# Threat Analysis for the Transport of Radioactive Material

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The Swedish Nuclear Power Inspectorate (SKI) is responsible for the supervision of the transport of nuclear material and nuclear waste, and also authorization for the transport of nuclear material. SKI is also responsible for preparedness planning as concerns antagonistic threats to these transports. It is therefore important for SKI to have a comprehensive picture of potential threats, of weak points along the chains of transport, and of different measures that can be taken in order to prevent or mitigate antagonistic actions.

In 2004, SKI commissioned a pilot-study to investigate the conditions for a revised set of regulations regarding physical protection for the transport of radioactive material. The pilot-study was to develop a model by which a comprehensive threat analysis could be carried out. For this purpose, a working group was formed, representing a wide range of competencies, including staff from the Nuclear Power Inspectorate, the Swedish Maritime Administration, the National Criminal Investigation Board and the Swedish Defence Research Agency. The group met in a series of structured workshops employing the non-quantified modelling method *morphological analysis*. The workshops were facilitated by the author.

## Method

A threat analysis concerning the physical protection of transports involving radioactive material (nuclear fuel, nuclear waste and other radioactive substances) is a complex area of study involving a number of disparate, non-quantifiable factors. These factors involve, for instance, technical, organisational, political, ethical and national security issues, and must be approached on the basis of expert judgements and evaluations. For this reason, FOI was commissioned by SKI to employ computer-aided *morphological analysis*, which is a flexible, non-quantified modelling method developed at FOI during the 1990s. Morphological analysis is especially useful for the initial structuring of very complex socio-technical issues when there is limited time and resources.

General morphological analysis (GMA) was developed by Fritz Zwicky - the Swiss-born astrophysicist and aerospace scientist based at the California Institute of Technology (CalTech) - as a method for structuring and investigating the total set of relationships contained in multi-dimensional, non-quantifiable, problem complexes (Zwicky 1966, 1969).

Zwicky applied this method to such diverse fields as the classification of astrophysical objects, the development of jet and rocket propulsion systems, and the legal aspects of space travel and colonization. He founded the Society for Morphological Research and advanced the "morphological approach" for some 40 years, between the early 1930's until his death in 1974.

More recently, morphological analysis has been applied by a number of researchers in the USA and Europe in the fields of policy analysis and futures studies (Rhyne 1995, Coyle 1996, Ritchey 1997-2006). In 1995, advanced computer support for GMA was developed at the Swedish Defence Research Agency (Ritchey, 2003). This has made it possible to create non-quantified inference models, which significantly extends MA's functionality and areas of application. Since then, some 80 projects have been carried out using computer aided morphological analysis, for structuring complex policy and planning issues, developing scenario and strategy laboratories, and analyzing organizational and stakeholder structures.

GMA goes through a number of iterative steps or phases which represent cycles of analysis and synthesis – the basic method for developing (scientific) models (Ritchey, 1991). The analysis phase begins by identifying and defining the most important dimensions of the problem complex to be investigated. Each of these dimensions is then given a range of relevant values or conditions. Together, these make up the variables or parameters of the problem to be structured. A morphological field is constructed by setting the parameters against each other, in parallel columns, representing an n-dimensional configuration space (See Figure 1, below). A particular constructed "field configuration" (morphotype) is designated by selecting a single value from each of the variables. This marks out a particular state or (formal) "solution" within the problem complex.

Ideally, one would examine all of the configurations in the field, in order to establish which of them are possible, viable, practical, interesting, etc., and which are not. In doing so, we mark out in the field a relevant "solution space". The solution space of a Zwickian morphological field consists of the subset of configurations, which satisfy some criteria – one of which is *internal consistency*. However, a typical morphological field of 6-10 variables can contain between 50,000 and 5,000,000 formal configurations, far too many to inspect by hand. Thus, the next step in the analysis-synthesis process is to examine the internal relationships between the field parameters and *reduce* the field by identifying, and weeding out, all mutually contradictory conditions.

This is achieved by a process of *cross-consistency assessment* (CCA). All of the parameter values in the morphological field are compared with one another, pair-wise, in the manner of a cross-impact matrix (Figure 2). As each pair of conditions is examined, a judgment is made as to whether – or to what extent – the pair can coexist, i.e. represent a consistent relationship. Note that there is no reference here to direction or causality, but only to mutual consistency. Using this technique, a typical morphological field can be reduced by up to 90 or even 99%, depending on the problem structure.

There are two principal types of inconsistencies involved here: purely logical contradictions (i.e. those based on the nature of the concepts involved); and empirical constraints (i.e. relationships judged be highly improbable or implausible on empirical grounds). Normative constraints can also be applied, although these must be used with great care, and clearly designated as such.

| Who ? | Objective | Do what ? | Where ? | Type of radioactive material |
|---|---|---|---|---|
| Individual | Revenge | Stop the transport | Sea | Plutonium |
| Small group (<8), no insider | Influence opinion | Steal the transport as a whole | Road | Uranium, fissile and irradiated |
| Small group (<8), with insider | Economic profit | Steal the cargo | By air | Uranium, fissile, not irradiated |
| Large group (>8), no insider | Political press | Demolish/burn | Railway | Waste with fissile material |
| Large group (>8), with insider | Extortion | | | Waste without fissile material |
| | Create confusion | | | Raw material/ semi-produce |

*Figure 1: Example of a threat model with one" threat profile" highlighted.*

| | | Who ? | | | | | Objective | | | | | | Do what ? | | | | Where | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Individual | Small group (<8), no insider | Small group (<8), with insider | Large group (>8), no insider | Large group (>8), with insider | Revenge | Influence opinion | Economic profit | Political press | Extortion | Create confusion | Stop the transport | Steal the transport as a whole | Steal the cargo | Demolish/burn | Sea | Road | By air | Railway |
| **Objective** | Revenge | | | | | | | | | | | | | | | | | | | |
| | Influence opinion | | | | | | | | | | | | | | | | | | | |
| | Economic profit | | | | | | | | | | | | | | | | | | | |
| | Political press | | | | | | | | | | | | | | | | | | | |
| | Extortion | | | | | | | | | | | | | | | | | | | |
| | Create confusion | | | | | | | | | | | | | | | | | | | |
| **Do what ?** | Stop the transport | | | | | | | | | | | | | | | | | | | |
| | Steal the transport as a whole | | | | | | | | | | | | | | | | | | | |
| | Steal the cargo | | | | | | | | | | | | | | | | | | | |
| | Demolish/burn | | | | | | | | | | | | | | | | | | | |
| **Where** | Sea | | | | | | | | | | | | | | | | | | | |
| | Road | | | | | | | | | | | | | | | | | | | |
| | By air | | | | | | | | | | | | | | | | | | | |
| | Railway | | | | | | | | | | | | | | | | | | | |
| **Type of radioactive material** | Plutonium | | | | | | | | | | | | | | | | | | | |
| | Uranium, fissionable and irradiated | | | | | | | | | | | | | | | | | | | |
| | Uranium, fissionable, not irradiated | | | | | | | | | | | | | | | | | | | |
| | Waste with fissionable material | | | | | | | | | | | | | | | | | | | |
| | Waste without fissionable material | | | | | | | | | | | | | | | | | | | |
| | Raw material/ semi-produce | | | | | | | | | | | | | | | | | | | |

*Figure 2. Cross-consistency matrix for the threat model (Figure 1).*

When the solution (or outcome) space is synthesized, the resultant morphological field becomes an inference model, in which any parameter (or multiple parameters) can be selected as "input", and any others as "output". Thus, with computer support, the field can be turned into a laboratory with which one can designate initial conditions and examine alternative solutions.

The morphological approach has several advantages over less structured approaches. Zwicky called MA “totality research” which, in an “unbiased way attempts to derive all the solutions of any given problem”. It may help us to discover new relationships or configurations, which may not be so evident, or which we might have overlooked by other – less structured – methods. Importantly, it encourages the identification and investigation of boundary conditions, i.e. the limits and extremes of different contexts and factors.

The method also has definite advantages for scientific communication and – notably – for group work. As a process, the method demands that parameters, conditions and the issues underlying these be clearly defined. Poorly defined concepts become immediately (and embarrassingly) evident when they are cross-referenced and assessed for internal consistency.

## Threat analysis for nuclear transports

The *focus question* developed by the subject specialist group was the following:

**“What are the most important factors involving the transport of nuclear material and nuclear waste , as concerns conditions and regulations for protective measures, and how do these factors relate to each other?”**

We began by developing a number of provisional morphological fields in order to get a common perspective on the problem area. (Please note: the fields and models presented in this paper do not represent the full scope of the models developed for the Swedish Nuclear Power Inspectorate. The parameters have been altered in order protect sensitive information.) The first four fields developed concerned:

- General threat situations (figure 1, above)
- Transport situations
- Actor scenarios
- Strategic measures

These fields were then condensed into a single 8-dimensional model which integrated *what can happen* with *suitable preventive measures* (Figure 3). Had we been carrying out a full, comprehensive threat analysis, instead of a “proof-of-principle” pilot study, we would have concentrated in developing this model. However, with the limited time available, we applied the following arguments, in order to reduce the size and complexity of the model.

- The *aim* or *purpose* of a particular antagonistic action against a nuclear transport is certainly of interest for the purpose of intelligence gathering, but is not of great importance for the present study. At this point, we are primarily interested in *what* possible antagonistic actions can be carried out against a transport, not why they are carried out.

- Likewise, a detailed description of the actors involved is not required for this preliminary study.
- Eventually, it will be important to designate high risk vs. low risk transports, depending on the nature of the materials being transported and how they are transported. However, in the present study, this need not be an important parameter. We wish to investigate the protection of transports of radioactive materials *in general*, irrespective of how dangerous the material is considered to be. Which types of transports are to be considered "high risk", and therefore warrant "maximum protection", is a later policy issue.
- We found that the "information parameters" ("Information about the transport" and "Who gets information") had little influence on the other parameters. We also found that there is a major conundrum concerning such information, and decided to leave this factor to a later – dedicated – investigation.

Thus, the most important contexts for the present study – given limited time and resources – were the following:

1. Where is the material in the transport chain?
2. What actions can be "perpetrated" against the transport at each step in a transport chain?
3. What different measures can be applied in order to protect and/or mitigate the transport against such actions, at each transport step?

| Transport situation | Where is the cargo in the transport chain ? | Actor/threat | Does what ? | Information about the transport | Who gets information | Physical protection/ technical measures | Administrative routines and measures |
|---|---|---|---|---|---|---|---|
| Import of UF6 | Onboard Swedish merchant vessel (open water) | Terrorist group | Destroy | Info on physical protection | Sender | Heavily armed escort | Limit the quantity of cargo |
| Spent fuel to storage | Onboard Swedish INF vessel (open water) | Organised crime | Highjack the whole transport | Advanced transport notification | Receiver | Lightly armed escort | Limit the number of people involved |
| Transit EU-to-EU country | Merchant vessel on way in or out of Swedish port | Organised nuclear power protesters | Steal the whole transport (when unattended) | Info on transport authorization | Carrier | Unarmed escort | Upgrade route planning |
| Import of fresh MOX | INF vessel on way in or out of Swedish port | General environmental activists | Rob the cargo | Dangerous goods documentation | Forwarding (shipping) agent | Hardened/attack protected vehicle | Upgrade personnel monitors |
| Fresh nuclear fuel to NPP | Loading/Unloading in port (not specially protected areas) | Lone "revenger" | Steal the cargo (when unattended) | Commercial information | Local authorities | Hardened/ protected container | Increased measures for secrecy |
| Swedish vessel outside of Sweden | Loading/Unloading in port (in specially protected areas) | | Stop/hinder the transport | Goods and vehicle labelling | Regional authorities | Basic-level protection | Transponder |
| Nuclear waste for treatment | Temporary storage in port area | | | No information | Nuclear Power Inspectorate | | Basic level routines |
| MTR fuel | Road transport | | | | Radiation Protection Agency | | |
| | Rail transport | | | | Police | | |
| | Planned stop during road transport | | | | Customs | | |
| | Unplanned stop during road transport | | | | Foreign authorities | | |
| | Arrival to/ departure from nuclear facility | | | | | | |

*Figure 3. Eight-dimensional integrated model (slightly altered from original).*

## The prototype "proof-of-principle" model

The prototype model consists of four parameters, as shown in Figure 4. These were subjected to a cross-consistency assessment (CCA), where the following *assessment keys* were applied:

"— " = This pair of conditions can co-exist, i.e. the is no contradiction.

"X" = This pair of conditions cannot co-exist, i.e. they are contradictory (for instance, the measure "Seal off the geographical area" is not consistent with the transport instance of "Aboard a Swedish merchant vessel (open water)".

"K" = This pair of conditions can co-exist, but is either highly improbable or, for other reasons, uninteresting for the study.

| Transport step: where is the cargo in the transport chain? | What is the transport subjected to ? | Level of physical protection/technical measures | Administrative routines and measures |
|---|---|---|---|
| Onboard Swedish merchant vessel (open water) | Destroy | Police guard/escort | Increased secrecy |
| Onboard Swedish INF vessel (open water) | Highjack the entire transport (when attended) | Unarmed escort | Up-graded trustworthiness checks on personnel |
| Merchant vessel on way in or out of Swedish port | Steal the entire transport (when unattended) | Continual surveillance of vehicle and cargo | Up-graded admittance controls |
| INF vessel on way in or out of Swedish port | Rob the cargo (when attended) | Seal off geographical area | Limit the number of people involved |
| Loading/unloading in port (not in special protected areas) | Steal the cargo (when unattended) | Rapid police mobilisation | Protected parking areas |
| Loading/unloading in port (in special protected areas) | Stop/hinder the transport | Hardened/attack protected vehicle | Up-graded delivery supervision |
| Temporary storage in port area | | Hardened/ protected containers | Present SKI levels |
| Road transport | | Present SKI levels | |
| Rail transport | | | |
| Planned stop during road transport | | | |
| Unplanned stop during road transport | | | |
| Arrival to/ departure from nuclear facility | | | |

*Figure 4: Prototype model for proof-of-principle (altered slightly from the original).*

When the morphological field is compiled into an inference model, all configurations which contain internal contradictions (one or more "X"s ) are deleted from the solution space. Configurations containing one or more "K"s are left in the solution space, but but can be toggled on and off.

The model can be examined in the following way:

1. Select a "Transport step": for example, left-click on "*Planned stop during road transport*" (Figure 5)

2. Under parameter "What is the transport subjected to?" are those *general actions* which the working group judged to be the most likely or credible for the selected transport step.

3. Select one of these actions, e.g. "Demolish/burn" (Figure 6)

4. The measures which are judged to be most relevant for the selected transport step and selected actions are shown in the blue cells on the right.

| Transport step: where is the cargo in the transport chain? | What is the transport subjected to ? | Level of physical protection/technical measures | Administrative routines and measures |
|---|---|---|---|
| Onboard Swedish merchant vessel (open water) | Destroy | Police guard/escort | Increased secrecy |
| Onboard Swedish INF vessel (open water) | Highjack the entire transport (when attended) | Unarmed escort | Up-graded trustworthiness checks on personnel |
| Merchant vessel on way in or out of Swedish port | Steal the entire transport (when unattended) | Continual surveillance of vehicle and cargo | Up-graded admittance controls |
| INF vessel on way in or out of Swedish port | Rob the cargo (when attended) | Seal off geographical area | Limit the number of people involved |
| Loading/unloading in port (not in special protected areas) | Steal the cargo (when unattended) | Rapid police mobilisation | Protected parking areas |
| Loading/unloading in port (in special protected areas) | Stop/hinder the transport | Hardened/attack protected vehicle | Up-graded delivery supervision |
| Temporary storage in port area | | Hardened/ protected containers | Present SKI levels |
| Road transport | | Present SKI levels | |
| Rail transport | | | |
| Planned stop during road transport | | | |
| Unplanned stop during road transport | | | |
| Arrival to/ departure from nuclear facility | | | |

*Figure 5.*

| Transport step: where is the cargo in the transport chain? | What is the transport subjected to ? | Level of physical protection/technical measures | Administrative routines and measures |
|---|---|---|---|
| Onboard Swedish merchant vessel (open water) | Destroy | Police guard/escort | Increased secrecy |
| Onboard Swedish INF vessel (open water) | Highjack the entire transport (when attended) | Unarmed escort | Up-graded trustworthiness checks on personnel |
| Merchant vessel on way in or out of Swedish port | Steal the entire transport (when unattended) | Continual surveillance of vehicle and cargo | Up-graded admittance controls |
| INF vessel on way in or out of Swedish port | Rob the cargo (when attended) | Seal off geographical area | Limit the number of people involved |
| Loading/unloading in port (not in special protected areas) | Steal the cargo (when unattended) | Rapid police mobilisation | Protected parking areas |
| Loading/unloading in port (in special protected areas) | Stop/hinder the transport | Hardened/attack protected vehicle | Up-graded delivery supervision |
| Temporary storage in port area | | Hardened/ protected containers | Present SKI levels |
| Road transport | | Present SKI levels | |
| Rail transport | | | |
| Planned stop during road transport | | | |
| Unplanned stop during road transport | | | |
| Arrival to/ departure from nuclear facility | | | |

*Figure 6.*

Any parameter in a morphological model can be employed as the primary *driver*. One can thus start by selecting "Level of physical protection/technical measures" in order to see which transport steps and actions are most relevant (Figure 7).

| Transport step: where is the cargo in the transport chain? | What is the transport subjected to ? | Level of physical protection/technical measures | Administrative routines and measures |
|---|---|---|---|
| Onboard Swedish merchant vessel (open water) | Destroy | Police guard/escort | Increased secrecy |
| Onboard Swedish INF vessel (open water) | Highjack the entire transport (when attended) | Unarmed escort | Up-graded trustworthiness checks on personnel |
| Merchant vessel on way in or out of Swedish port | Steal the entire transport (when unattended) | Continual surveillance of vehicle and cargo | Up-graded admittance controls |
| INF vessel on way in or out of Swedish port | Rob the cargo (when attended) | Seal off geographical area | Limit the number of people involved |
| Loading/unloading in port (not in special protected areas) | Steal the cargo (when unattended) | Rapid police mobilisation | Protected parking areas |
| Loading/unloading in port (in special protected areas) | Stop/hinder the transport | Hardened/attack protected vehicle | Up-graded delivery supervision |
| Temporary storage in port area | | Hardened/ protected containers | Present SKI levels |
| Road transport | | Present SKI levels | |
| Rail transport | | | |
| Planned stop during road transport | | | |
| Unplanned stop during road transport | | | |
| Arrival to/ departure from nuclear facility | | | |

*Figure 7.*

## Conclusions

Morphological analysis is based on the fundamental scientific method of alternating between analysis and synthesis. For this reason, it can be trusted as a useful, conceptual modeling method for investigating problem complexes, which cannot be treated by formal mathematical methods, causal modeling and simulation. We have found the method highly useful for the present study, which has allowed for a number of specific conclusions.

There are a number of possible, new and up-graded measures that can be taken in order to increase the safety and security of nuclear transports. It is especially interesting to attempt to identify those measures which would give the broadest effect for a given cost. By "broad effect" we mean that the measure should be efficacious for as many of the transport steps and actions as possible.

The morphological model revealed that the following three measures in the category *Level of physical protection/technical measures,* gave the broadest effect for conditions in Sweden:

1. Police guard/escort
2. Unarmed escort
3. Continual surveillance of vehicle and cargo

Both of the *escort measures* stand out as interesting alternatives, since there are some positive side effects associated with them. An escort could provide additional functions and thereby lead to safer, more secure transports. The escort could include a specialist in, for example, the nuclear material being transported and in radiation detection. This would be of benefit even in the case of a road or loading accident. Also, a standardised and institutionalised form of escort (whether armed or not) should lead to better routines for co-operation with police and rescue services, as well as better trained personnel.

As concerns the *Administrative routines*, the measures which provided the broadest effects were:

1. Increased secrecy
2. Up-graded security checks on personnel
3. Up-graded administrative controls

Another central aspect of the threat analysis – which was discussed during the working sessions but not included in the prototype model – was the potential ”dangerousness” of different transported nuclear substances. This concerns both the radiological consequences of an emission, and the potential consequences of the proliferation of nuclear material to other countries and actors. However, which types of transports are to be considered *high risk*, and therefore warrant special measures, is a policy issue which lies outside the scope of the present pilot study.

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## References and Further Reading

Bailey, K. (1994) *Typologies and Taxonomies - An Introduction to Classification Techniques*, Sage University Papers: Sage Publications, Thousand Oaks.

Coyle, R.G. and Yong, Y. C. (1996) "A Scenario Projection for the South China Sea", *Futures* 28 (3), 269-283.

Doty, D. H. & Glick, W. (1994) "Typologies as a Unique Form of Theory Building", Academy of Management Review, Vol. 19, No.2.

Rhyne, R. (1995) "Evaluating Alternative Indonesian Sea-Sovereignty Systems", Informs: Institute for Operations Research and the Management Sciences.

Ritchey, T. (1991) "Analysis and Synthesis - On Scientific Method based on a Study by Bernhard Riemann" Systems Research 8(4), 21-41. (Available for download as REPRINT at: www.swemorph.com/downloads.html.)

Ritchey, T. (1997) "Scenario Development and Risk Management using Morphological Field Analysis", Proceedings of the 5th European Conference on Information Systems (Cork: Cork Publishing Company) Vol. 3:1053-1059.

Ritchey, T. (1998) “Fritz Zwicky, 'Morphologie' and Policy Analysis”, Presented at the 16th Euro Conference on Operational Analysis, Brussels.

Ritchey, T. (2002). General Morphological Analysis. A general method for non-quantified modelling. (Available for download at: www.swemorph.com/downloads.html.)

Ritchey, T. (2002) "Modelling Complex Socio-Technical Systems using Morphological Analysis", Adapted from an address to the Swedish Parliamentary IT Commission, Stockholm, December 2002. (Available for download at: www.swemorph.com/downloads.html.)

Ritchey, T. (2003). MA/Camra: Advanced Computer Support for General Morphological Analysis. (Online at: www.swemorph.com/macarma.html.)

Ritchey, T. (2003a) "Nuclear Facilities and Sabotage: Using Morphological Analysis as a Scenario and Strategy Development Laboratory". Adapted from a Study for the Swedish Nuclear Power Inspectorate, and presented to the 44th Annual Meeting of the Institute of Nuclear Materials Management - Phoenix, Arizona, July 2003. (Available for download at: www.swemorph.com/downloads.html.)

Ritchey, T. (2005a) "Wicked Problems. Structuring Social Messes with Morphological Analysis". Adapted from a lecture given at the Royal Institute of Technology in Stockholm, 2004. (Available for download at: www.swemorph.com/downloads.html.)

Ritchey, T. (2005b) "Futures Studies using Morphological Analysis". Adapted from an article for the UN University Millennium Project: Futures Research Methodology Series (Available for download at: www.swemorph.com/downloads.html.)

Ritchey, T. (2006a) "Problem Structuring using Computer-Aided Morphological Analysis". *Journal of the Operational Research Society*, Special Issue on Problem Structuring Methods, (2006) **57,** 792–801. (Download available at: http://www.swemorph.com/downloads.html.)

Ritchey, T. (2006b) "Modelling Multi-Hazard Disaster Reduction Strategies with Computer-Aided Morphological Analysis". Reprint from the Proceedings of the 3rd International ISCRAM Conference, Newark, NJ, May 2006. (Available for download at: www.swemorph.com/downloads.html.)

Ritchey, T. (2009) Developing Scenario Laboratories with Computer-Aided Morphological Analysis Presented at the 14th International Command and Control Research and Technology Symposium, Washington DC. (Available for download at: www.swemorph.com/downloads.html.)

Ritchey, T. (2011) *Wicked Problems – Social Messes: Decision support Modelling with Morphological Analysis*. Berlin: Springer. (First dedicated book on GMA. See description at: http://www.swemorph.com/book.)

Zwicky, F. (1969) *Discovery, Invention, Research - Through the Morphological Approach*, Toronto: The Macmillan Company.

Zwicky, F. & Wilson A. (eds.) (1967) New Methods of Thought and Procedure: Contributions to the Symposium on Methodologies, Berlin: Springer.