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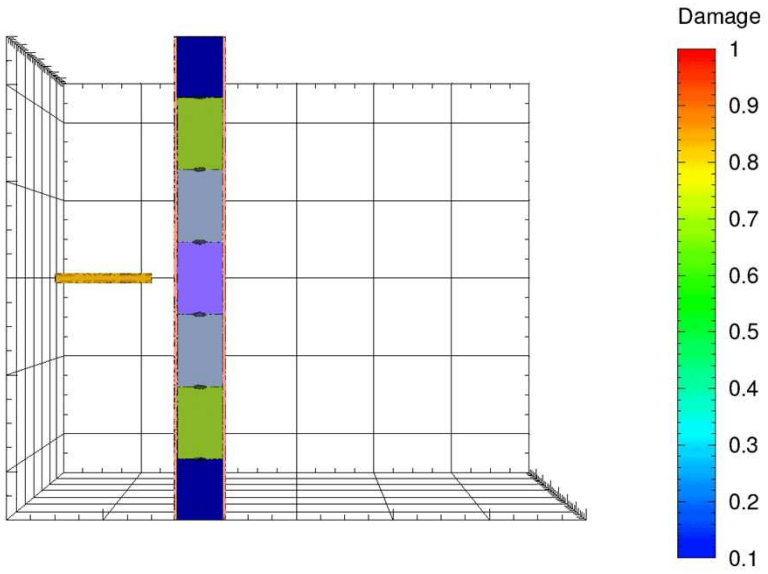
SAND2016-0205C

Ongoing Research on Spent Fuel Security Topics



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Eric Lindgren
Sandia National Laboratories

Institute of Nuclear Materials Management
31st Spent Fuel Seminar
Washington, DC
January 13, 2016

SAND2016-####C

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Spent Fuel Security Research

- **DOE-NE Material Protection, Accounting, and Control Technologies (MPACT)**
  - Spent Fuel Ratio (SFR)
  - Modeling of multi-stage sabotage scenarios
  - Evaluation of security for conceptual interim storage facilities
  - 2020 roadmap for used fuel extended storage (UFXS) security and safeguards by design (SSBD)
- **DOE-NE Used Fuel Disposition (UFD)**
  - Force-on-force simulations for various guard force configurations
  - Consequence modeling studies of sabotage events
    - Including economic modeling for clean-up
- **NRC – Office of Nuclear Security Incident Response (NSIR)**
  - Advise NRC staff on potential source terms from sabotage scenarios
  - Provide technical expertise to assist NRC staff with ISFSI and MRS rulemaking activities

MATERIAL PROTECTION, ACCOUNTING, AND CONTROL

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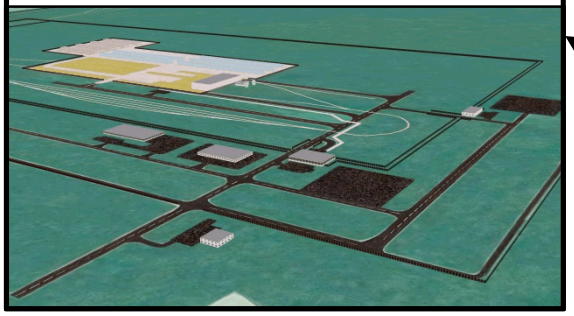
Collaboration Activities

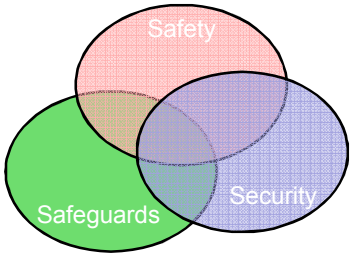
SRNL

Design of pilot storage facility (PSF)



Los Alamos NATIONAL LABORATORY

Develop best practices guide for PSF using SSBD



Sandia National Laboratories

- **Preliminary security evaluation of PSF**
  - Consequence modeling
  - SSBD considerations
- **Spent fuel ratio modeling**
- **Complex sabotage scenario evaluations**
  - CTH and ALE-3D
- **Maintain interface with regulatory rulemaking**

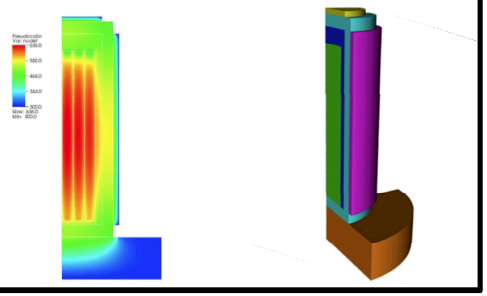
OAK RIDGE National Laboratory

ISFSI inventories from UNF-ST&DARDS

	Canister ID								
Nuclide	TSC-1	TSC-2	TSC-3	TSC-4	TSC-5	TSC-6	TSC-7	TSC-8	TSC-9	TSC-10
Am-241	2.38E+04	4.62E+04	2.23E+04	2.35E+04	2.08E+04	2.52E+04	1.69E+04	1.71E+04	2.68E+04	2.42E+04
Ce-144	6.59E+01	7.65E+01	2.68E+01	1.13E+01	4.61E+03	2.17E+03	8.47E+03	1.43E+03	7.61E+02	3.06E+01
Cm-244	1.88E+04	3.79E+04	1.55E+04	1.43E+04	2.00E+04	3.55E+04	2.54E+04	3.54E+04	2.50E+04	1.98E+04
Co-60	2.89E+03	5.68E+03	2.35E+03	2.24E+03	6.36E+03	6.04E+03	8.22E+03	6.21E+03	4.60E+03	2.78E+03
Cs-134	9.68E+03	1.70E+04	6.46E+03	4.96E+03	5.43E+04	4.79E+04	8.40E+04	5.45E+04	3.19E+04	8.12E+03
Cs-137	5.60E+05	1.12E+06	5.04E+05	4.97E+05	7.15E+05	7.93E+05	7.64E+05	6.98E+05	7.16E+05	5.67E+05
Eu-154	1.48E+04	2.59E+04	1.25E+04	1.17E+04	2.46E+04	2.92E+04	3.01E+04	2.84E+04	2.22E+04	1.49E+04
Kr-85	2.91E+04	5.81E+04	2.55E+04	2.46E+04	4.97E+04	4.83E+04	5.85E+04	4.53E+04	4.11E+04	2.89E+04
Pu-238	2.32E+04	4.70E+04	2.01E+04	1.91E+04	2.62E+04	3.71E+04	2.85E+04	3.22E+04	3.01E+04	2.39E+04
Pu-239	3.13E+03	6.18E+03	3.03E+03	3.02E+03	3.47E+03	3.52E+03	3.43E+03	2.59E+03	3.49E+03	3.12E+03
Pu-240	4.37E+03	8.60E+03	4.01E+03	4.13E+03	4.65E+03	5.35E+03	4.51E+03	4.15E+03	5.17E+03	4.44E+03
Pu-241	5.05E+05	1.00E+06	4.42E+05	4.44E+05	7.21E+05	7.75E+05	8.00E+05	6.91E+05	6.73E+05	5.03E+05
Ru-106	4.20E+02	5.83E+02	2.05E+02	1.13E+02	1.03E+04	6.51E+03	1.80E+04	5.90E+03	3.28E+03	2.57E+02
Sr-90	3.67E+05	7.32E+05	3.34E+05	3.26E+05	4.93E+05	5.17E+05	5.28E+05	4.43E+05	4.73E+05	3.69E+05
Y-90	3.67E+05	7.32E+05	3.34E+05	3.26E+05	4.93E+05	5.18E+05	5.28E+05	4.43E+05	4.73E+05	3.70E+05

Lawrence Livermore National Laboratory

Cask sabotage modeling with ALE-3D



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Spent Fuel Ratio (SFR)

- **Surrogate fuel pellets may aerosolize differently than actual spent fuel**
  - Spent fuel pellets undergo changes to bulk material properties such as density and porosity due to irradiation
- **Data needed to scale release fractions determined from previous large-scale tests conducted with surrogate (DUO_2)**
- **SFR quantifies the respirable aerosols produced by an high energy device (HED) acting on spent fuel compared to a surrogate material**
  - $SFR = \frac{RF_{Spent\ Fuel}}{RF_{Surrogate}}$, Aerodynamic Equivalent Diameter (AED) < 10 μm
  - Comparisons must be made under identical conditions
    - Statistically significant number of experiments are required
    - Or modeling using acceptable, simplifying assumptions
- **Underlying physics highly complex**

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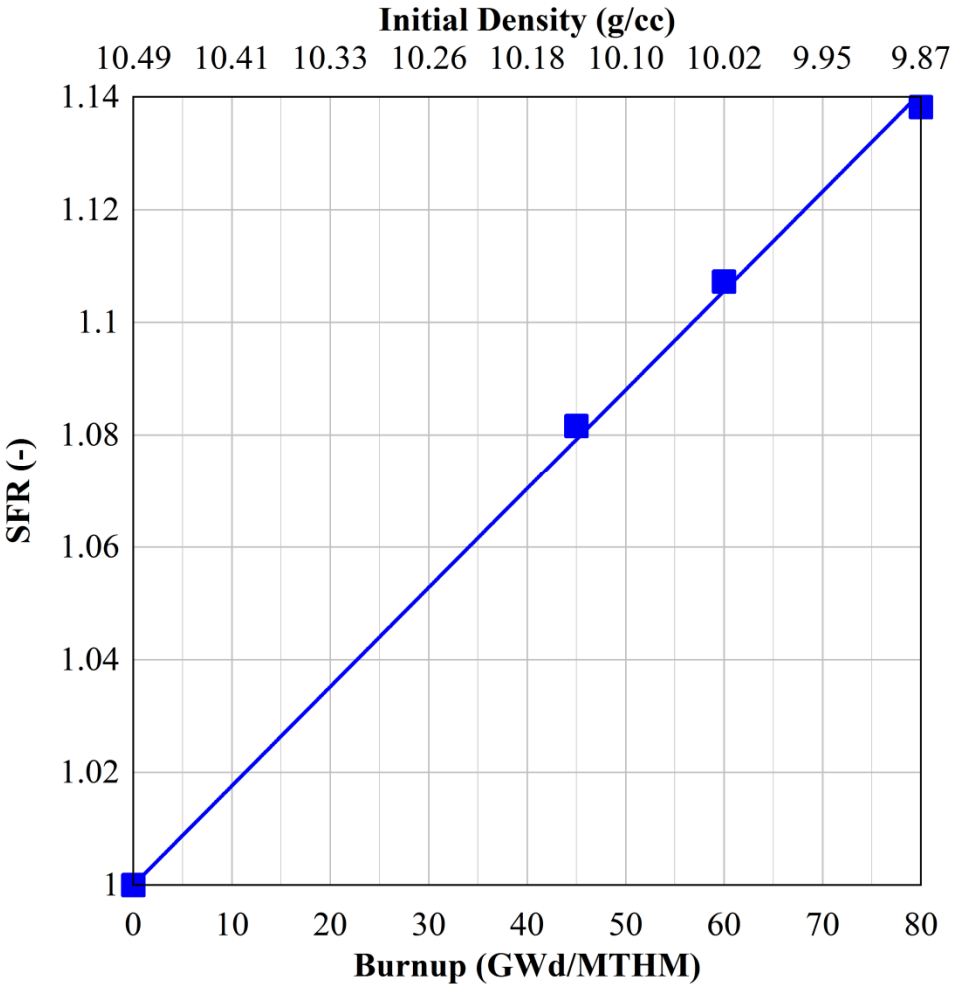
Spent Fuel Ratio Results



- ***Maximum SFR = 1.14*** **for all cases**
  - Determined for maximum burnup 80 GWd/MTHM (minimum density)
  - Max. respirable percentage = 1.8%, Baseline (DUO_2) = 1.6%
- **SFR effectively linear with burnup (and density)**
- **Calculated SFR ~3× smaller than currently assumed**

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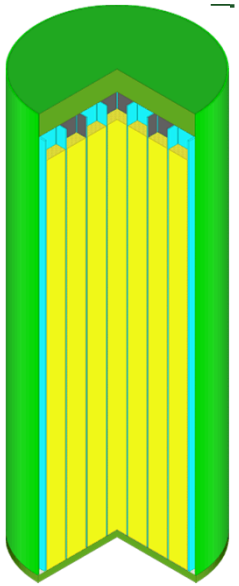
Sabotage Modeling

- **Collaborating with LLNL**
- **Multiple models required to capture physics over length scales with six orders of magnitude**
  - Various treatments of fuel and cask using shock physics modeling
    - Bulk models – Overall cask response, homogenous or simplified fuel treatment
    - Refined fuel models – Fuel level modeling, discrete pellets with cladding
  - Empirical relationship used to define respirable fractions
    - Based on limited, small sample tests



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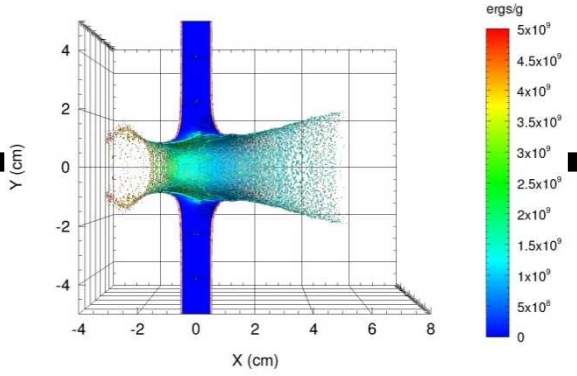

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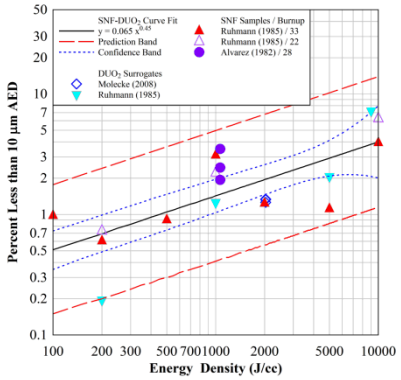

=RF

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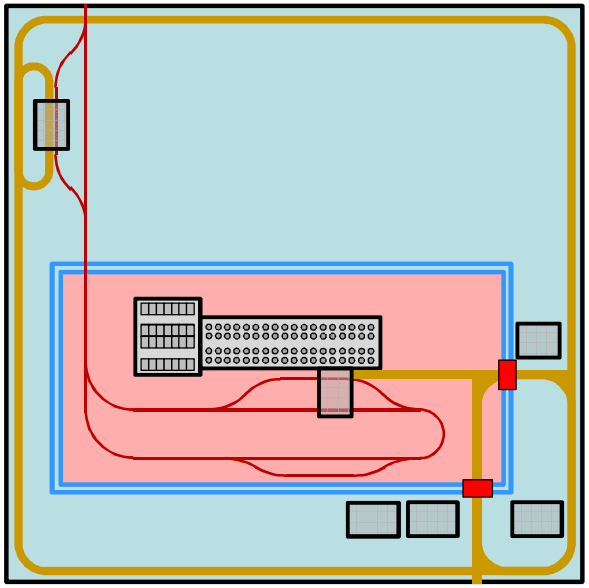
Consolidated Interim Storage



- **Collaborating with SRNL and ORNL**
- **Apply site definition for modeling**
  - Force-on-force
  - Source term calculation
  - Consequence analysis
  - Evaluation for difficulty of attack
- **Provide feedback to facility planners**
  - Changes to improve security and/or reduce vulnerability

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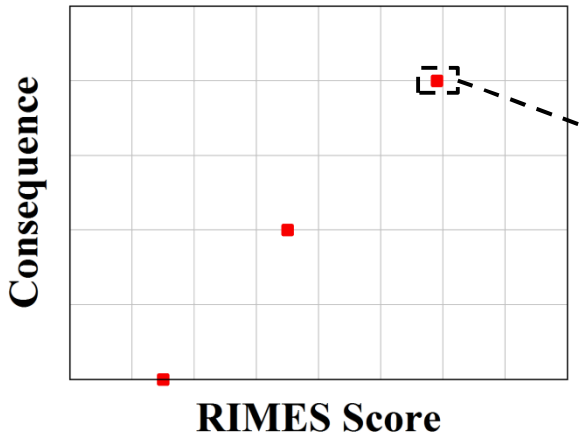
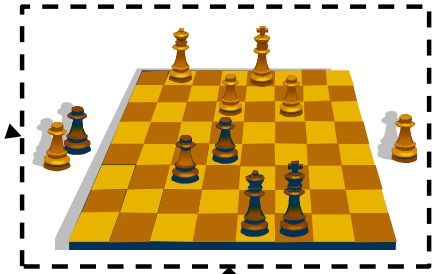
Analysis Methods

Consequence Analysis

- Assume ADV success
- Source terms
  - Engineering analysis
  - Large-scale testing
- Dispersion analysis
  - Source characteristics
  - Weather
  - Exposure
  - Location / terrain





RIMES

- Expert panel
  - Top-down evaluation of security
  - Assigns levels of difficulty
- Aggregated score
  - Assumes ≥ 67% ADV success

STAGE

- Force-on-force simulator
  - Bottom-up approach
  - Compute probability of neutralization
- Evaluate different security measures
  - GF configurations
  - Access delay

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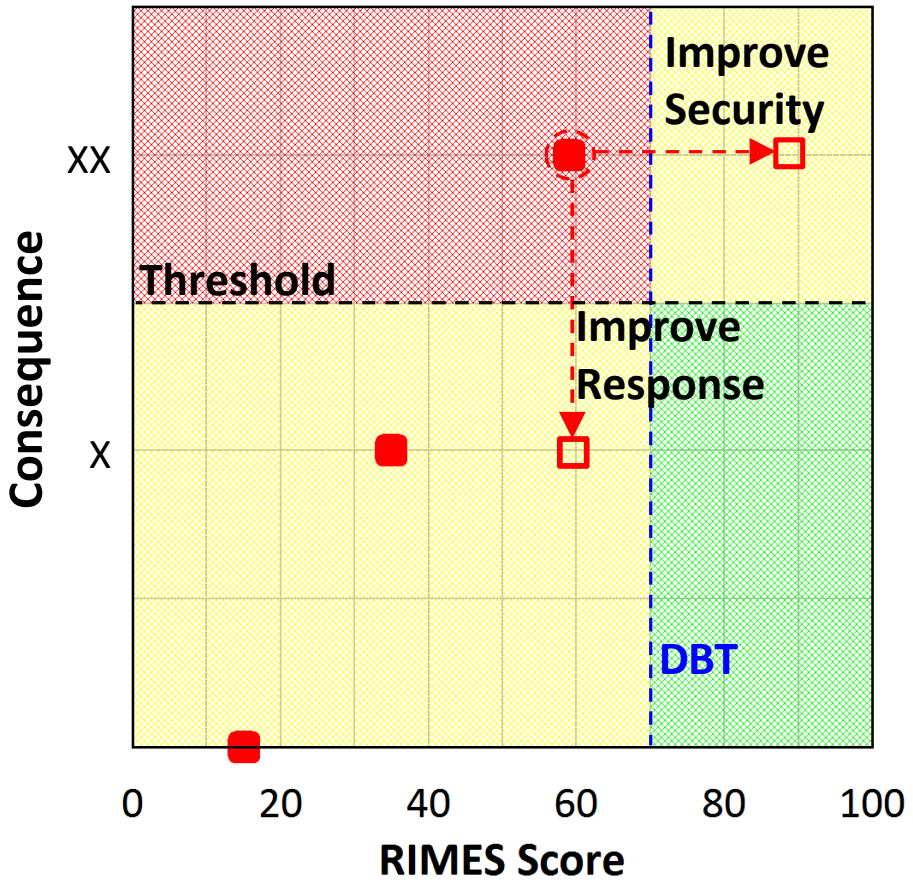
Combined Results



- **Are the consequences acceptable?**
  - Can the consequence be mitigated by improving the system response to the attack?
    - Evaluated with consequence analysis
- **Is the postulated attack beyond the DBT?**
  - Can security be improved to make the attack more difficult?
    - Evaluated with STAGE
    - Changes to GF configuration
    - Additional access delay

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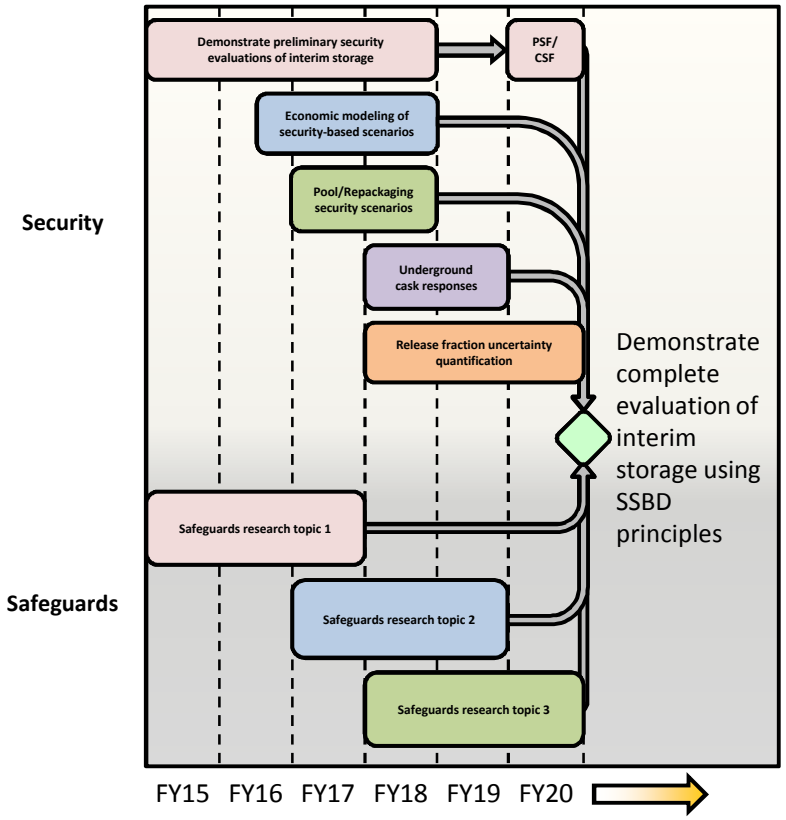
2020 Used Fuel SSBD Roadmap



- **Collaborating with LANL, SRNL, ORNL, and LLNL**
- **Identify and rank knowledge gaps**
- **Integrate with MPACT campaign and SSBD principles**
- **<u>Vision</u>: *By 2020, this research path will deliver the tools and models needed to better quantify and thereby allow the optimization of the security and safeguards approaches for an interim spent fuel storage site over the lifetime of the facility***

USED FUEL DISPOSITION CAMPAIGN

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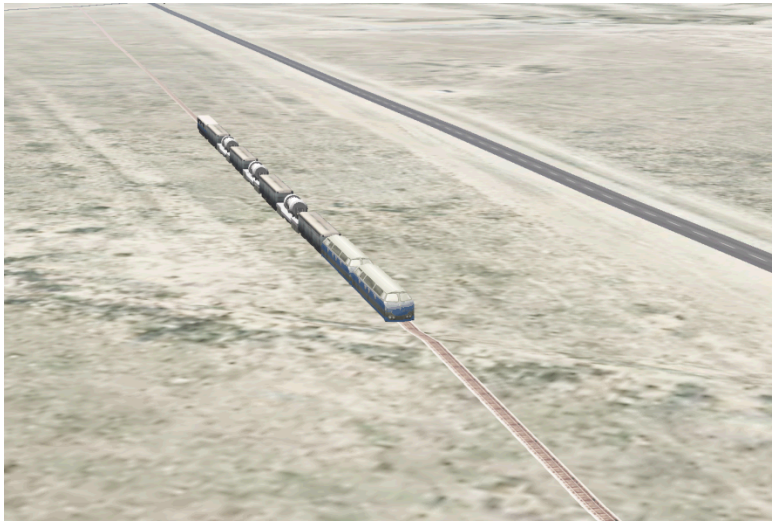
Security Considerations for Transport



- **Significant technical overlap with onsite storage**
  - Design basis threat
  - Source term definitions
  - Dispersion analyses
- **Substantial differences in security from fixed storage sites**
  - Detection times considerably shorter
  - More constraints on physical delay and denial (primarily weight)
  - Emphasis on primary (on-train) security

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Research Topics

- **Previously investigated various security force configurations and potential delay/denial technologies**
  - Identified best configuration to defend against currently assumed DBT
- **Currently exploring consequence modeling for transport scenarios**
  - Use source terms from previous storage studies
  - Investigate potential economic impact of a successful attack using different assumptions
    - Location of attack
    - Level of remediation

NSIR RULEMAKING SUPPORT

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Support of Rulemaking for SNF Storage

- **NRC-HQ-11-14-D-0002 – Rulemaking and Guidance Development for Security Requirements Related to Storage of Spent Nuclear Fuel**
  - Scope: Provide technical expertise to assist NRC staff with ISFSI and MRS rulemaking activities and with associated regulatory guides
  - Driver: The Commission has directed NSIR staff to update security requirements for the storage of SNF and HLW from a prescriptive DBT approach to a performance, dose-based approach
  - Status: Drafting SNSI and SGI reports to support NSIR staff
  - Impact: Development of a performance based DBT approach requires significant technical work to develop usable unclassified and safeguards information guidance documents for staff and industry

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Current Activities

- **Activities: Ongoing information exchanges**
  - NSIR staff attended MPACT classified meeting on September 17, 2015
  - MPACT/NSIR classified meeting on October 20, 2015
  - SGI meeting with stakeholders (Currently unscheduled)
- **Issues: Ongoing, parallel activities that inform current analyses**
  - NRC/RES (NRC-HQ-6014-D-0019): Bi-modal thermal attack scenario
  - DOE/NE-52 (MPACT): Spent fuel ratio (SFR) modeling and bi-modal explosive attack scenario

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Summary

- **Several research activities with relevance to spent fuel security**
- **Sponsors at DOE/NE-52 (MPACT and UFD) and NRC/NSIR**
- **Collaborations with several national labs (LANL, SRNL, ORNL, and LLNL)**
- **Wide range of technical topics including:**
  - Spent Fuel Ratio modeling
  - Complex sabotage scenario modeling
  - Source term evaluations
  - Force-on-force modeling
  - Consequence modeling including economics
  - Security evaluations of conceptual consolidated interim storage facilities
  - 2020 roadmap for used fuel extended storage