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Material Protection, Accounting and Control Technologies (MPACT) Campaign

Daniel A Vega
MPACT Federal Program Manager

Outline

- **Introduction – Fuel Cycle Technologies R&D**
- **Materials Protection, Accounting and Control Technologies (MPACT) Campaign Overview**
- **Details of the R&D Program**
  - Used Fuel Security Analysis and Best Practices
  - Advanced Instrumentation
  - Analysis and Assessments
  - Advanced Integration
- **International Engagement and Nuclear Energy University Program (NEUP)**
- **Summary**

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Introduction

- **The U.S. DOE Office of Nuclear Energy Fuel Cycle Technologies program develops used nuclear fuel management strategies and technologies to support meeting federal government responsibility to manage and dispose of the nation's commercial used fuel and high-level waste; develop sustainable fuel cycle technologies and options that improve resource utilization and energy generation, reduce waste generation, enhance safety, and *limit proliferation risk*.**

- **The program is organized into focused R&D areas**
  - Used Fuel Disposition: enable storage, transportation and disposal of used nuclear fuel and wastes generated by existing and future fuel cycles
  - Nuclear Fuel Storage and Transportation Planning Project: focused on interim storage prior to final disposal
  - Advanced Fuels: next generation LWR and transmutation fuels
  - Material Recovery and Waste Forms: technologies that enable a sustainable fuel cycle
  - Material Protection, Accounting and Control Technologies (MPACT): *next generation nuclear materials management* for US fuel cycle
  - Fuel Cycle Options: comprehensive evaluation of nuclear energy system options

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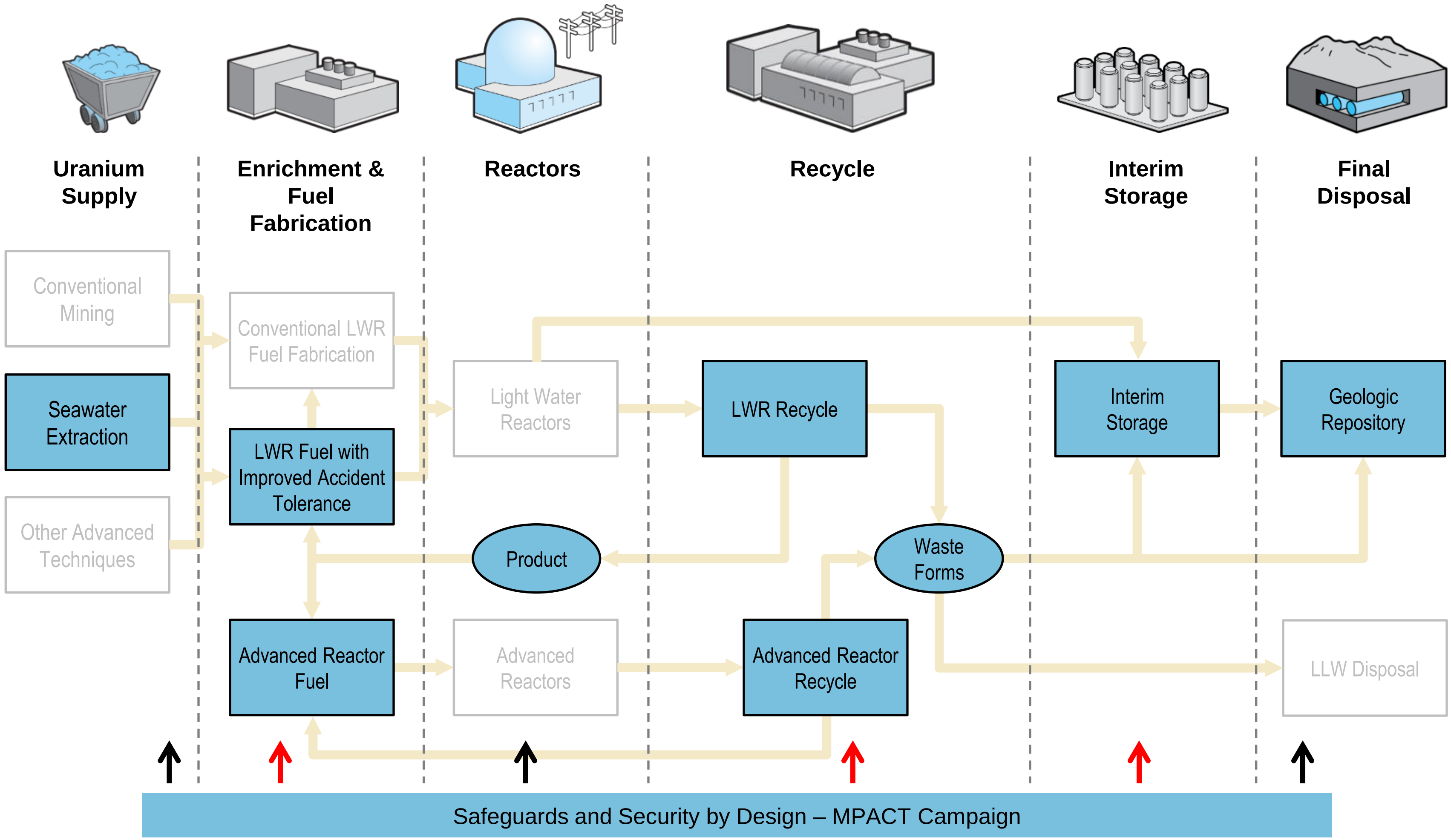
Focus Areas of DOE Fuel Cycle Technologies



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MPACT is about Next Generation Nuclear Materials Management

- **Mission** – Develop innovative technologies and analysis tools to enable *next generation nuclear materials management* for existing and future U.S. nuclear fuel cycles, to manage and minimize proliferation and terrorism risk.

- **Objectives**
  - Develop and demonstrate advanced material control and accounting technologies that would, if implemented, fill important gaps
  - Develop, demonstrate and apply MPACT analysis tools to assess effectiveness and efficiency and guide R&D
  - Develop tools, technologies, and approaches in support of used fuel safeguards and security for extended storage, electrochemical processing, and other advanced nuclear energy systems

  } Technology Development

  - Perform technical assessments in support of advanced fuel cycle concepts and approaches

  } Applications

  - Develop guidelines for safeguards and security by design and apply to new facility concepts

  } Leadership

Long Term Objectives (10 – 20 years)

- **Help to establish Safeguards and Security by Design as a standard paradigm for nuclear energy systems**
- **Demonstrate and implement next generation nuclear materials management technologies and approaches**
  - Echem, H-Canyon, bilateral engagements, new fuel cycle facilities,…
- **Address safeguards and security issues associated with technology development in other Campaigns**
- **Support NRC rulemaking through engagement and data generation**
- **International engagement to help influence and support the nuclear energy enterprise and demonstrate U.S. leadership**

MPACT Campaign – 3-Year High Level Milestones (FY 2016 – FY 2018)

- **Develop field test plans for at least two promising new instrumentation technologies** (completed FY15), **conduct field tests** (one ongoing)
- **Initiate at least three new exploratory instrumentation projects** (two in FY15)
- **Develop an integrated approach for EChem safeguards and security**
- **Test at least two technologies for EChem safeguards and security** (three in prep)
- **Perform sensitivity studies for EChem safeguards and security performance**
- **Develop a risk-based concept and approach for safeguards and security of used fuel extended storage**
- **Develop physics-based time-dependent signatures to guide advanced monitoring technology development**
- **Perform consequence and vulnerability assessments of used fuel extended storage and advanced nuclear energy systems of interest**
- **Develop an advanced integration approach for disparate data**

2020 Milestone – complete lab-scale demonstration of advanced safeguards and security system

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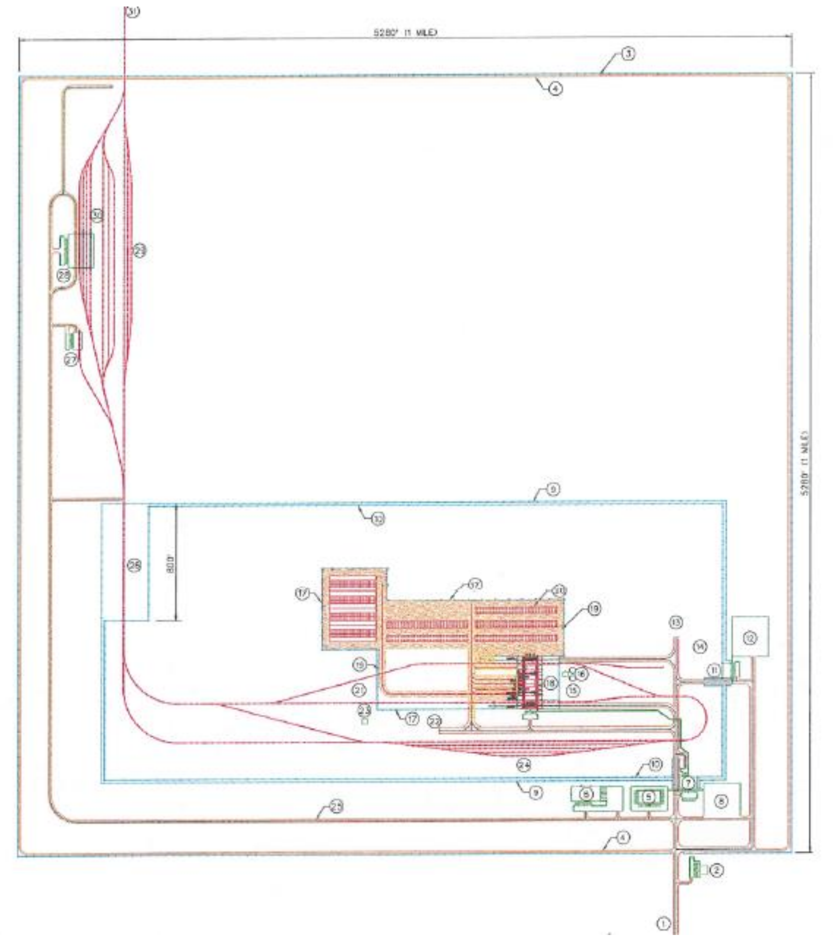
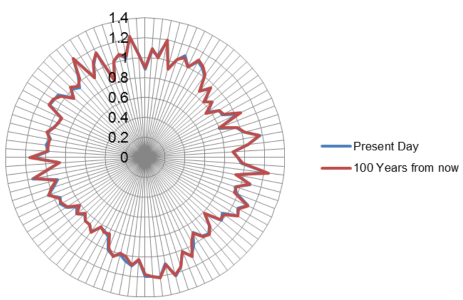
SSBD for Dry Storage Roadmap

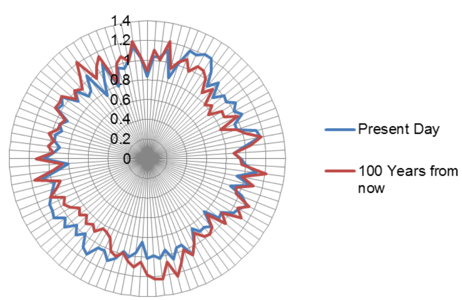
- **Builds on earlier gaps report**
- **Further integrates with NFST and UFD**
- **Security analysis needs**
- **Benchmark experiments**
- **Termination of safeguards**
- **International leadership and engagement**

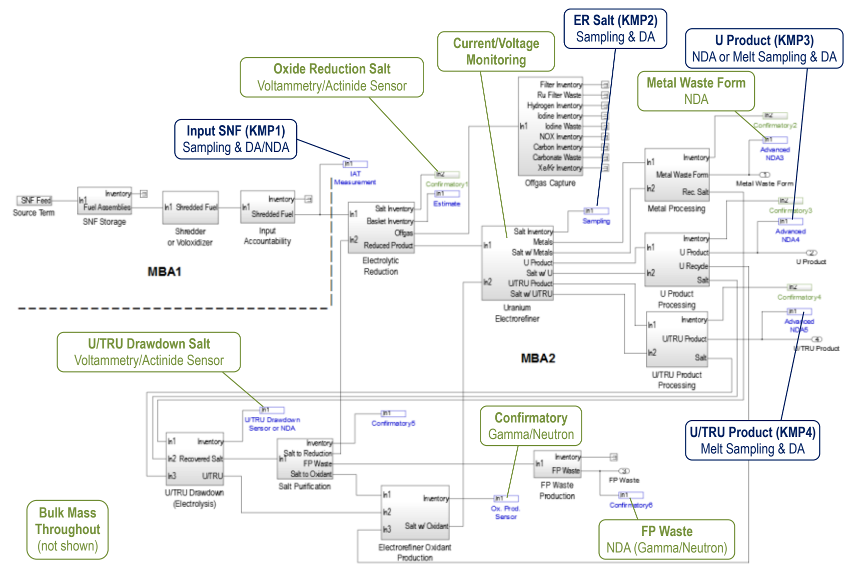


MPACT Modeling and Simulation Roadmap

- Physics based signatures and fundamental process models
- Systems and facility modeling
- Security and consequence analysis
- Data simulation

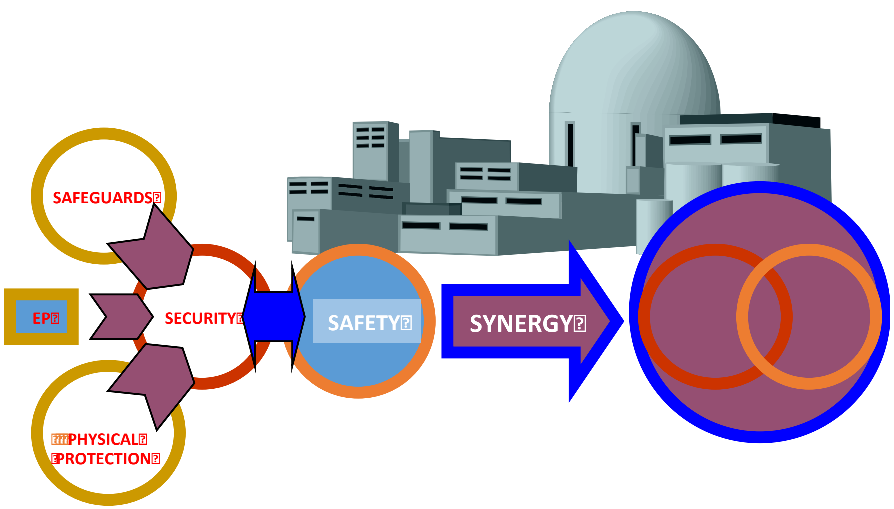


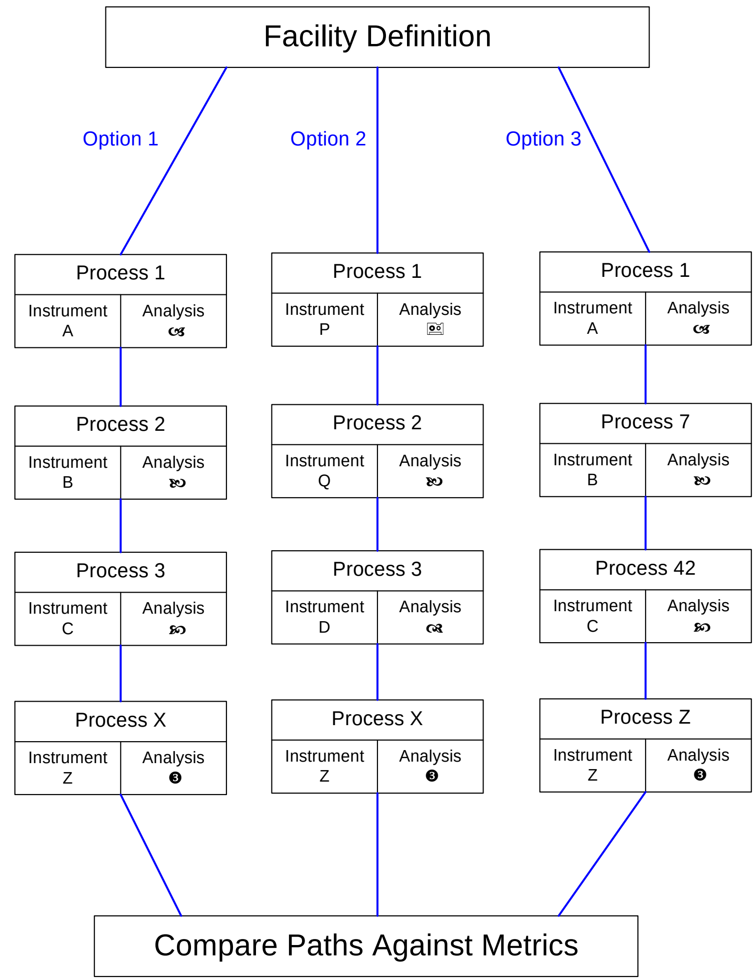




Advanced Safeguards and Security Systems Concept

- Virtual facility, distributed test bed for lab-scale demo
- Advanced integration
- Uncertainty quantification, including correlations
- Data and analysis needs





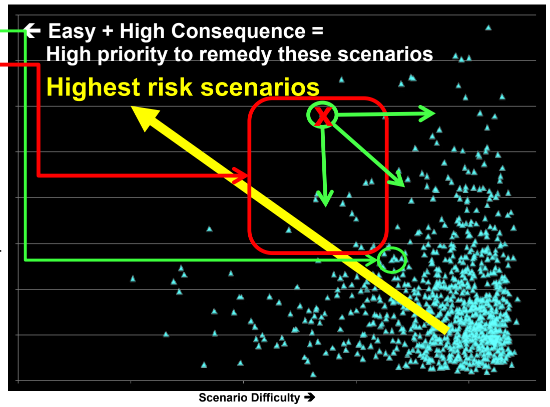
Used Fuel Security Analysis and Best Practices for Extended Dry Storage

If we fix this…

Without fixing this…

We may not have improved security. *Because…*

Many scenarios still exist that are both easier to achieve AND provide higher consequences!



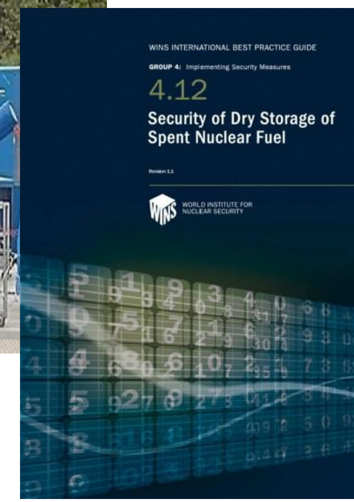
Why use scenario difficulty in security risk management?

- Difficulty better reflects the adversary planning process
- Difficulty changes more slowly and predictably than likelihood
- Problem: How do we assess the difficulty of an attack?

To "fix" a scenario we must

- Eliminate it (make it impossible to achieve)
- Reduce the consequences if it is completed
- Make it harder to accomplish successfully

… or any combination of these

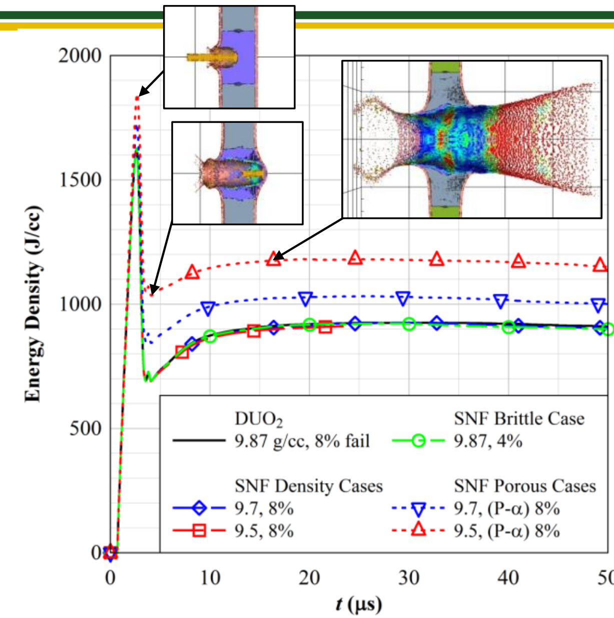


- **Consequence versus difficulty formulation for risk analysis applied to a variety of used fuel storage security scenarios**
- **Best practices for used fuel security for extended dry storage – WINS workshop and report (June 2014, Vilnius, Lithuania)**

- G.D. Wyss, et al., "Risk-Based Cost-Benefit Analysis for Security Assessment Problems," Proc. IEEE (2013)
- "Security of Dry Storage of Spent Nuclear Fuel – A WINS Best Practices Guide" (2015)

Improving our understanding of the Spent Fuel Ratio

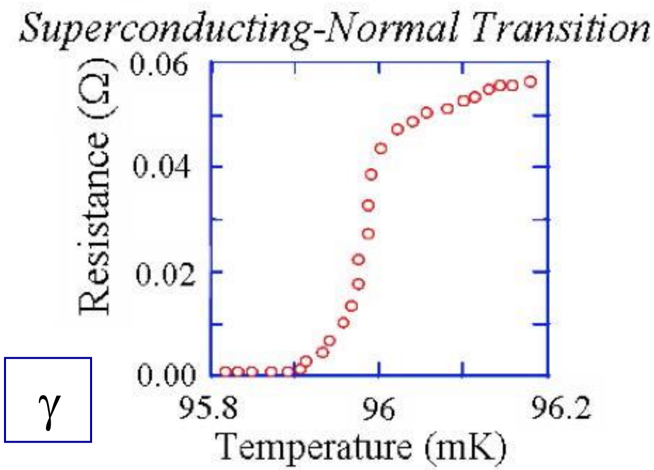
- **No definitive value to date**
  - Large degree of experimental scatter
- **Battelle Columbus Laboratories**
  - *SFR = 0.42 to 0.71*
    - *Analysis of BCL results by Sandoval (SAND82-2365)*
  - *SFR = 2.5 to 12*
    - *Subsequent review by Luna (SAND99-0963)*
    - ***Current RF calculations assume SFR = 3***
- **Idaho National Laboratory**
  - *SFR = 5.6*
    - *Based on questionable extrapolation of wet sieve data*
    - ***Value used in previous analyses***
  - *SFR = 0.53*
    - *Bulk aerosol measurements*
- **Sandia National Laboratories**
  - Testing on different surrogate materials resulted in similar respirable release fractions
    - *Provided confidence in using lower SFR estimate*
    - *No SNF testing*



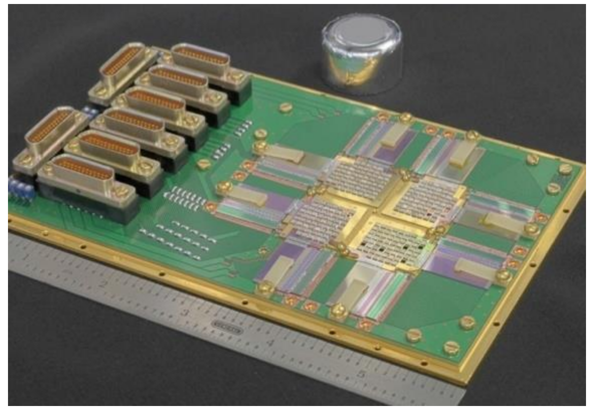
	Density (g/cc)	Energy Density (J/cc)	Resp. (%)	SFR
DUO_2 (Base Case)				
	9.87	925	1.4	--
SNF: Density Cases				
	9.7	924	1.4	1.0
	9.5	910	1.4	1.0
SNF: Brittle Case				
	9.87	923	1.4	1.0
SNF: Porous Cases (P-alpha)				
	9.7	1030	1.5	1.1
	9.5	1180	1.6	1.1

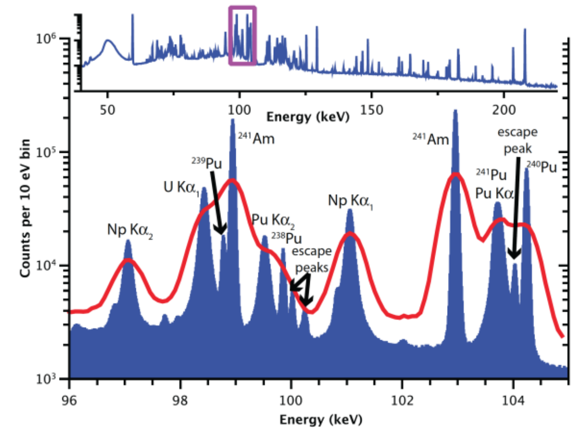
- S.G. Durbin, et al., "Numerical Estimation of the Spent Fuel Ratio," Proc. IHLRWM (2015)

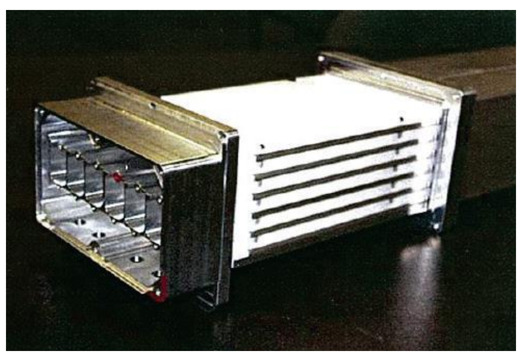
Super-High Resolution Gamma Spectroscopy (Microcalorimetry) & High-Dose Neutron Detector

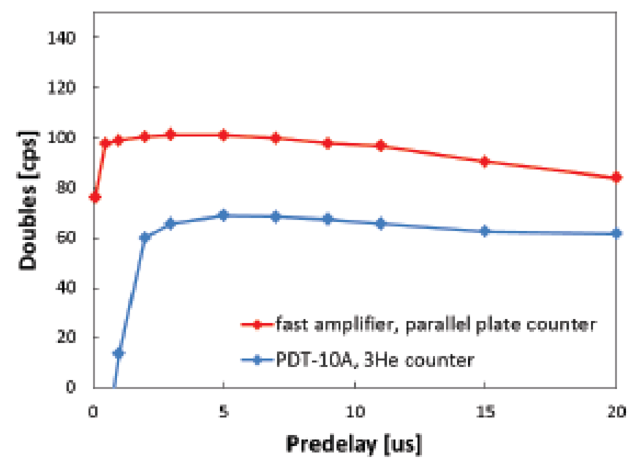


γ









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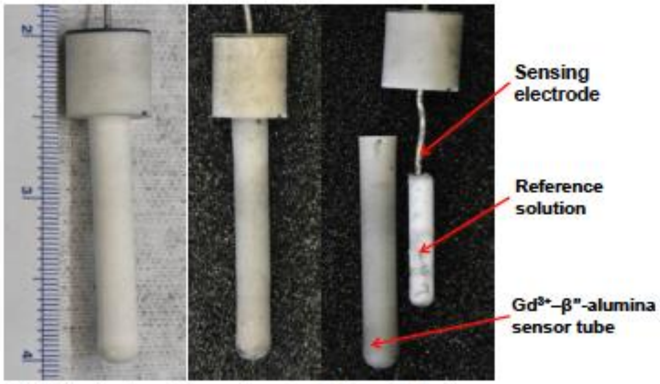
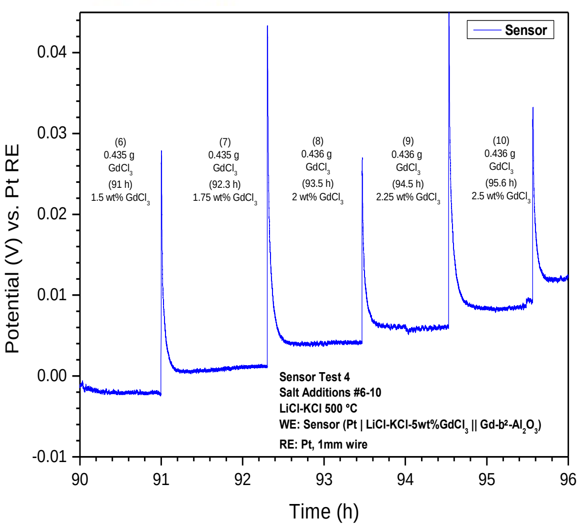
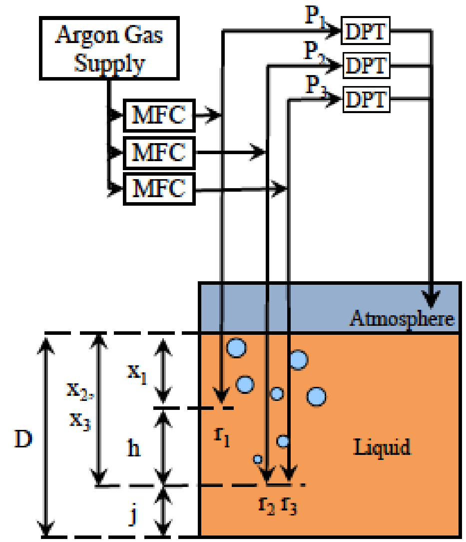
- R. Winkler, et al., “256-Pixel Microcalorimeter Array for High-Resolution γ-Ray Spectroscopy,” NIMA (2015)
- A. Hoover, et al., “Determination of Plutonium Isotopic Content by Microcalorimeter Gamma-Ray Spectroscopy,” IEEE TNS (2013)
- D. Henzlova, et al., “Design and Development of a 3He Replacement Safeguards Neutron Counter Based on 10B-Lined Proportional Detector Technology,” Proc. INMM (2012)

Potentiometric Sensor and Level-Density Probe for Molten Salts



Gd-β″-alumina tube and contact electrode before and after immersion in LiCl-KCl-$GdCl_3$ based molten salt at 500 °C (middle). Tube after disassembly (right).





Static Pressure w/ Laplace

$$P = \rho g h + \frac{2\gamma}{r}$$

Density (ρ)

$$\rho = C_p \frac{\Delta P_{1,2}}{gh}; \text{ where } r_1 = r_2$$

Surface Tension (γ)

ASTM standard D3825 – 90 (Reapproved 2005)
Where r = Inner radius of wide capillary (mm)

$$\gamma = A\Delta P\left(1 + \frac{675 r \rho}{\Delta P}\right)$$

Depth (D)

$$D = \frac{1}{\rho g}(P_2 - P_B) + j$$

- **Potentiometric sensor - surrogate work (Gd) demonstrates survivability and sensitivity in molten salt environment**
- **Triple bubbler allows for surface tension correction - <1% may be possible**

- N.J. Gese, et al., "Potentiometric Sensor for Real-Time Remote Surveillance of Actinides in Molten Salts," Proc INMM (2012)

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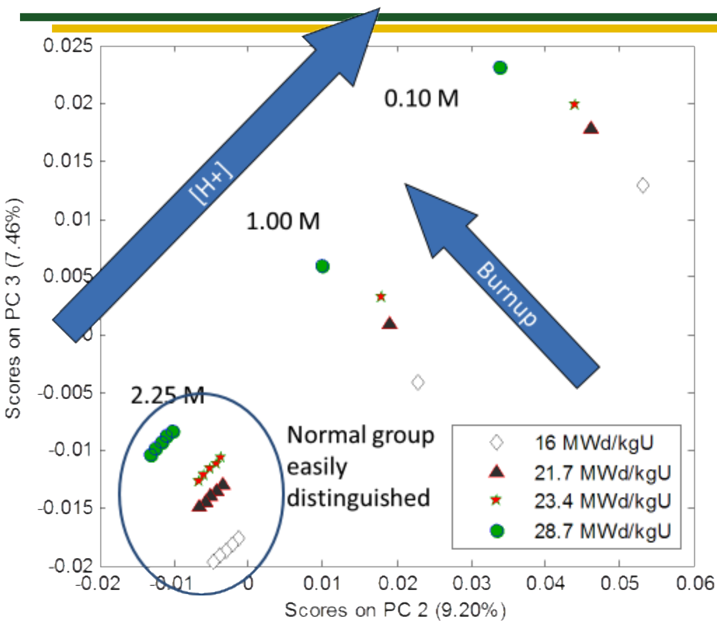
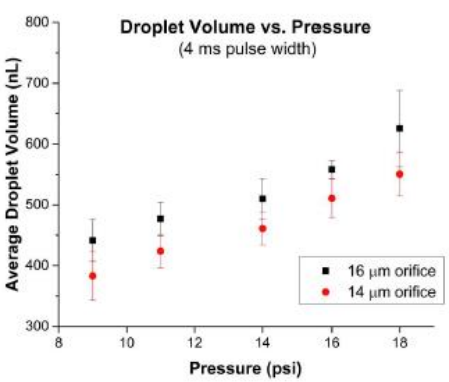
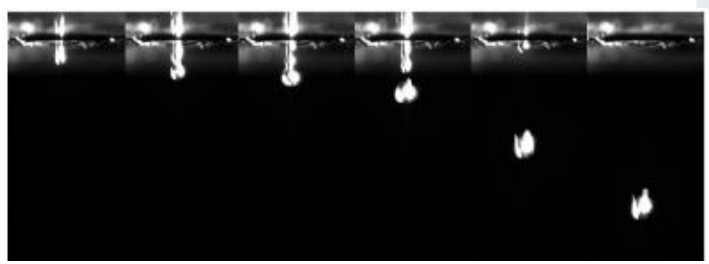
Multi-Isotope Process Monitor and Microfluidic Sampling

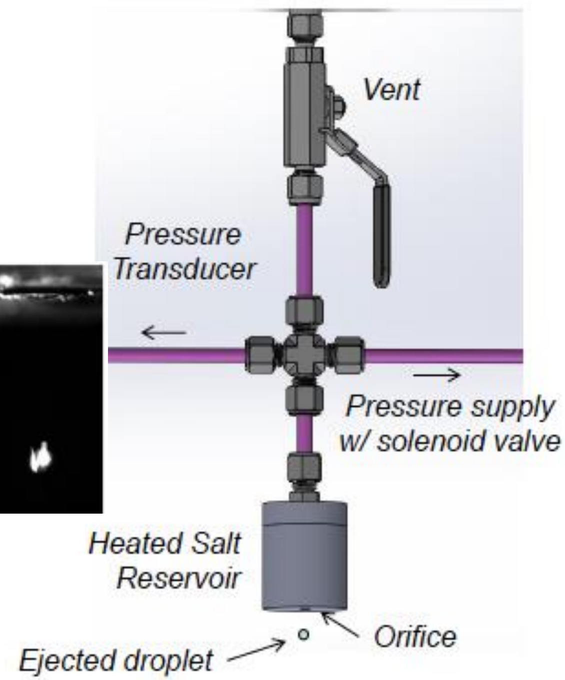


- **Correlation of multiple isotopes via gamma spectroscopy to enable detection of process changes**

- D. Meier, paper 5395, Global 2015







- **nL droplet formation and characterization**

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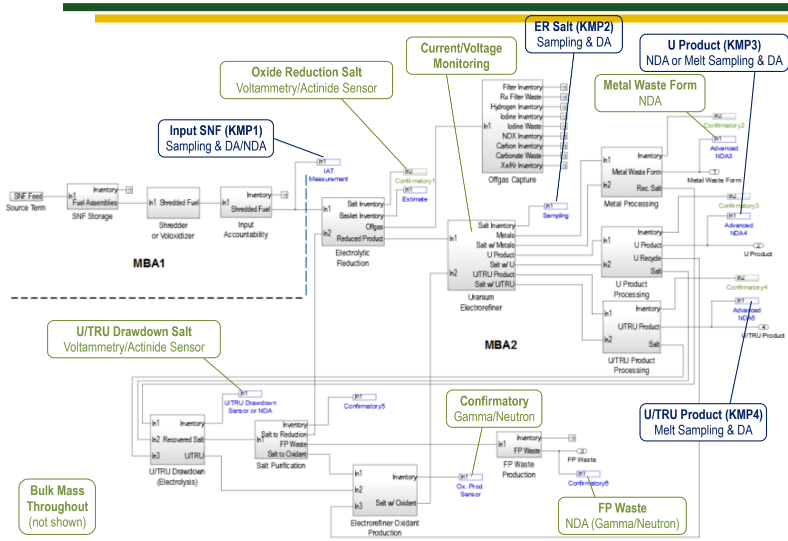
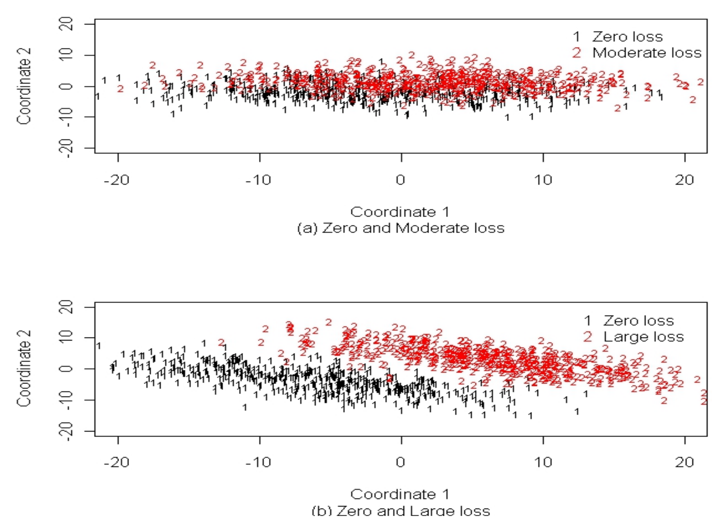
Safeguards and Security Performance Modeling and Statistical Inference



- **Facility model incorporating safeguards and security can be used to conduct system performance studies, including uncertainties**
- B.B. Cipiti, paper 5089, Global 2015

Two PCs representing distance in 19-dimensions



- **Pattern recognition of multivariate data – putting process monitoring on equal footing with nuclear material accountancy**

- B.B. Cipiti, “Electrochemical Reprocessing Safeguards Model,: Proc INMM (2012)
- T. Burr, et al., “Hybrid Statistical Testing for Nuclear Material Accounting Data and/or Process Monitoring Data in Nuclear Safeguards,” Energies (2015)

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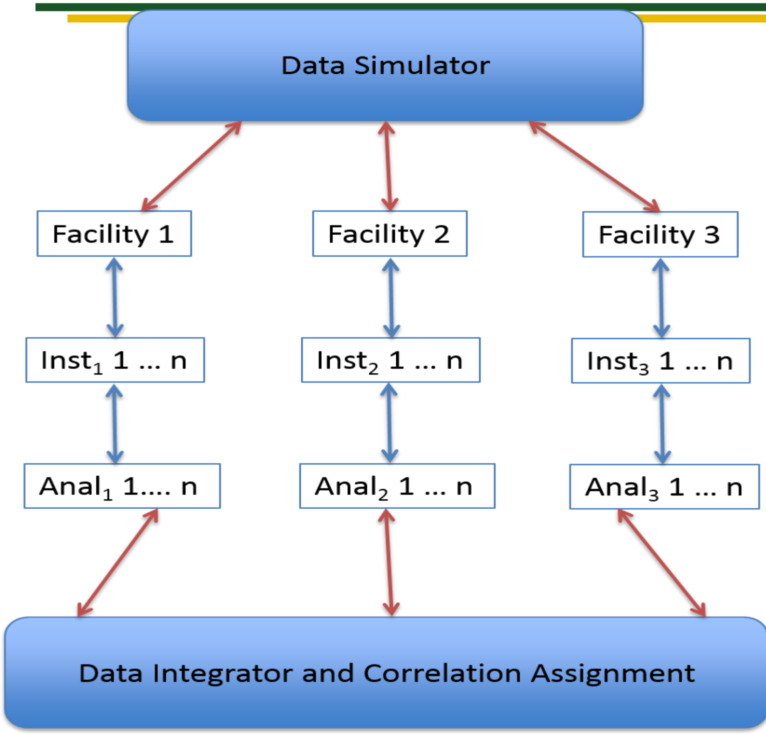
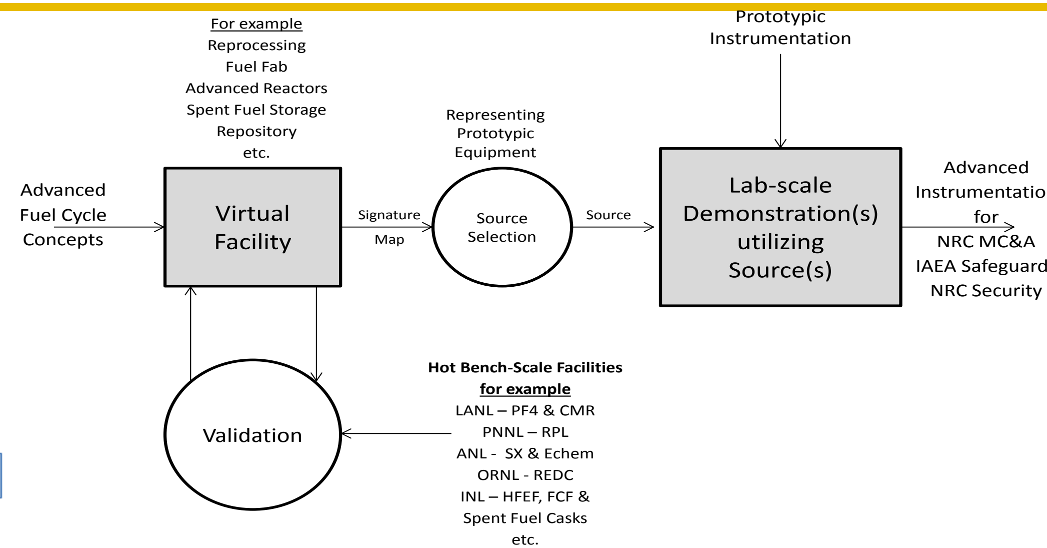
Virtual Facility, Distributed Test Bed Concept for Lab-Scale Demo





2020 Milestone –lab-scale demonstration of advanced safeguards and security system

- **Take advantage of facilities, materials, and capabilities where they exist**
- **Data driven, gaps bridged by modeling and simulation**
- **Applicable to process, facility, and fuel cycle level**
- **Integrated analysis of process, facility, fuel cycle performance**

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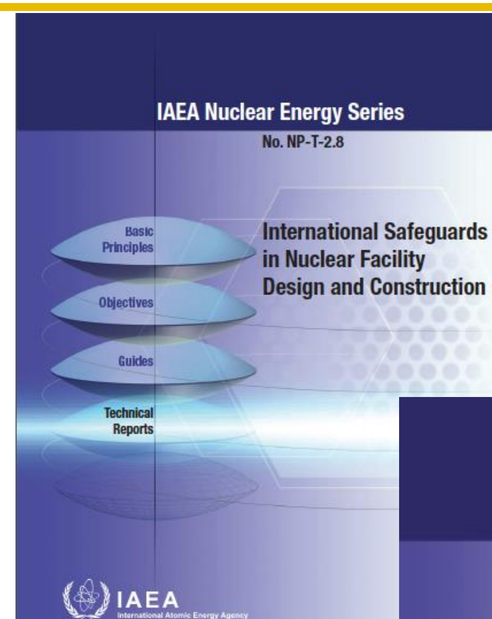
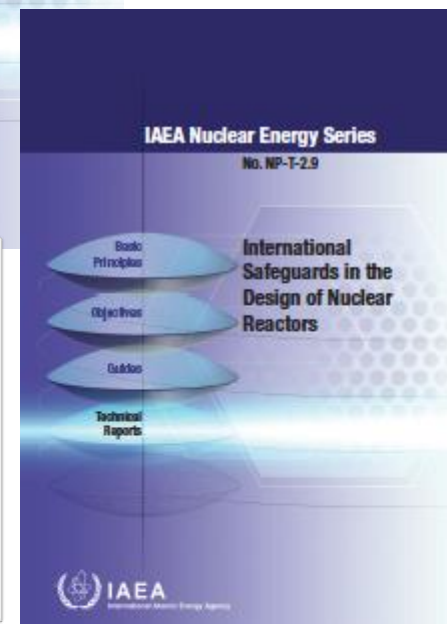
International Engagement

- **Safeguards by Design IAEA Nuclear Energy series documents addressing full fuel cycle**
  - Nuclear facility design and construction (No. NP-T-2.8, 2013)
  - Reactors (No. NP-T-2.9, 2014)
  - Conversion, fuel fabrication, spent fuel management, enrichment, and reprocessing (in press)
- **ASTOR experts group**
- **WINS workshop on best practices for security of dry cask storage**
- **IAEA Nuclear Security for spent fuel**





Summary

- A broad-based program of research and development is underway to support next generation nuclear materials management for the nuclear energy enterprise
- Advanced instrumentation and analysis/assessment tools are being developed and integrated into a distributed test bed
- The Nuclear Energy University Program is pursuing R&D of relevance and training the next generation of experts
- The MPACT Campaign is engaging the broader international community in promoting safeguards and security by design

MPACT Linkages and Dependencies

- **The MPACT campaign has internal customers (dependencies) and provides external connectivity (linkages)**
- **Dependencies – Material Recovery and Waste Forms, Used Fuel Disposition, Nuclear Fuel Storage and Transportation, Fuels**
- **Linkages – Fuel Cycle Options, NNSA (NA-22, NA-24), NRC, International (bilateral and IAEA via NE-6 and NA-24)**
- **MPACT also has strong university engagement**
- **Industry continues to show a strong interest in the MPACT Campaign**

Project Descriptions

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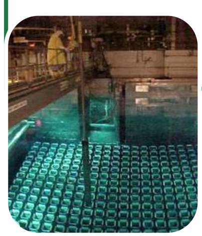
An integrated database and analysis system has been established for managing the nation’s SNF

- **Used Nuclear Fuel Storage Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS)**
- **Unified Database consolidates, controls, and archives key information from multiple sources**
- **Integration of data with analysis capabilities enables automated characterization of eventually all SNF assemblies and canisters/casks in the domestic inventory**

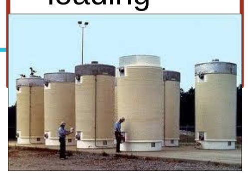
859 data
- Assembly ID
- Assembly type
- Initial enrichment
- Discharge burnup
- Cycle start and end dates



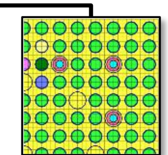
Assembly data
- Geometric configuration
- Materials of construction
- Design dimensions
- Control components

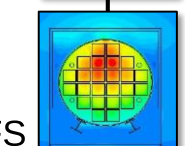
Reactor data
- Cycle specific burnup
- Soluble boron
- Rod insertion history
- Batch loadings
- Axial burnup profiles
- Moderator temperature

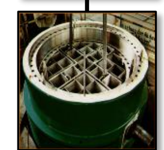
Cask data
- Geometric configuration
- Materials of construction
- Design dimensions
- Cask loading patterns
- Component loading



Models
- Depletion: Triton, ORIGEN
- Thermal: COBRA-SFS
- Criticality: KENO-VI
- Dose
- Containment
- Fuel Performance







- K. Banerjee et al., “Streamlining Analysis Capabilities for SNF Management,” Proc. WM (2015)

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MPACT Control Accounts - $6M Base

- **Management and Integration ($700k)**
  - Technical and project management, maintain internal and external interfaces, provide technical support, international engagements
- **Safeguards and Security by Design – EChem ($2250k)**
  - Integrated safeguards and security for electrochemical process
  - Systems approach (safeguards and security performance model, fundamental mass flow models, pattern recognition and statistical inference)
  - Technology development (actinide sensor, level/density sensor, microfluidic sampler, voltammetry)
- **Used Fuel Extended Storage ($1600)**
  - Concepts and approaches for integrated safeguards and security for used fuel extended dry storage (risk-informed security framework, data gaps, interface to NFST and UFD)
  - Signatures and assessments (signature development, advanced monitoring techniques, vulnerability assessments, consequence analysis)
- **Exploratory Research/Field Tests ($1450)**
  - Advanced instrumentation development and field tests for next generation nuclear materials management
  - Microcalorimetry, multi-isotope process monitor, high-dose neutron detector, thermocouple

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Safeguards and Security by Design - EChem

			FY15	FY16
				Base
WBS	Title	Lab	Funds ($k)	Funds ($k)
1.02.04.04	Safeguards and Security by Design (EChem)			
	Microfluidic Sampler	ANL	250	250
	Mass Balance Models	ANL	300	300
	Potentiometric Sensor	INL	300	300
	Level and Density Sensor	INL	250	250
	Voltametry	ANL	0	150
	Voltametry	INL	150	150
	Concepts and Approaches/Pattern Recognition	LANL	300	300
	EChem Signatures Development	LANL	250	250
	EChem Safeguards and Security Performance Model	SNL	300	300
		Subtotal	**2100**	**2250**

- Base funding allows for expanding one project – voltammetry (ANL)
- Leveraging equipment funds from NA-24 for field testing at INL

Used Fuel Extended Storage

			FY15	FY16
				Base
WBS	**Title**	**Lab**	**Funds ($k)**	**Funds ($k)**
1.02.04.05	Used Fuel Extended Storage			
	SSBD for Extended Storage	LANL	250	250
	Signatures Extended Storage	LANL	250	250
	Consequence Analysis	LLNL	250	250
	Technical Support Characterization	ORNL	150	150
	UFXS Concepts and Approaches	SNL	500	550
	Technical Support SF Design	SRNL	150	150
		Subtotal	**1550**	**1600**

- Base funding – small increase for roadmap (SNL)

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Exploratory Research/Field Tests

			FY15	FY16
				Base
WBS	**Title**	**Lab**	**Funds ($k)**	**Funds ($k)**
1.02.04.06	Exploratory Research/Field Tests			
	Microcalorimeter	LANL	400	400
	MIP Monitor	PNNL	400	400
	High-Dose Neutron Detector	LANL	250	350
	H-Canyon Support	SRNL	0	100
	Thermocouple	INL	0	200
		Subtotal	**1050**	**1450**

- Base funding keeps lab demonstration and field testing activities on track, with additional SRNL support and a new sensor project (thermocouple, INL)

Integration of NEUP Projects

- **NEUP projects are being integrated into the MPACT Campaign through attendance at our working group meetings and subsequent connection to the national laboratory researchers**
  - This provides for important context of their research and provides a forum for exchange and networking
- **Current active projects**
  - Phongikaroon (VCU) – LIBS for pyroprocessing
  - Ullom (CO) – Microwave readout for very large sensor arrays
  - Nino (FL) – BI3 gamma spectrometer
  - Tsoukalas (Purdue) – Geant4 muon tomography module
  - Zhang (OSU) – Integrated safeguards model for pyroprocessing
  - Yang (Oregon State) – Dry cask imaging with cosmic ray muons
  - Slaybaugh (UCB) – Hybrid modeling of used fuel storage facilities
  - Simpson (U Utah) – Advanced voltametry for pryroprocessing
- **New projects**
  - Cao (OSU) – Actinide monitor for molten salts using boron-doped diamond
  - Jordon (FL) – Used fuel storage monitor using fast neutrons (He-4 scintillator)
- **FY16 – Advanced integration, future IRP?**