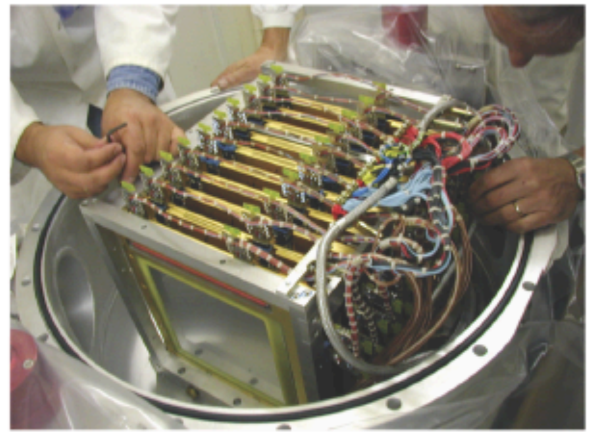


Total Absorption Calorimeter (TAC): 4π array to detect the entire deexcitation cascade with high efficiency.

Ideal for measurements of actinides.

The Fission setup

M. Calviani et al., Nucl. Instr. Meth. A 594, 220 (2008)



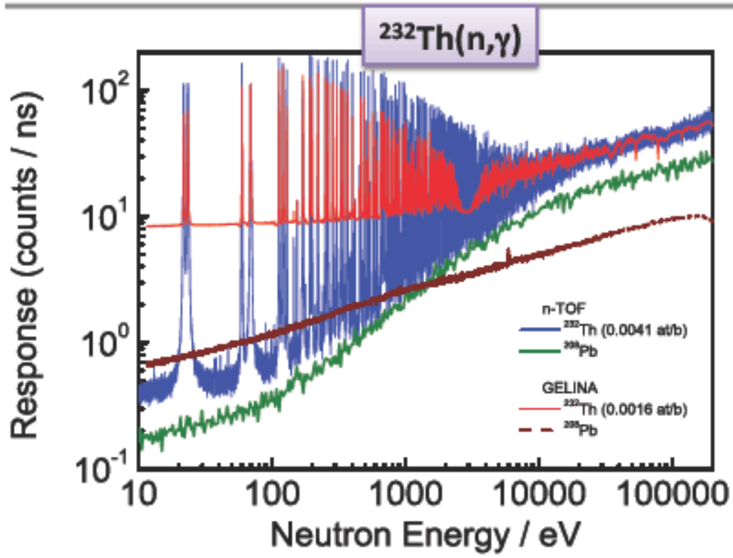
Fission chamber (single fragment) :

^{235}U, ^{238}U	reference (standad)
^{236}U	U/Pu fuel cycle
^{232}Th	Th/U fuel cycle
^{233}U, ^{234}U	Th/U fuel cycle
^{237}Np	Gen IV and ADS
$^{241,243}Am$	Gen IV and ADS
^{245}Cm	Gen IV and ADS

PPAC (coincidence method):

^{235}U, ^{238}U	reference (standad)
^{232}Th	Th/U fuel cycle
^{233}U, ^{234}U	Th/U fuel cycle
^{237}Np	Gen IV and ADS
^{209}Bi, ^{nat}Pb	ADS

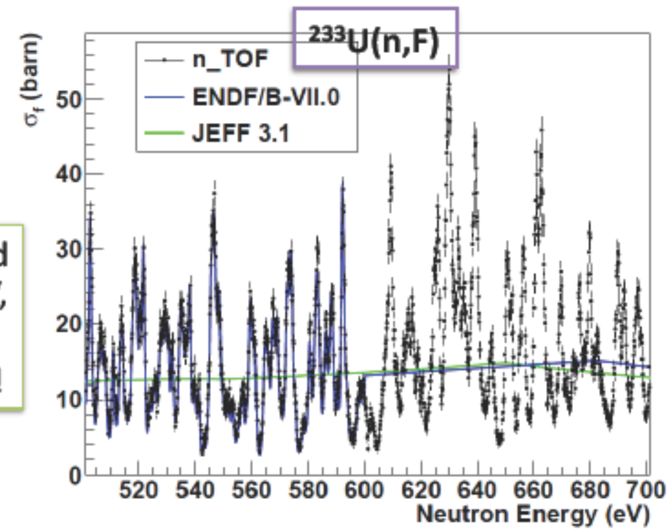
The n_TOF results: Th/U fuel cycle



Very accurate data collected at n_TOF on neutron capture for ^{232}Th:

- clear advantage over GELINA in the Resolved Resonance Region.
- important results also at high energy, (previous data off by 40 %).

G. Aerts *et al.*, Phys. Rev. C 73, 054610 (2006)
F. Gunsing *et al.*, Phys. Rev. C, in preparation

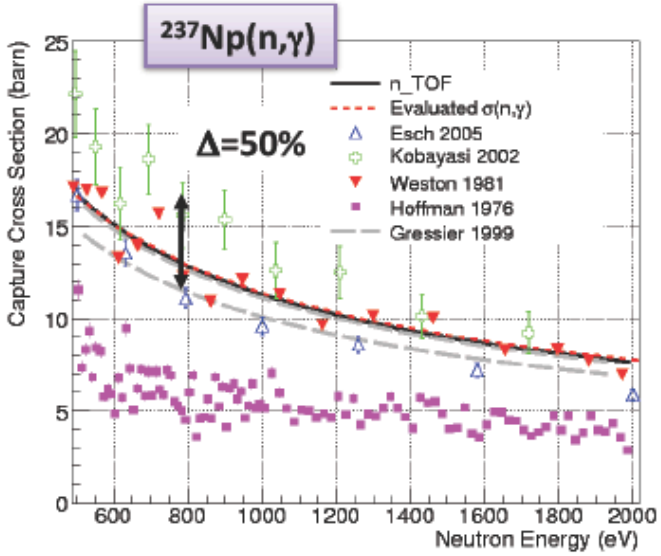


Fission cross-section on ^{233}U measured for the first time from thermal to 50 MeV, with **5 % accuracy, and high resolution**.

Extremely important data for Th/U cycle !

M. Calviani *et al.*, Phys. Rev. C 80, 044604 (2009)
F. Belloni *et al.*, Eur. Phys. J., in preparation

The cross-sections of ^{237}Np



Previous data scattered all over.

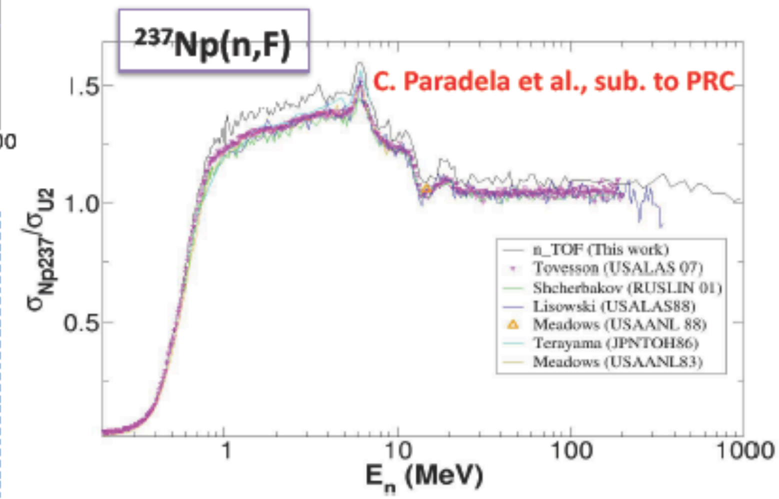
Accuracy of n_TOF results better than 4% (up to 10 keV).

Solved large discrepancy in the Unresolved Resonance Region

C. Guerrero *et al.*, Phys. Rev. C, in preparation

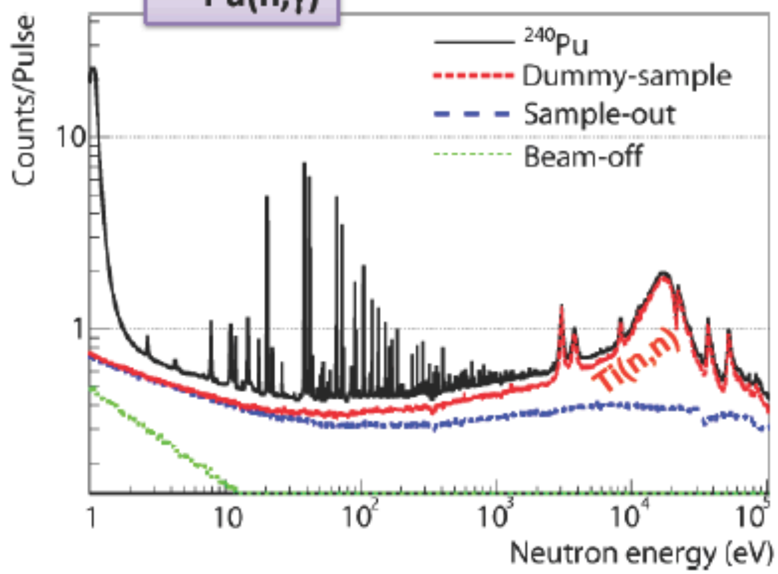
n_TOF results 6% higher than previous data and evaluations (all normalized to ONE measurements of 1983).

Very important result for design of future generation reactors (Np is the most abundant MA produced in current reactors)



The cross-sections of ^{240}Pu

$^{240}Pu(n,\gamma)$



First capture measurement in resolved resonance region.

Accuracy 6% (up to 10 keV).

Extracted nuclear properties (level spacing, average gamma widths, etc…).

C. Guerrero *et al.*, Phys. Rev. C, in preparation

$^{240}Pu(n,F)$

To be performed in 2011

The cross-sections of ^{241}Am

^{241}Am(n,γ)

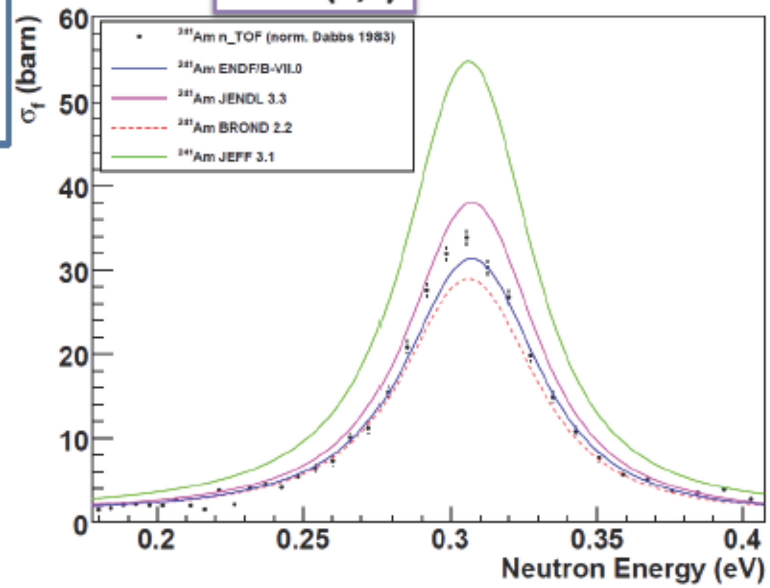
To be performed in 2010

Large discrepancies in databases for several resonances.

Overall uncertainty too high for nuclear energy applications

Preliminray n_TOF data show 10% accuracy (still needs refinement)

^{241}Am(n,F)



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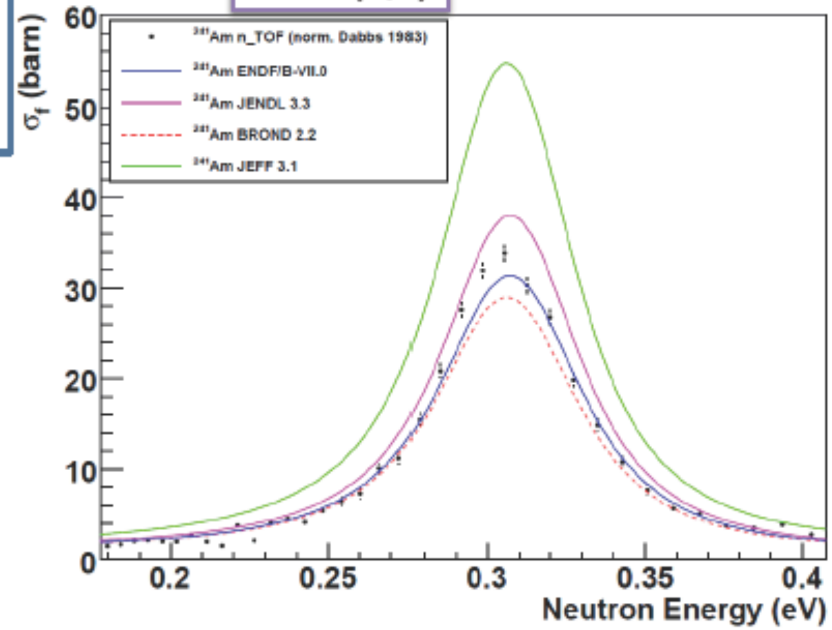

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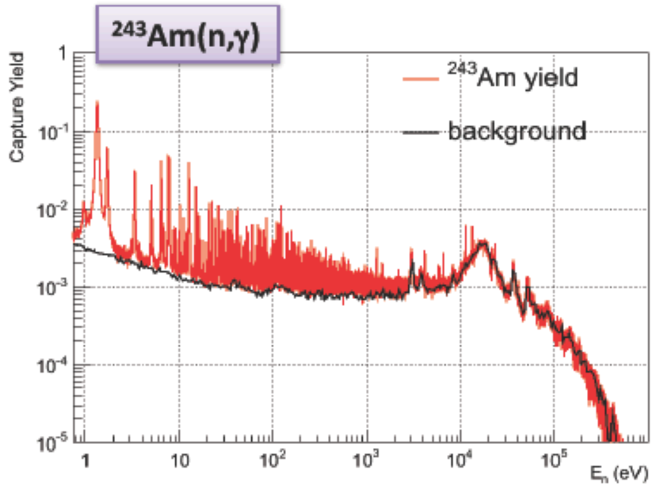


Clarified a **long-standing discrepancy** of more than 15 % !

n_TOF data (3% accuracy) confirm current evaluations, against previous results (even of 2004 !!).

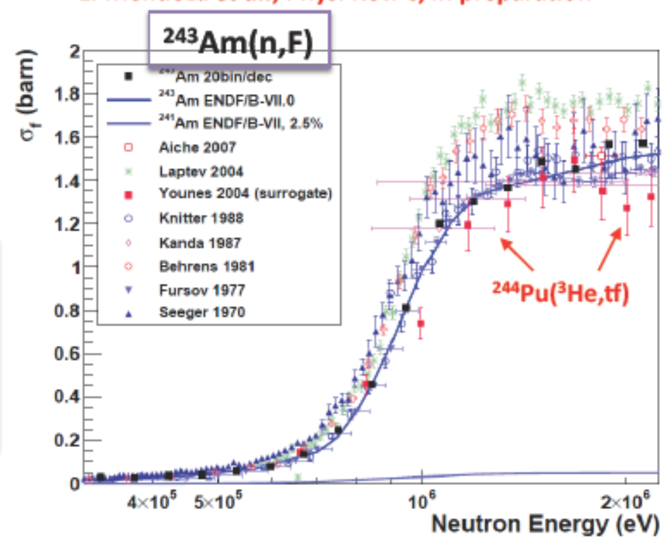
F. Belloni *et al.*, Nucl. Sci. Eng., in preparation

Unique measurement (not easy to perform).

Accurate data up to a few keV (because of thick Ti+Al capsule).

Improvements and new measurements are needed.

E. Mendoza *et al.*, Phys. Rev. C, in preparation



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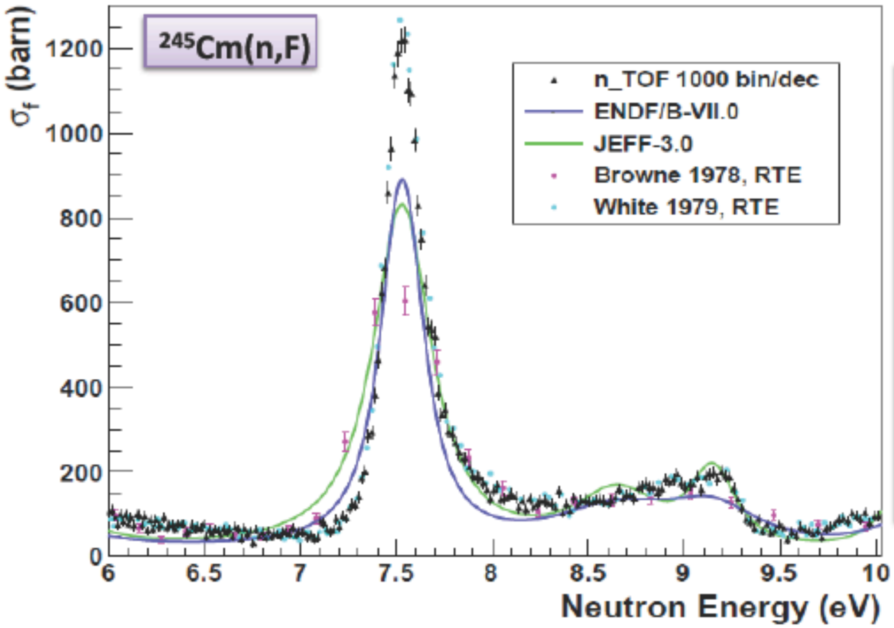
LBNL and Tech Source Inc.

The ^{245}Cm(n,F) reaction



M. Calviani *et al.*, Phys. Rev. C, in preparation

Only two measurements available, with factor of 2 difference (evaluation in between).

The only reliable measurement is from a nuclear explosion

New data from n_TOF have clarified that one of the previous measurements is wrong.

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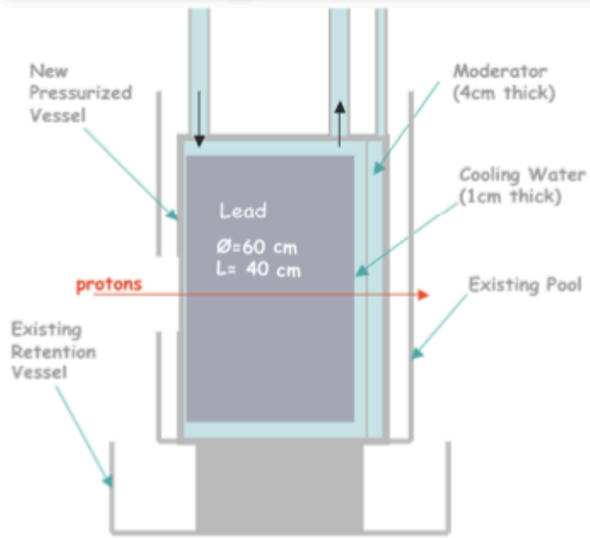
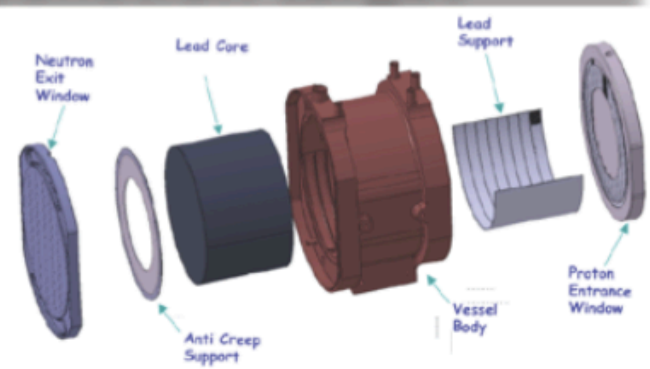
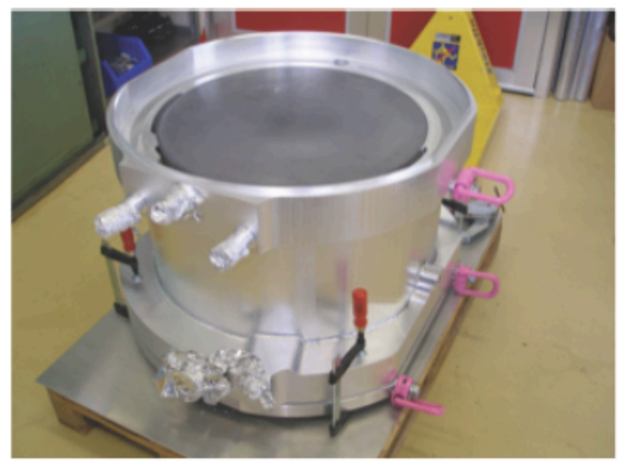
n_TOF new spallation target





- ✓Optimized for a better cooling
- ✓two different circuit for cooling and moderation
- ✓reduced size
- ✓Additional aluminum windows



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n_TOF Phase 2

Capture measurements	
Mo, Ru, Pd stable isotopes	calculation of r-process residuals isotopic patterns in SiC grains
Fe, Ni, Zn, Se stable isotopes	s-process nucleosynthesis in massive stars accurate nuclear data needs for structural materials
A≈150 (isotopes varii)	s-process branching points long-lived fission products
^{234,236}U, ^{231,233}Pa	Th/U nuclear fuel cycle
^{235,238}U	standards, conventional U/Pu fuel cycle
^{239,240,242}Pu, ^{241,243}Am, ^{245}Cm	incineration of minor actinides
^{197}Au, C, Pb	Calibrations
Fission measurements	
^{231}Pa, ^{245}Cm, ^{241}Pu, ^{241,243}Am, ^{244}Cm	fission cross section data for minor actinides
^{235}U(n,f) with p(n,p')	new ^{235}U(n,f) cross section standard
Varii	FF angular distribution
Varii	FF mass distribution
^{234}U(n,f)	study of vibrational resonances at the fission barrier

Program discussed and accepted by **INTC** (measurements subject to specific approval).

The isotopes in red need the **Experimental Area 2** (20 m from spallation target).

Main problem for actinide program: procurement of targets with adequate **mass**, **purity**, **uniformity**, etc... In the past, present also **radioprotection issues**.

A big step forward starting this year is the transformation of the experimental area in **Working Sector Type A**.

Conclusions

- Current generation nuclear reactors affected by two main problems:
  - Inefficient use of U resources
  - Production of long-lived nuclear waste
- Gen IV fast breeder reactors and/or ADS would solve major problems of current reactors
- The design and advanced nuclear systems require **accurate new data** on neutron cross-section of several actinides.
- Since 2001, n_TOF is contributing to the **world efforts** aimed at collecting high quality data, mostly on capture and fission.
- The main advantage of n_TOF for actinides is the high instantaneous **neutron flux** and the high-performance **detectors**.
- **Many isotopes** have been measured in the first campaign (2002-2004), but a lot more still remains to be done.
- A **large experimental program** on actinides and LLFP foreseen for the next few years.