United States
Department of Energy
National Nuclear Security Administration
International Nuclear Security

M3: Research Reactor Sabotage Targets

Research Reactor Sabotage Protection Workshop

SAND2025-02023O

Learning Objectives

Objectives:

- Become familiar with the HRC and URC concepts
- Describe the process for sabotage scenario analysis
- Identify notional sabotage targets at a hypothetical MTRF

Sabotage Target Identification

- PPS design and implementation require the knowledge of protection targets
- Sabotage target identification is a seven-step process
  - Establish the URC (HRC) criterion
  - Identify radioactive material inventories that require protection
  - Conduct sabotage scenario analysis
    - Identify events of malicious origin (IEMOs)
    - Identify mitigating systems (if any)
  - Develop sabotage logic tree and identify target sets
  - Screen and validate target sets (and protection targets)
  - Document location and nature of targets
  - Identify and secure vital areas (if required)

HRC and URC

- Identification of HRC and/or URC is a starting point in sabotage target identification
    - A policy decision by the State's competent authorities
    - There is no IAEA recommendation regarding methodology

- Normally, HRC is associated with high-consequence events
    - Deterministic and significant long-term stochastic health effects for population
    - Contamination of land and water
    - Societal and economic damage
- URC may involve radioactive releases requiring protective actions on-site as well as possibly off-site

HRC (URC) (1)

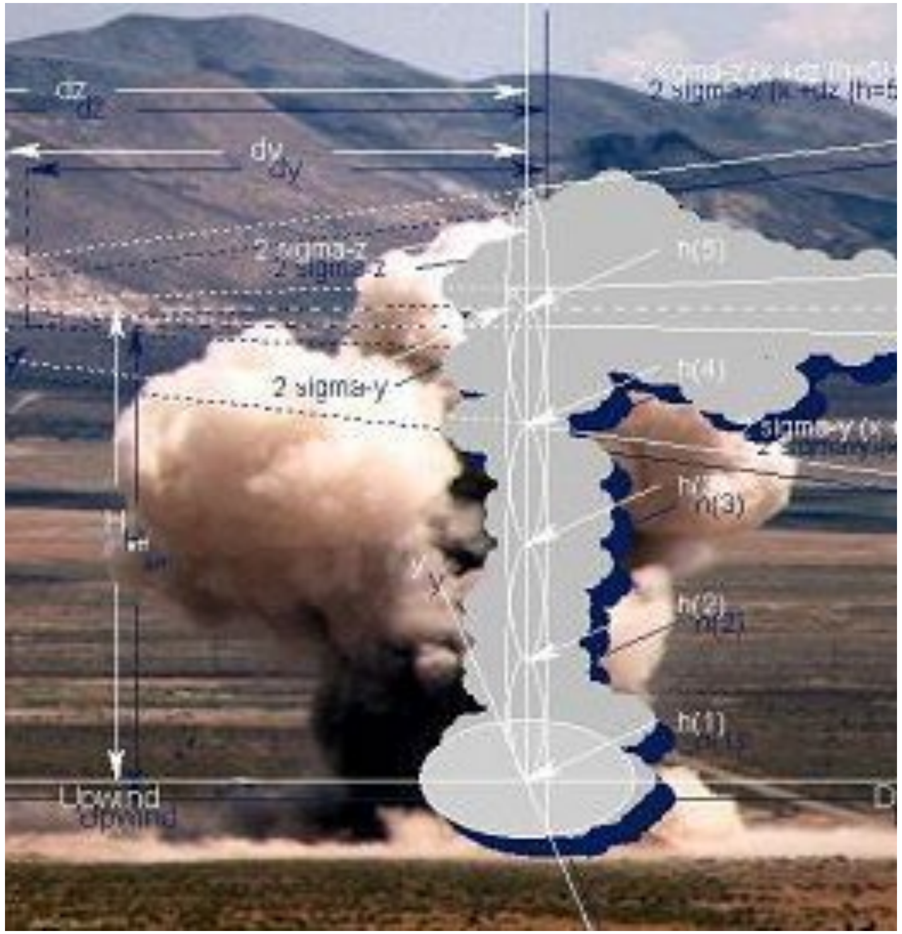
- Condition-based criteria
  - Specifies unacceptable facility state (e.g. significant reactor core damage)
  - Generally conservative
- Dose- or release-based criteria
  - Maximum allowable release or dose for population
  - Requires modeling of material transport
  - Still requires identification of specific protection targets

HRC (URC) (2)

- In some countries, the sabotage consequence criterion is aligned with that used for the purposes of emergency preparedness and response
  - European country – 100 mSv at site boundary
    - Evacuation dose threshold in a radiological emergency
  - Emergency Management Protective Action Guidelines
    - 50 mSv for evacuation of population
      - IAEA TECDOC 1432, Development of an extended framework for emergency response criteria

Identification of Radioactive Material Inventories

- Consider all inventories that may cause a release beyond URC/HRC
  - Irradiated fuel in the reactor core
  - Irradiated fuel storage facilities
  - Co-located facilities with significant inventories of radioactive materials
    - Isotope production facilities (e.g., Mo-99 filters)
- Evaluate whether a release of the inventory can cause URC/HRC
  - Puff release can be used as a bounding scenario
  - Gaussian Plume Dispersion Models are useful
- If the inventory can cause URC/HRC, conduct a more detailed sabotage scenario analysis
  - Source term and Airborne Release / Respirable Particle Fractions may need to be assessed



Sabotage Scenario Analysis (1)

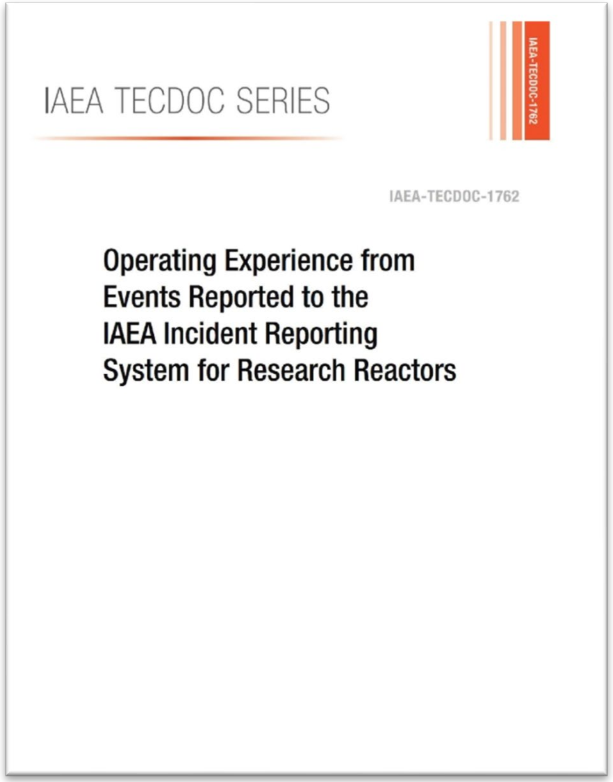
- Direct sabotage – attack against the radioactive material inventory
    - E.g., an explosive or thermal attack to disperse irradiated fuel

- Indirect sabotage – attack against reactor systems seeking to use the internal energy to cause radioactive release
    - Cause an initiating event that exceeds mitigating system capacity (e.g., exceeds design basis accident)
    - Cause an initiating event **<u>and</u>** disable systems needed to mitigate it

- Sabotage scenario analysis uses engineering safety analysis to determine consequences and targets

Sabotage Scenario Analysis (2)

- Common relevant safety scenarios for research reactors
  - Radioactive material (irradiated fuel) damage and dispersal
  - Reactor Overpower Transient
    - Increase reactor power and disable automatic overpower shutdown (SCRAM) by using cyber means or manipulation of controls
  - Loss of coolant accident
  - Failure of Decay Heat Removal System
  - Cooling channel blockage

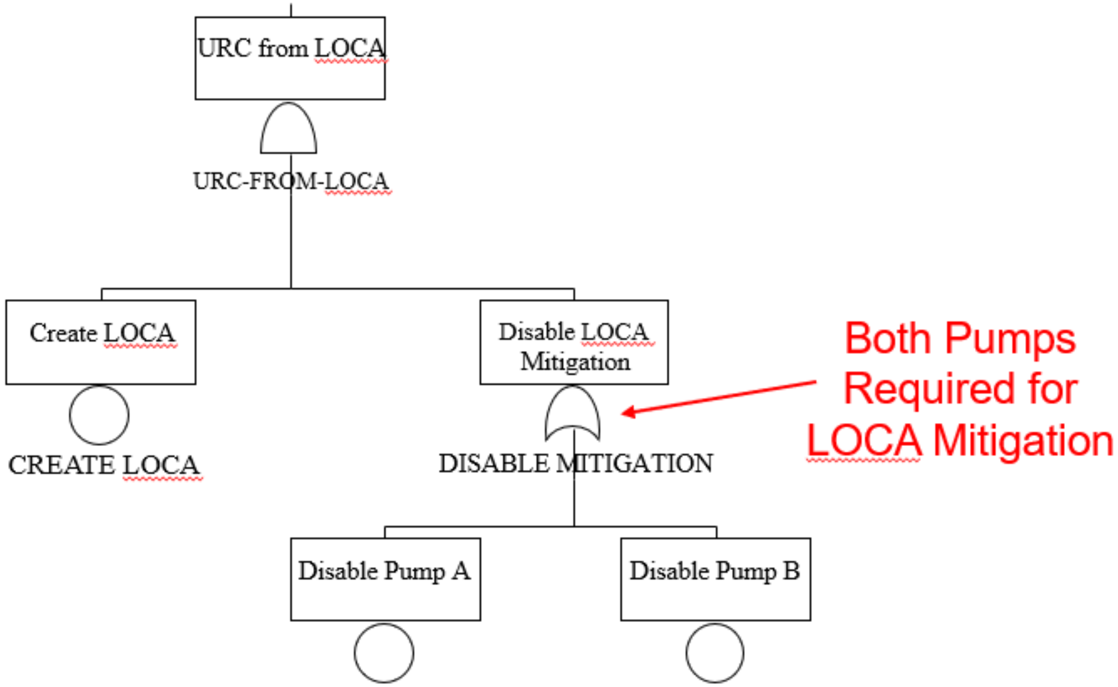


Sabotage Logic Model and Target Sets

IAEA NSS 16 and NSS 48-T describe the target identification approach and serve as a useful reference

- Sabotage logic model
  - Top Event – URC / HRC
  - Intermediate events – AND / OR combinations of events leading to Top Event (system level)
  - Terminal Events – Destruction or disablement of components or structures (component level)
- Structure is similar to fault tree used in engineering safety analysis (PSA)
- Output: target set combinations
  - A target set is the minimum combination of equipment or operator actions, which, if all are prevented from performing their intended safety function of prevented from being accomplished, would likely result in HRC / URC

Illustration: Sabotage Logic Model



Logic Symbols		
Symbol	**Operation**	**Definition**
+	OR	Either of two events occurs. A+B means that either event A or event B occurs.
*	AND	Both of two events occur. A*B means that both event A and event B occur.
Logic gates		
Symbol	**Gate Name**	**Definition**
	OR Gate	Output occurs if any of the inputs occur.
	AND Gate	Output occurs if all of the inputs occur.
Boolean algebra rules		
A+A=A	A+A*B=A	$\overline{(A+B)} = \overline{A}*\overline{B}$
A*A=A	A*(B+C)=A*B+A*C	$\overline{(A*B)} = \overline{A}+\overline{B}$

Target Set Screening and Validation

- Target set screening and validation is completed through a multi-disciplinary security and engineering analysis
- Key question: Can the target set be completed by a DBT (postulated threat) adversary?
  - Number of personnel required
  - Specialty skills (cyber, etc)
  - Amounts of explosives and other materials required
- Desirable target sets may be determined
  - Minimum adversary resources and task time
  - Ease of accessibility and identification
  - Greater severity of consequences
  - Shortest time to release
  - Potential for off-site release

Target Location and Documentation

- Target components are tied to specific facility locations
  - Building/ floor/ room
  - Fenced-in area

- Target sets are documented and are subject to a periodic review

- Targets sets information can be sensitive
  - Information regarding specific techniques for target destruction is highly sensitive

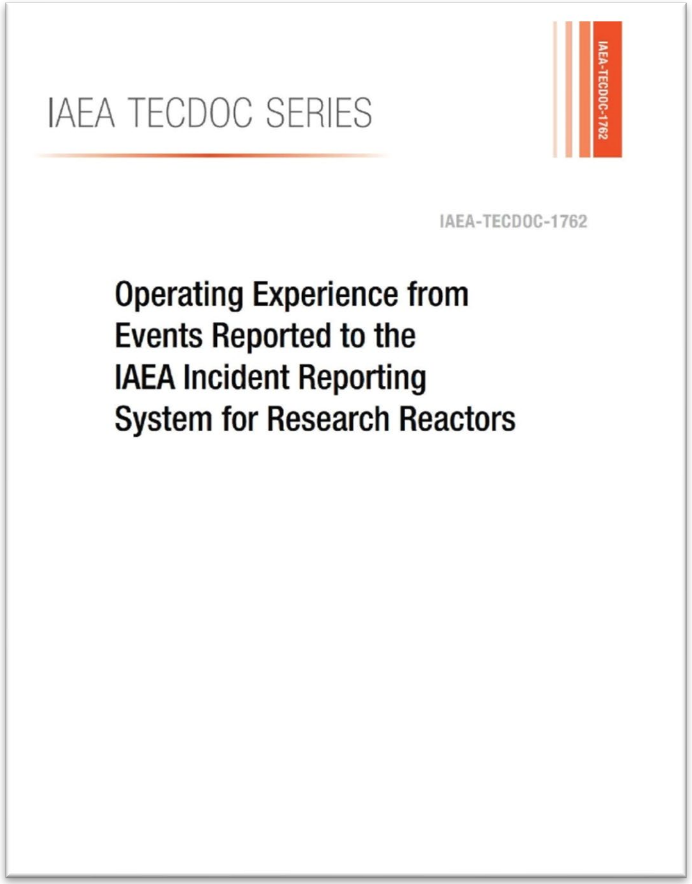
- Vital areas can be determined based on the analysis of target locations

Example: Sabotage Targets at MTRF (1)

- Radioactive material inventories of concern
  - Irradiated fuel in the reactor pool
  - Spent fuel storage area
    - Fresh fuel is not a concern (but is a theft target)
- Puff release of irradiated fuel would exceed URC

Example: Sabotage Targets at MTRF (2)

- Sabotage scenarios (IEMOs)
  - Direct attack against irradiated fuel to cause damage and dispersal
  - Cause Reactor Overpower Transient (ROT, increase reactor power and disable automatic overpower shutdown)
  - Cause a loss of coolant
  - Disable the Decay Heat Removal System
  - Block reactor cooling channels



Example: Sabotage Targets at MTRF (3)

- Sabotage logic model
  - Top level
    - URC = Direct attack + ROT + LOCA + DHRS
  - Component level
    - Example: ROT = Control Room manipulation + Mechanical removal of control rods
- Target sets (hypothetical)
  - Direct attack: reactor pool OR spent fuel pool
  - ROT: Control Room OR reactor pool
  - LOCA: Reactor coolant piping*ECCS OR Beam channel tube OR ECCS*reactor pool
  - DHRS: Coolant pumps OR Heat sink*ECCS OR heat exchanger*ECCS

ROT – Reactor Overpower Transient
LOCA – Loss of Coolant Accident
DHRS – Decay Heat Removal System
ECCS - Emergency Core Cooling System

Example: Sabotage Targets at MTRF (4)

- Partial list of target locations

Malicious Act (target)	Location	Rationale
SCRAM	Control room	SCRAM system controlled from controlled room
SCRAM	Reactor hall	Mechanical removal of control rods
Direct attack / core	Reactor hall	Reactor core is accessible
Direct attack / SFP	SFP building	Spent fuel pool (SFP) is accessible
LOCA – coolant piping	Equipment room	Piping is accessible
LOCA - ECCS	Equipment room	Systems are accessible

Example: Sabotage targets at MTRF (5)

- Vital areas (areas requiring protection)
  - Can be a room, a building, or a fenced-in area
  - Additional layer of access control, detection, delay
  - Help to mitigate insider threat and support protective strategy against an outsider attack

- Possible vital areas
  - Reactor hall
  - Control Room
  - Equipment Room
  - Beam tube access locations
  - Spent fuel pool hall

In Conclusion

- Research reactor sabotage targets are determined based on State-provided URC/HRC through a multi-step process
- IAEA NSS 16 and NSS 48-T describe the target identification approach and serve as a useful reference
- Target identification should consider engineering safety analysis
- Target identification is a basis for PPS design and evaluation
- Several MTRF areas may require protection against sabotage

National Nuclear Security Administration

Questions, Comments, Concerns?

International Nuclear Security
Reducing Risk of Nuclear Terrorism

Back-up Slide

Airborne Release Fractions (ARF)/Respirable Fractions (RF)

- Explosions
  - Metals
    - Maximum ARF/ RF occurs when TNT equiv. explosive mass equals mass of metal containing MAR, ARF*RF = 0.12
    - Powders: ARF = 0.8 x TNT equiv. / (MAR + Inert), RF=0.25
- Fires
  - Uranium Metal Fire: ARF * RF ranges from ~ 1E-5 to 4E-4 depending upon temperature
  - Uranium Oxide Powder: ARF = 6E-3, 1E-2

DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, http://www.energy.gov/ehss/downloads/doe-hdbk-3010-94
NUREG-1320, *Nuclear Fuel Cycle Facility Accident Analysis Handbook, http://www.nrc.gov/docs/ML1225/ML12254A158.pdf*