# Improvements in Transportation Security Analysis from a Complex Risk Mitigation Framework for the Security of International Spent Nuclear Fuel Transportation

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# Outline

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# Introduction

- The nuclear fuel cycle faces **more complex risks** from a growing & evolving operational environment
  - Interdependencies between security, safety & safeguards (3S) risks & dynamic operational environments challenge traditional risk analysis methods

- Exemplified in the multi-modal or **multi-jurisdictional complexity** of the international transport of spent nuclear fuel (SNF)
  - 1996 shipment of HEU from Colombia to U.S.
  - Agreed shipment of SNF from Iran to Russia

# Introduction

- According to Olli Heinonen (2017):
  - '***Safeguards, security, and safety*** are commonly seen as ***separate areas*** in nuclear governance. While there are technical and legal reasons to justify this, they also ***co-exist and are mutually reinforcing***. Each has a ***synergetic effect on the other***…'

- Recently completed LDRD research at Sandia National Laboratories explored **integrated** safety, security & safeguards (**3S**) **frameworks** for **managing risk complexity** in international SNF transportation
  - The results of this study present intriguing implications reducing transportation security risk(s) against 21st century threats

# Risk Complexity

- A new concept of risk that, for international SNF transportation, that includes
  - The traditional definitions of risk associated with ***security***, safety & safeguards
  - Social and political contexts/dynamics that may prevent the completion of the desired safety, security and safeguards objectives
  - The emergence of risk resulting from interactions among security, safety, and safeguards risks and mitigations

# Risk Complexity

- Incorporating complexity & systems theories into traditional engineering approaches to risk introduces:
  - **Interdependence**: how interactions influence desired functions
  - **Emergence**: how system level behavior results from interactions
  - **Hierarchy**: how higher levels constrain the behaviors of lower levels

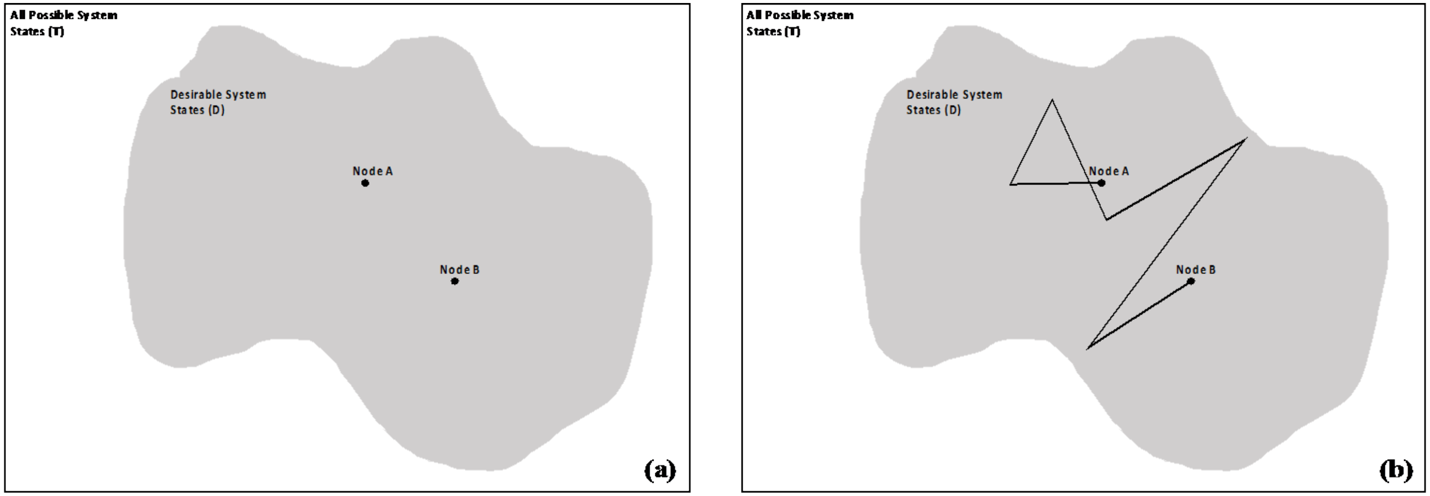
- The result: a state-space description of complex risk where
  - (T) = total state space
  - (D) = some subset of (T) representing all desirable system states
  - (T-D)= a complementary subset representing the undesirable, or 'risky,' states

- All else equal, complex risk is manipulating the technical/social components of a system to stay in the desirable system states

# Risk Complexity

- Such systems may exist at ***different places*** in the desirable space at ***different points in time***
  - Complex risk is dynamic and also includes all system states between beginning & end points
  - The requirements that define the desirable space are implemented in different social, political, and technical contexts.

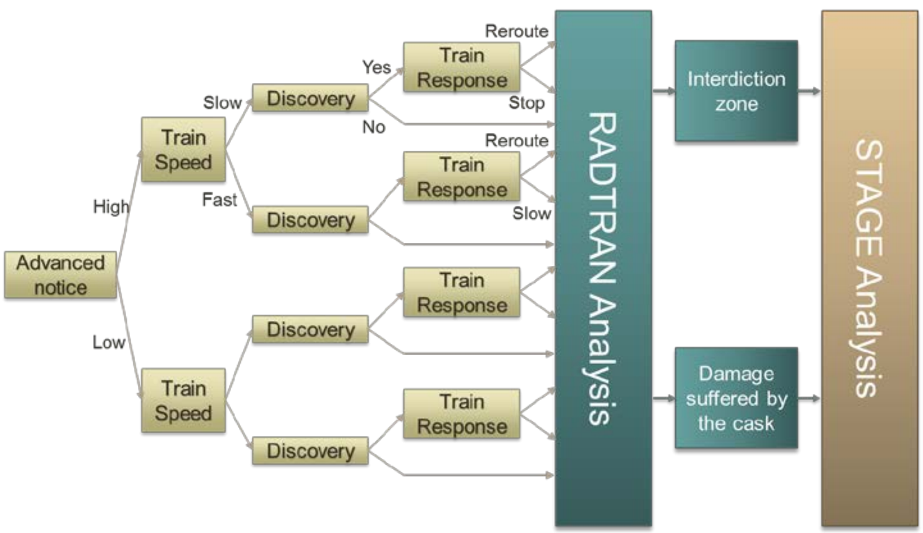
- Therefore, while Figure (a) may appear to have relatively low risk at Nodes A and B, Figure (b) illustrates how there are multiples points that approach the boundary of the desirable space



# Risk Complexity

**Dynamic Probabilistic Risk Assessment (DPRA)**

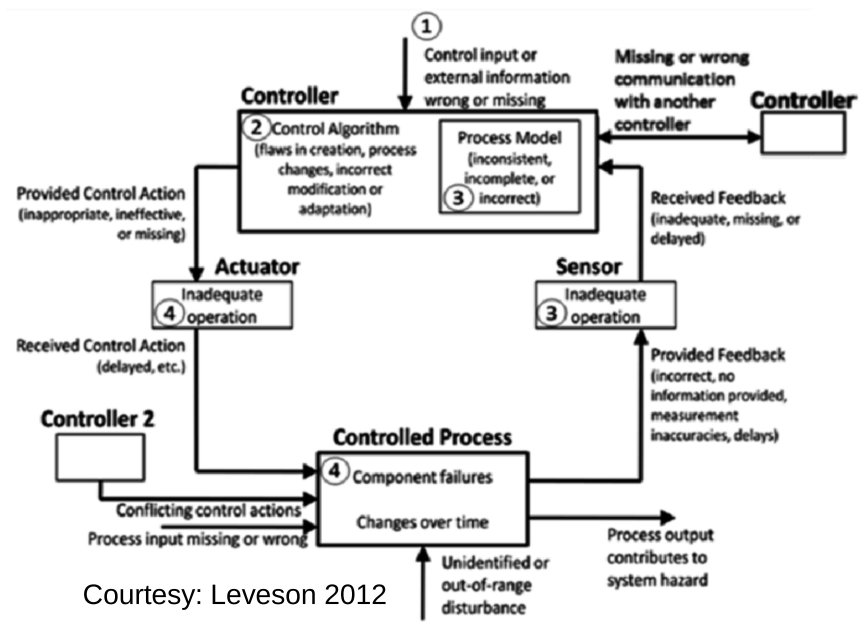
- Bottom-up & deterministic
- Uses Dynamic Event Trees (DETs) for systematic and automated assessment of possible scenarios arising from uncertainties
- Models/tools used:
  - Safety: **RADTRAN**
  - Security: **STAGE**
  - Safeguards: **PRCALC**, Markov Chain model of safeguards from BNL




Courtesy: Kalinina, et. al. 2017

**System-Theoretic Process Analysis (STPA)**

- Top-down & based on system-level behaviors
- Based on abstracting real complex system operations into hierarchical control structures & functional control loops
- Two Primary Steps:
  - ‘**Step One**’: identify possible violations of control actions that lead to system states of higher risk
  - ‘**Step Two**’: derive specific scenarios that could cause these theorized violations to occur




Courtesy: Leveson 2012

# Lessons from SNF Transportation

- Key benefits of the state-space descriptions of risk include:
  - ***Improved*** understanding over traditional approaches to transportation security risk
  - ***Enhanced*** understanding & ability to manage increasing risk complexity
  - ***Distinguishing*** sources of risk that can be controlled (i.e., defining & high level requirements) from those that cannot (i.e., inherent risk of shipping)
  - ***Identifying*** sources of risk variability (e.g., those from implementation vs. those regardless of implementation)

| **Attributes** | **Traditional Characterization (e.g., security in isolation)** | **Complex Risk Characterization** |
|---|---|---|
| **Risk Definition** | *Probabilistic ability to protect along path(s) against anticipated adversary capabilities* | *Emerges from potential system migration toward states of higher risk* |
| **Risk Reduction** | *From improved component reliability & defense-in-depth* | *Realized as part of complex risk management trade-space* |
| **Risk Measure** | *System effectiveness (e.g., combinatorial reliability of security components)* | *State description including nuclear material loss, area contamination & socioeconomic harms* |
| **Solution Space** | *Limited to increasing security component reliability or reducing adversaries capabilities* | *Expanded to technical, organizational or geopolitical influences & safety/safeguards leverage points* |
| **Relationship to Safety & Safeguards** | *None, treated as an independent risk* | *Parallel characteristic, treated as interdependent component of complex risk* |

# Lessons from SNF Transportation

- A potential ***paradigm shift*** in risk assessment & management for international SNF transportation security (and, nuclear fuel cycle activities writ large)
  - Risk from the ‘inside out’ as a dynamic balance within a system state-based tradespace

- Additional major lessons include:
  - realities of international SNF transportation will challenge current approaches and assumptions;
  - risk itself is complex;
  - some aspects of/influences on risk are controllable, some are not;
  - 3S interdependencies exist;
  - risk is a complex trade space; and,
  - integrated 3S risk management frameworks can reduce risk/uncertainty, even for individual (e.g., security only) perspectives

# Implications for Transportation Security (1/2)

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- These conclusions offer a better understanding of 3S interactions that ***can improve SNF transportation security design & analysis***

| Lessons Learned | Implications for SNF Transportation Security |
|---|---|
| **Realities of international SNF transportation will challenge current approaches and assumptions** | • Need to (re)assess the validity of assumptions underlying current approaches to transportation security<br>• Technical analysis tools need to account for the variation in implementation of the PPS in transit among different operators |
| **Risk itself is complex** | • Security risk metrics (e.g., system effectiveness, $P_E$) may be insufficient to adequately describe security risk/assess vulnerabilities<br>• Need to identify key aspects/descriptors of new challenges to transportation security |
| **Some aspects of/influences on risk are controllable, some are not** | • Not all security risks lie in adversary action or can be described in probabilistic/technical reliability terms<br>• Implementation decisions & how technical components within transportation security systems matter—and should be included in analytical frameworks |

# Implications for Transportation Security (2/2)

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- These conclusions offer a better understanding of 3S interactions that ***can improve SNF transportation security design & analysis***

| Lessons Learned | Implications for SNF Transportation Security |
| --- | --- |
| **3S interdependencies exist** | • Need to change the assumption that transportation security can be accurately & adequately evaluated independently<br>• A broader solution space exists for managing complex risk in transportation security (e.g., leveraging safeguards material accounting practices to mitigate insider issues) |
| **Risk is a complex trade space** | • There is no 'true' minimization of security risk, therefore attempts at security design optimization are more complex<br>• Need to develop expertise/experience in making security-related trade-offs during international SNF transportation |
| **Integrated 3S risk management frameworks can reduce risk/ uncertainty, even for individual perspectives** | • Integrated approaches have been shown to incorporate more contributor to complex risk<br>• Need to develop new analytical approaches to assess non-uniform, larger types of uncertainty (between safety, security & safeguards) |

# Conclusions

- This SNL study demonstrated how incorporating complexity & systems theories supports ***complex risk***, a concept that better addresses
  - Non-traditional risk-related pressures & dynamics (e.g., social contexts & changing security implementation capabilities)
- Related insights offer improved management strategies to ensure the protection of nuclear (& radiological) materials against dynamic, complex risks while in transit
- This concept provides implications for improving SNF transportation security—and security of nuclear materials in transit more generically—against 21st century threats