Vital Area Identification (VAI) in Transport: Countering the Threat from Sabotage

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Abstract

The International Atomic Energy Agency's (IAEA) Implementing Guide, Nuclear Security Series (NSS) No. 9, 'Security in the Transport of Radioactive Material' outlines that "the threat of malicious acts including sabotage is now more widely recognised". However, there is a perception internationally that the security arrangements to counter the threats of sabotage during transport are in a less mature position than that of those currently applied at nuclear facilities. This perception therefore highlights the need for better alignment in order to continue the safe and secure transportation of nuclear materials, and the development and sharing of international relevant good practice. The aim of this paper is to do just this. It will outline what a vital area in transport looks like, drawing from INS's expertise and experience in this area, as well as providing examples taken from nuclear licensed sites, to clarify the differences between site and transport when defining a vital area. Following this, it will then outline what the identification process consists of when applied to nuclear transport, engulfing the technical implications that arise from applying said process to transport cases; be it from varied materials or an absence of "site boundaries" and will draw upon existing processes currently in place for nuclear facilities (such as the use of sabotage logic models). Finally, it will consider the application of proportionate security measures to mitigate the risks identified during the assessment phase to ensure an effective and graded approach is adopted. These steps combine to provide the holistic approach to sabotage analysis in transport; through defining, identifying security risks accurately. The results of this paper are expected to be assistance in obtaining a more resolute definition of vital areas in transport as well as a clear and logical process of their identification. Achieving this will further operational security standards of nuclear material transport.

Introduction

Vital area identification is a method currently in use internationally on nuclear sites to counter sabotage by grading areas in which; nuclear material is being held, Initiating Events of Malicious Origins (IEMOs) can take place or key mitigating systems, structures or components are situated. The grading can then be used to assign proportionate security measures to the selected areas. An IEMO is defined as an act that can directly or indirectly lead to Unacceptable Radiological Consequences (URCs) through the dispersal of inventory. When looking to the transport of nuclear material, this procedure has not been adopted, which brings into question the maturity of anti-sabotage practices taking place in nuclear transport. The threat from sabotage is ever present for both nuclear facilities and nuclear transport, and it is the presence of this threat that highlights a need for alignment between the two. Aligning to the current methodology in place (this report will focus primarily on content from the [1] *IAEA NSS No. 16 "Identification of Vital Areas at Nuclear Facilities")* is not straight forward, and the aim of this report is to explore the implementation of VAI in transport.

Objective

To discuss the differences for vital area identification in nuclear transport when migrating the current process outlined in *IAEA NSS No. 16* [1] to the context of nuclear transport, as well as investigating potential modifications to the process that could help to make it more applicable to the transport of radioactive materials. Following this a fictitious example will be conducted to demonstrate how modifications proposed might be implemented.

Theft vs Sabotage

Understanding threats is a key aspect of strong security in any industry; within the nuclear industry it is critical. Many potential threats to security are present, and categorising these threats helps to produce appropriate arrangements in order to mitigate them. Threats within the nuclear industry can be placed into 2 distinct categories; threat of theft or threat of sabotage, and the difference between these two threat types is why a holistic approach to security is necessary.

Threat of theft is graded on how desirable a material is to be stolen, usually based heavily on material quantities in combination with material type, amongst other factors. The threat of theft typically increases with the amount of material present; with the goal of theft being to gain control of the material at some point. For sabotage however, the only goal is to produce radiological releases to the environment or to the public. Due to the different objectives of each threat, the capabilities of the threat actor for both theft and sabotage to be completed are differing. A theft scenario will typically have 2 phases, the first being to obtain the nuclear material, the second being to escape with it. Sabotage will typically have only one phase "defeating the protection of the nuclear material by means of weapons or intrusive tools and creating a radiological hazard." *(IAEA Nuclear Security Series No. 26-G).* Consequently the ability to carry out sabotage requires less sophistication than what is required for theft, as the primary aim is to deliberately destroy or damage in order to cause radiological release, and not to acquire the material at any point. Therefore from this we can see that an act of theft is, typically, harder to carry out and complete than an act of sabotage, again indicating a need for anti-sabotage measures to be at optimal capabilities relative to threat assessments.

Another interesting factor that must be approached differently from the perspective of analysing sabotage threat is the form of material. The form of material is also a key factor when looking at threat of theft of course as it affects desirability. However for sabotage material form is linked to how easily dispersible the material is and in turn how easily its release could lead to URCs. This means that the form of the material poses an extra consideration for its categorisation, should the form of material be powder for example, the risk of airborne contamination is greater (something that could arise following an act of sabotage).

Simplistic Illustrative Example

Take a shipment of 350g Pu-239 in powder form, the flask carrying the material has been impacted with an explosive device resulting in direct dispersal of the powder 10m above the ground. A population of 750 people is situated 1.5km to the east (critical group) with the wind blowing from the west, the wind blows in the eastern direction 75% of the time therefore making the town's population what we could consider a "critical group".

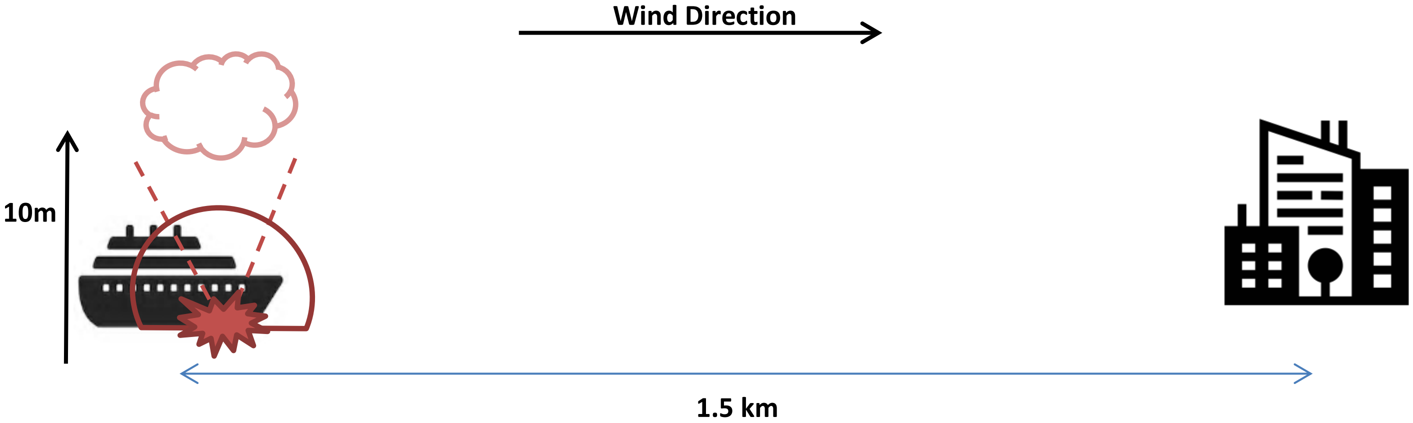

Figure 1 Simplistic illustrative example diagram

Assumptions and values:

- Values for dose factor taken from International Commission on Radiological Protection Annals[2] (Clement et al., 2012) for adult male, $DF_{inh} = 2.5x10^{-7}$ Sv/Bq
- Airborne concentration taken from dispersion plot for off-site dose assuming uniform dispersion over a 30^{o} sector in average weather conditions. Value @ 10m height from plot = 10^{-6} Bq/m^3 [3] (NRPB-R19, 1979)
- Average breathing rate for an adult = 1m^3/hr
- Specific Activity Pu 239, $A = N\lambda$

N @ 105g (30% dispersal of 350g) = 2.64 X 10^{23} $\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{760 \times 10^{9}} = 9.12 \times 10^{-13}$

Therefore Specific activity, A = 240768 MBq

$$Airborne\ Concentration = A \times\ Value\ from\ dispersion\ plot\ [3]@\ 10m$$
$$= 240768 \times 10^{-6}$$

$= 240.7 \times 10^{3} Bq$

$$Intake = Breathing\ rate \times Airborne\ Concentration = 1 \times (240.7 \times 10^{3})$$

$= 240.7 \times 10^{3} Bq/hr$

$Dose\ Rate = Intake \times DF_{Inh} = (240.7 \times 10^{3}) \times (2.5 \times 10^{-7}) = \mathbf{0.06\ Sv/hr}$

Using dose calculations we can see that a member of the population (the critical group in the nearby town) could expect a dose via inhalation of 0.06 Sv/hr**.** This is an oversimplified example of reality however it highlights that threats from sabotage and threats from theft don’t directly correlate with each other. Material quantity, although being part of the equation, is not necessarily a deciding factor in analysing potential radiological consequences from acts of sabotage; the inputs are far more varying. These varying inputs are present throughout the process of Vital Area Identification (VAI), and it is these that give the process its complexity.

Vital Area Identification (VAI) Process on Site Overview

The VAI process detailed in *IAEA NSS No. 16 Identification of Vital Areas at Nuclear Facilities* [1] can be broken down into 3 phases:

Phase I

The basis of the VAI process is formed from the state set definition of URCs given in terms of Sieverts at a reference point, which for nuclear sites is the site boundary. Inventory analysis must then be conducted to document the nature and form of material as well as incorporating any site characteristics that could impact the doses level at the site boundary. Conservative analysis should then be undertaken to determine if the complete release of the inventory would be in excess of the URC criteria set by the state, naturally if complete release is unable to meet URC criteria then VAI process does not need to take place.

Phase II

Following the initial phase of analysis the events that could lead to URC need to be investigated, these are labelled IEMOs and initiating events (IEs) that can either alone or in conjunction with other malicious acts lead to URC. The systems in place to mitigate these events must be documented, with key components and their locations also noted. Following this, general guidance is to use a “sabotage logic model” to plot the IEs and IEMOs and to identify the events or event combinations that could lead to URC. The sabotage logic model will include any event that can overcome the mitigating system capacities, as well as ones that cannot. In the cases of events that cannot overcome mitigating system capacities it then becomes necessary to identify the systems, components or structures that mitigate the event and include them in the sabotage logic model.

Threat capabilities need to be included in analysis, threat capabilities at each site will be unique to the site due things such as geographical location and political climate. Using the threat capabilities it is then possible to eliminate any events from the sabotage model that the assumed threat does not have the ability to carry out. With the remaining events left in the sabotage logic model, the events are replaced with the corresponding area in which they can be carried out or for mitigating systems, components or structures these are replaced with the area in which they are situated.

Phase III

The sabotage logic model will now be a list of candidate areas in which the set of vital areas can be selected, using Boolean algebra to equate the logic model will give the lists of areas that if classed as Vital Areas (VA) or High Consequence Vital Areas (HCVA) will prevent all acts of sabotage placed in the model.

Application to Transport

Determining URC/High Radiological Consequences (HRC) Definitions

When transferring this approach to transport the initial problem arises from the reference of a site boundary, in order to make the adoption of this process smoother this should be considered to be the boundary of the transport. Using the boundary of the transport can then be used for URC/HRC calculations from the state set limits. Having state set URCs and HRCs is fundamental in the vital area identification process, however for international transport, different states will be encountered by the transport. Therefore it is likely that states encountered will have to be aware of procedures used (not URCs/HRCs themselves) and be in agreement with them. The transporter should work to their own state’s set definitions and then make sure all regulators with invested interests in the transport have reviewed the measures in place for the transport in order to agree that they are suitable and significantly capable.

Initiating Events and Threat Capabilities

Initiating events for each specific transport will be determined in the same manner as that for a nuclear site, being events that could lead to URC/HRC criteria. A key consideration for initiating events unique to transport is accounting for the transport package robustness. The individual flask characteristics will have to be included in the process of determining initiating events; with flask types widely varying in robustness, analysis will require a detailed knowledge of the transport packages in use to accurately determine initiating events.

Having a route analysis as part of phase II analysis enables the threat capabilities to be incorporated to determine which sabotage events are possible. A nuclear site will have knowledge of threat capabilities (likely from the state Design Basis Threat (DBT)). For transport this capability is to be determined from initially knowing the route being taken and then having knowledge of the threats present on said route. For a nuclear site, the threat capabilities are much less varying than that for transport (due to the site being stationary of course). Therefore the transport route taken will have a massive impact on determining threat capabilities and in turn determining if the sabotage events identified are possible. This issue poses the question:

Would the set of vital areas change for nuclear transport as it completes its route?

The most logical way forward is to further analyse the route, highlighting which sabotage events are possible in which sections of the route. From this the vital area analysis must be done on a incorporating the entirety of possibilities on the route for the transport. This would mean a sabotage logic model which includes the entire set of sabotage events possible throughout the whole transport. The varying threat capabilities for the route mean that a rational measure would be to divide the route into sections based on level of threat of sabotage, potentially adopting a graded approach. Division of the route introduces the possibility of Time Variable Security Systems (TVSSs), which is a security system that it is deemed practicable to stand up and stand down dependant on threat level present (which would be determined by what section of the route the transport is currently on). With the vital areas then drawn from this analysis and the process stated above, the security systems and protection measures can be input. It means that for every time a threat is deemed capable of performing an IE it is included in the sabotage logic model, with all IEs deemed capable of being performed being placed into one model in order to produce vital area sets for the route as a whole. Once inputted in the model, any location that requires protecting at certain sections of the route (where the events are deemed possible due to increased threat capability) can be subject to TVSSs if practicable.

For systems that it is deemed unpractical to stand down these must remain in place throughout the transport, as to consider the stand down would have an impact of security of the nuclear material. So when deciding on the necessary implications of physical security to have in place surrounding VAs and HCVAs, the ease of implementation should also be considered when applying the process for transport. The security systems that must be stood up and stood down throughout the route can then be categorised as time variable security systems.

Example

The following example is being made to illustrate the points made above.

Take a vessel loaded with nuclear material at point A in figure 2, the inventory analysis tells us that it exceeds the URC limit of the country of departure. The vessel is travelling through a second country's waters, and arriving at a third to complete the transport.

Following analysis of the potential route it becomes apparent that the most suitable path for the vessel to take is through a canal at point B due to frequent reports of high piracy activity ,making it a high risk area, in the sea to the north of the canal.

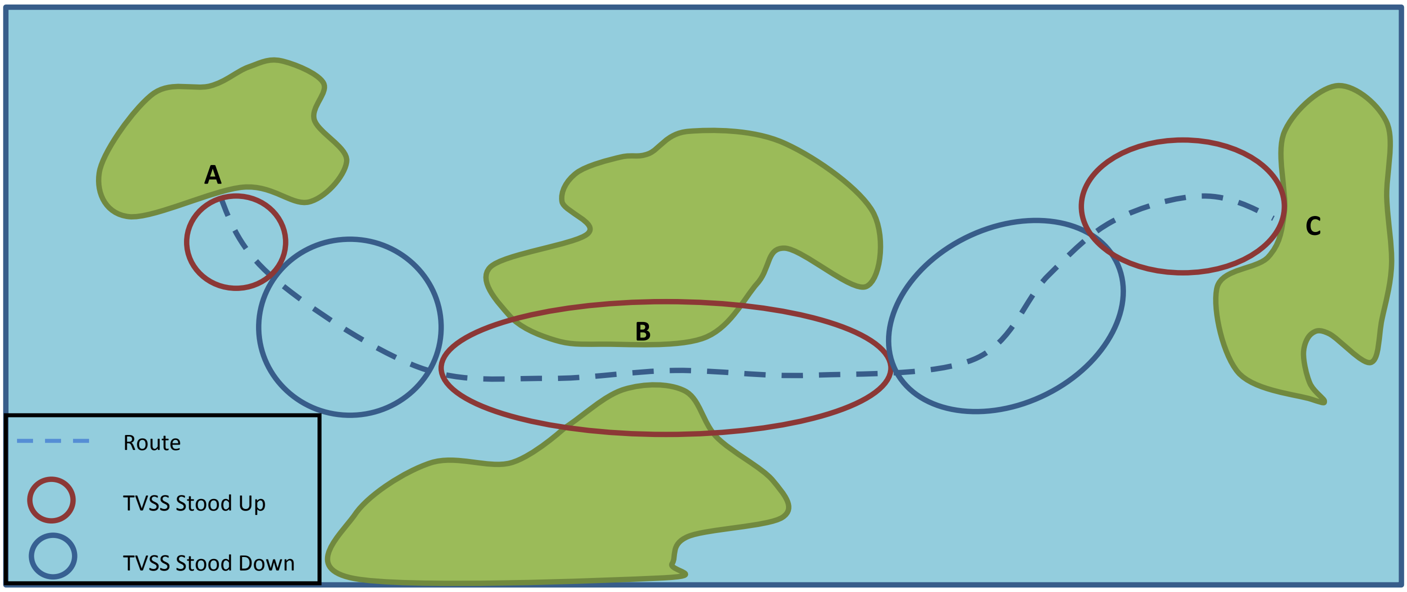

Figure 2 Route and zone diagram for example vessel

The route analysis has split the route into 5 sections, with the 2 ports and the canal section being highlighted as areas on route where threat and threat capabilities are increased; therefore these sections of the route will have the TVSSs stood up. These systems can be stood down in the sections of the route that lie within the blue circles.

After analysis of the vessel and the threat capabilities present from the entire route; 3 initiating events have been identified, 2 of these with systems in place to mitigate them, these are IE1 with mitigating system 1 and IE2 with mitigating system 2 (mitigating systems are systems such as ones that prevent criticality or provide cooling etc.). Another initiating event of malicious origin has been identified that is direct dispersal and therefore included in the sabotage logic model as IEMO1. Following route analysis it is deemed that sabotage event 2 is possible 3 distinct sections of the route due to the associated threat capabilities with these sections, therefore sabotage event 2 locations will be subject to TVSSs if locations unique to this event are in the candidate vital areas.

Mitigating system 1 has 3 corresponding equipment lines that are in place to make sure the system functions, if any of these 3 equipment lines fail mitigating system 1 will be fail. Equipment line 1 (shown as EL1) has redundancy and segregation of components (shown as

C) and therefore both C1 and C2 must be disabled for EL1 to stop functioning. For EL2 and EL3 disabling any single component within the equipment line will disable the equipment line (i.e. disabling C3 or C4 will disable EL2 and disabling C5 or C6 will disable EL3). For sabotage event 2, the equipment line has been made redundant and replicated elsewhere on the vessel, therefore in order for the sabotage event to overcome the system both EL4 and EL5 must be disabled. EL4 also has redundancy in place therefore C7 and C8 must be disabled to overcome EL4. For EL5 disabling C9 or C10 will disable the equipment line.

Definition	Logic Model	Equation Symbol
OR		+
AND		*

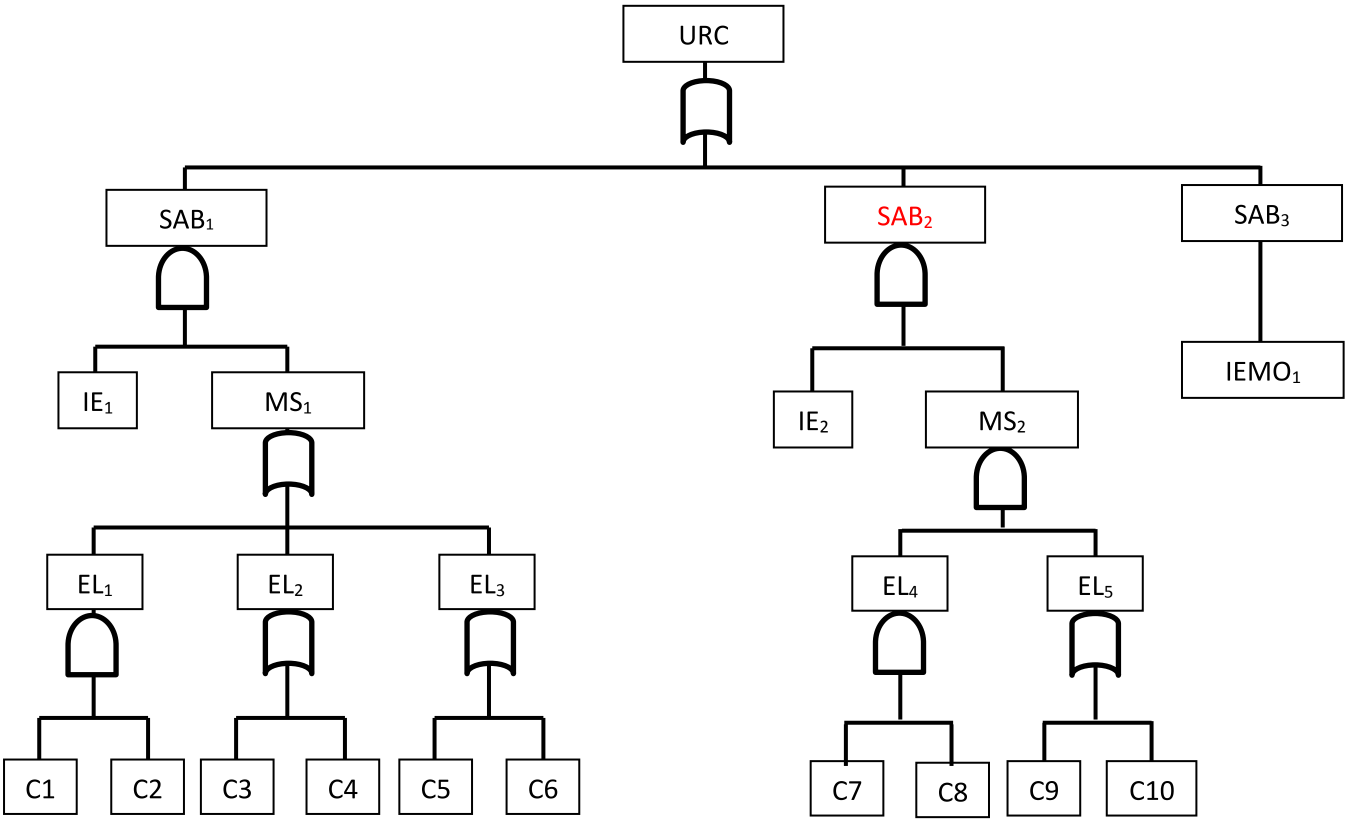

Figure 3 Sabotage Logic Model

Equating the Sabotage Logic Model

The next step to solving the sabotage logic model is the replace the events and components with the locations in which they would occur or are situated, then through the laws of Boolean algebra reducing the locations to one final set in which selections can be made for the minimum number of areas to be designated as VAs or HCVAs.

Event	Location
C1	L1
C2	L2
C3	L3
C4	L3
C5	L4
C6	L4
C7	L6
C8	L5
C9	L6
C10	L1
IE1	L7
IE2	L8
IEMO1	L9

Each component will be replaced by the location that the threat actor would need to be in order to disable this component, so C1 will be replaced with L1 etc. For the initiating events these are replaced with the locations in which they must be carried out. The direct dispersal IEMO is denoted by L9 which is the location that the threat actor must be to carry out the act identified which leads to direct dispersal.

By use of Boolean algebra, the candidate sets of vital areas can be determined through the following equations (note: equations associated with sabotage event 2 have been highlighted red to indicate that these locations will be subject to TVSSs):

(1) $$URC = (IE_1 * MS_1) + (IE_2 * MS_2) + IEMO_1$$

(2) $$MS_1 = EL_1 + EL_2 + EL_3$$

(3) $$MS_2 = EL_4 * EL_5$$

Equation (1) states that for unacceptable radiological consequences to occur either of the two initiating events in combination with the failure of its associated mitigating system must happen or the IEMO leading to direct dispersal must happen. Equations (2) and (3) then breakdown the relevant equipment lines for each mitigating system. Following this we can equate the equipment lines with reference to the locations associated with the disablement of each component within them (see table 2 for corresponding locations).

$$EL_1 = L_1 * L_2$$

$$EL_2 = L_3 + L_3 = L_3$$

$$EL_3 = L_4 + L_4 = L_4$$

$$EL_4 = L_6 * L_5$$

$$EL_5 = L_6 + L_1$$

Then the associated locations of the equipment lines equations can be placed back into the equation for the relevant mitigating system:

$MS_1 = EL_1 + EL_2 + EL_3$ becomes $MS_1 = L_1 * L_2 + L_3 + L_4$

and $MS_2 = EL_4 * EL_5$ becomes $MS_2 = (L_6 * L_5) + (L_6 + L_1) = L_6 + L_1$

The two location equations for MS1 and MS2 can then be combined with the initiating events relevant to each to give the final location equation for each sabotage event:

$$SAB_1 = L_7 * ((L_1 * L_2) + L_3 + L_4) = (L_7 * L_1 * L_2) + (L_7 * L_3) + (L_7 * L_4)$$

$$SAB_2 = (L_8 * L_6) + (L_8 * L_1)$$

$$IEMO = L_9$$

$$URC = (L_7 * L_1 * L_2 + L_7 * L_3) + (L_7 * L_4) + (L_8 * L_6) + (L_8 * L_1) + (L_9)$$

Equating this final equation to get proposed vital area sets means taking 1 location from each set of brackets in order to prevent all 3 sabotage events, for example, all sabotage events can be prevented by the following vital area candidates:

$$L_7 * L_8 * L_9$$

$$L_1 * L_4 * L_8 * L_9$$

$$L_7 * L_6 * L_1 * L_9$$

$$L_2 * L_4 * L_8 * L_9$$

The selection of vital area set will be influenced by different factors, such as characteristics of the areas themselves and associated costs, but using this model we can obtain an equation which gives the minimum to protect as well as identifying which vital areas can be subject to TVSSs if deemed practicable.

Conclusion

The application of vital area identification in the transport of nuclear material is not easily mapped across from what is currently in use on site. Other considerations, such as route or flask robustness, must be included in the analysis prior and it is this that alters our inputs to the sabotage logic model. However the use of a sabotage logic model is not so differing, solving the model is an identical process but now it bears the potential to highlight locations fit for TVSSs should this be an option. Aligning with the anti-sabotage methodology currently present on site will help to mature the processes currently in use to combat sabotage on nuclear transport.

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