SAND2007-6946C

Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2007
October 21-26, 2007, Miami, Florida, USA

A RISK BASED APPROACH TO DESIGN OF SECURITY ARRANGEMENTS

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ABSTRACT

A method for security risk in transportation of radioactive materials is treated in a manner similar to that used for safety risk assessment. The analytic approach is reviewed and explanation of the methodology and methods used to evaluate risk are explored. Graphic output of release expectation, release consequence, and risk are provided for a generic problem.

INTRODUCTION

Terrorism involving radioactive material shipments has received some notoriety as part of the considerations of building a repository for high-level nuclear waste materials and spent fuel in Nevada. The DOE considered a sabotage scenario in its environmental impact statement (EIS) for the proposed Yucca Mountain repository and the Nuclear Regulatory Commission (NRC) considered and dismissed sabotage as a potential release mechanism for the interim spent fuel storage facility in Utah. In addition, in the post 9/11 world there has been a tightening of security requirements for a variety of radioactive materials in transport and a developing worldwide effort to track and control radioactive sources through International Atomic Energy Agency (IAEA) efforts on the Code of Conduct [1] and related documents [2]. This latter effort was the impetus for an international meeting held in Vienna in March of 2003 [3] to help coordinate international efforts in control of sources.

There have been a few minor incidents in which radioactive materials have been used for malevolent purposes [4] and an event like that in Goiania [5] shows the kind of consequences, both socioeconomic and radiological, that can result from dispersal of radioactive materials. However, the threat has been addressed relatively forcefully in recent work by the IAEA and its member states in the Code of Conduct referred to above and development of security guidelines for transport of radioactive materials of all types. There has been relatively little focus on radioactive materials in transport as a potential avenue for producing a major terror event until a series of meetings at the IAEA in Vienna devoted to developing security guidelines for

* Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

radioactive materials in transport. The document [6] containing these recommendations were published in draft in June 2006. The guidelines provide a minimum set of security criteria for material perceived to present significant hazard, but were conceived independently of a national analysis of likely threats that might indicate that greater or lesser stringency in security might be warranted.

Developing a security regimen for facilities and/or operations typically is accomplished using a regimen of assessing likely threats, consequences, and vulnerabilities and then designing a security system likely to meet the threat. A more transparent process for performing a security analysis could be modeled after safety risk assessment for transport. Requirements for the safe transport of RAM rely heavily on risk assessment to help define what regulatory changes are most likely to reduce the public's risk. The risk assessment techniques used depend on concatenation of event sequences together with consequence estimates from material releases. These risk assessments are driven with data obtained from accident incident statistics, occurrence statistics for environmental influences and estimates of package and material response to accident environments used to estimate material release fractions and potential consequences. Assessing changes in the amount of material released as a result of changes in operations, material properties or package design allows understanding of what the reduction of risk is likely to be realized.

A similar process can be applied to design of security systems that uses similar formalism to represent the initiating events and the conditional probabilities of subsequent events that ultimately result in the success or failure of the security system. Because any attempt to breach security of a shipment depends on overt decisions on what and how to attack as well as the capability of the threat and performance of security measures, a security risk analysis cannot rely on occurrence statistics for events. Instead the analysis described here uses expert opinion of the likelihood of success of the various events leading from the initiating decision to the success or failure of the attempt to breach security.

METHODOLOGY

Decisions related to providing security (or enhancing security) procedures to minimize the likelihood of a successful sabotage or terror attack should be based on threat, potential consequence of an attack scenario, and likelihood of successful execution of the scenario. The latter two considerations are the determinants of risk presented by the malevolent act. Risk is a measure that combines both the likelihood of the event (which is related to threat and other factors) as well as its potential consequence. Using risk in that manner places in context low likelihood, but potentially high consequence events with more likely, but lower consequence events and allows better decisions to be made on expending funds to avoid low risk attacks. A principal difficulty with using a risk measure in this context is the problem associated with estimating likelihood of a malevolent scenario occurring. Consequence estimation for a given scenario, in contrast, is relatively straightforward.

Risk analysis techniques applied to transportation accidents use the statistical frequency of the triggering accident and conditional probabilities that determine overall frequency and consequence of each accident scenario. In contrast, there are few deterministic or statistical aspects to guide an estimate of a malevolent act's likelihood. In the National Research Council's report, "Making the Nation Safer" [7], a case is made for basing protection decisions on risk and it also notes the difficulty in estimating the likelihood of a terrorist attack. The report notes that an "indicator of likelihood is the ease with which the act may be accomplished". Ease in their context included cost, number of persons, an insider, complexity and level of technology. A somewhat simpler formulation of the ease concept has been used by the authors in some unpublished studies that used three parameters to estimate “Ease”; time to execute, number of steps, and level of technology. The “Ease” estimate was then used as a multiplier of consequence to give an approximate risk weighting to the various scenarios and shipments considered.

This paper explores a methodology to estimate the risk from malevolent acts that is constructed in a manner that parallels transportation accident risk assessment methods, but which utilizes decision support methodology. Some of the concepts have been presented before [8]. The basic structure of the analysis is somewhat similar to what is perceived as the likely decision process that might be used by a terror group to decide whether to pursue an attack against a radioactive shipment. Figure 1 provides a conceptual view of what might be the terrorist’s decision process. In the figure, the logical consideration of consequence (expressed in terms of national social and economic impacts) is modified by the likelihood of success and the scope of effort required. These, in turn, are functions of the material, attack location, and attack scenario. As a result, there is likely to be significant regenerative feedback in the process of settling on how and what to do that could meet the terror goals of the group.

For the purposes of this paper the following definitions will be used:

- Attempt (At) is the decision to undertake sabotage or terror attack on a target shipment in order to attain goals specified in general in terms of deaths, injuries, and interdiction of an area, societal costs or other measures of consequence.
- Consequence (Cx) is a measure of the result of a release expressed in whatever units represent a radiological or societal impact of concern (denoted by x). The units might include peak dose, population dose, area contaminated above safe levels, cost for cleanup, or many others.
- Expectation (E) is the estimated occurrence of a specific event compared with all other events in the group being considered. Thus it is not unlike a probability, but is not statistically or mathematically defined in the same sense as probability.
- Location (Ln) is the site chosen to execute a given scenario. Location carries with it specifications of population, level of economic development, material dispersal potential (meteorology), and other features related to the estimation of consequence.
- M represents the radioactive material shipment selected as the target of a scenario designed to produce a release of radioactive material.
- Release fraction (RFx) is what is expected to be released from perfect execution of the scenario chosen. The release fraction is in units that are relevant to the consequence measure (x) of concern (respirable, large particles, etc.).
- Risk (R) from a specific scenario is the product of its expectation (E) and its consequence (C) or R = E • C. More general risk measures (□) might be constructed that utilize enhancement factors on E and C to account for increased sensitivity of Risk to one or both factors in order to reflect public opinion or other qualitative judgments. Thus, □ = (A*E) x (B*C), where A and B are the enhancement factors that could be constants or functions of E and C or other factors.
- Scenario (Sc) means the series of deterministic actions taken by a group of saboteurs or terrorists (Threat) together with a subsequent event chain that could lead to a release of radioactive material.

- Success (Su) is the fraction of the maximum release fraction that could be achieved from the scenario and varies from 0 to 1. If Su is 1, the scenario undertaken by the threat is fully successful; if 0, the attack has failed.
- Threat (T) means the number of persons, their capabilities, and their equipment that can be brought to bear in pursuing a given malevolent scenario.

Conceptually the risk can be represented in an equation for R1 as shown below.

$$R1 = \{E[At] \bullet E[M \mid At] \bullet E[Sc \mid M] \bullet E[Ln \mid Sc] \bullet E[T \mid Sc, Ln] \bullet E[Su \mid M, T, Sc, Ln]\} \bullet \{Cx(M, Ln, Su \bullet RFx)\}$$

The equation contains multiple conditional expectations of the form E[a | b]. The meaning of this expression is the expectation that state "a" is realized, given that state "b" has been specified. Without the pipe and second argument it is simply the expectation that state "a" is realized. The first set of bracketed terms contains the terms that relate to the expectation and the second contains the consequence of the sabotage/terror event. The equation represents the totality of the security risk in the most general terms.

Looking at R1

The first term E[At] is the decision to make an attack on a radioactive material of some sort. This decision might be made on the basis of the generally perceived public fear and ignorance of exposure to radioactive material as an effective mode for generating terror within the general population. The second term E[M | At] is the expectation that a given radioactive material shipment (like spent fuel by rail) will be selected as a target, given that a decision to attack radioactive materials in transport has been made. The third term E[Sc | M] is the expectation that a specific attack scenario will be chosen, given the choice of material. The forth term E[Ln | Sc] is the expectation that a given location for attack will be chosen, given that a scenario has been selected. The fifth term, E[T | Sc, Ln] is the expectation that a given threat will be deployed, given that a scenario and a location has been chosen. The sixth term E[Su | M, T, Sc, Ln] is the expectation of success, given the material, threat, scenario, and location (Su may be interpreted as the release fraction). The last term Cx(M, Ln, Su•RFx) is the estimated consequence, given the material, the location, and the release fraction.

Determination of Expectations

The 2nd through 5th expectation terms in the equations given above may be formulated in a different order, but must be evaluated in a way that allows the interrelationships in the various parameters to influence the resulting overall expectation of success, given a combination of material, threat, scenario and location. The evaluation of the terms is likely to be based largely on opinions of, and intelligence assessments known to, persons responsible for assessing the likelihood of terror activity. As a result there is the paradox that these quantitative estimates of expectation are essentially qualitative.

Assessment of the expectations is probably best handled by averaging the opinions of a group of individuals composed of several persons who are familiar with transportation packages and practices and several persons familiar with current intelligence on terror activities and goals. With appropriate interaction between the two groups each person can separately provide their views of the relative importance of the various parameters involved. Those choices, when combined and examined statistically, provide a mean estimate of the various expectations and an understanding of the uncertainty of the estimate.

Following this process allows an estimate of the overall expectation of an attack on a specific material and the expected consequence. Because this method allows, even encourages, the evaluation of multiple threats, scenarios, and materials at risk, it offers the opportunity to compare risks in a manner that will indicate the highest risk situations and thus show where additional security measures might be needed if the risks are viewed as excessive. Moreover, comparison with other hazardous materials, evaluated in a similar manner, could provide a rationale for greater levels of protection for one type of hazardous materials relative to another, e.g., chlorine vs. spent fuel.

Variants of the process can lead to some simplification. Two possible variants are independent expectations and truncation to use of just the success matrix. In the former, some or all of the first five terms could be made independent of the condition. For instance, E[Ln | Sc] could become E[Ln], an expectation that the location of an attack is not dependent on scenario. In the latter case, the security assessment process is truncated to deal only with the last two terms in the equation, the expectation of success and the consequence terms. This is equivalent of assuming the threat, scenario, material and location of an event are known. The expectation of success, E[Su | M, T, Sc, Ln], becomes a measure of vulnerability associated with the security regimen associated with the system that leads to a consequence given by Cx(M, Ln, Su•RFx). Evaluating the expectation of success with existing and candidate security systems against the potential consequences could provide a way of evaluating the cost effectiveness of changes in security.

RESULTS

Because of the sensitivity to any detailed discussion of sabotage scenarios, their potential consequences, and the potential for success, the following discussion is, for the most part, couched in generalities and dealing with idealized situations. Using Excel spreadsheets for the computation of the conditional expectations allows a certain amount of flexibility in the computations that need to be performed in this effort. The matrix of expectations implied in each term of the equation is produced by application of an experienced based relative rating. The relative ratings are then normalized to produce the expectation matrix for that term in the equation. The matrix product of all the terms in the equation is then calculated. Figure 2 shows a result for a group of 10 material/shipments and 10 potential scenarios that were considered in this example.

To get to an estimate of relative risk, a similar matrix containing estimates of the amount of material released for each material/shipment and scenario combination was developed from the literature or other sources. This matrix is shown in Figure 3. It is important to note that the releases shown are for optimum execution of the scenario against the material/shipment.

Figure 4 shows the matrix for risk that results when the product of the release matrix and the expectation matrix is computed. This presentation gives an understanding of the relative risk in the cases considered and may identify levels of risk that need to be reduced by the application of operational controls, additional safeguard systems, or perhaps design changes to packages or conveyances that reduce the incidence or effectiveness of a scenario of concern.

CONCLUSION

The methodology discussed and displayed here provides a path to evaluation of the level of transport security that places the qualitative assessment processes currently in use in a more formal evaluation schema. There is no substitute for the kind of hands on experience that persons familiar with safeguards technology have in understanding the capability of a protection system and that experience. That judgment can be linked in a semi-quantitative way using this methodology to allow understanding of the tradeoffs in the selection of the features of a safeguards system for radioactive material transportation.

REFERENCES

1. IAEA, "Code of Conduct", IAEA/CODEOC/2004 IAEA, VIENNA, 2004.
2. IAEA, "Categorization of Radioactive Sources", IAEA-TECDOC-1344, IAEA, Vienna (2003).
3. IAEA, "Security of Radioactive Sources", Proceedings of an international conference held in Vienna, Austria, 10-13 March 2003, IAEA, Vienna.
4. Gonzalez, A. J. "Security of Radioactive Sources: The Evolving New International Dimensions", IAEA BULLETIN 43, April 2001.
5. IAEA, "The Radiological Accident In Goiania", International Atomic Energy Agency, IAEA, Vienna, 1988, STI/PUB/815, ISBN 92-0-129088-8.
6. IAEA, "Security of Radioactive Material during Transport: Implementing Guide" Draft 2006-06-211988, Vienna, June 2006.
7. NRC, "Making the Nation Safer", (ISBN 0-309-08481-4), National Research Council Report Washington DC 2002.
8. Luna, R. E., Sorenson, K. B., "Overview of Vulnerability and Projected Impacts of Attacks on Radioactive Materials in Transport", Paper 148, Proceedings of the 43rd Annual Meeting, Institute of Nuclear Materials Management, July 2002.

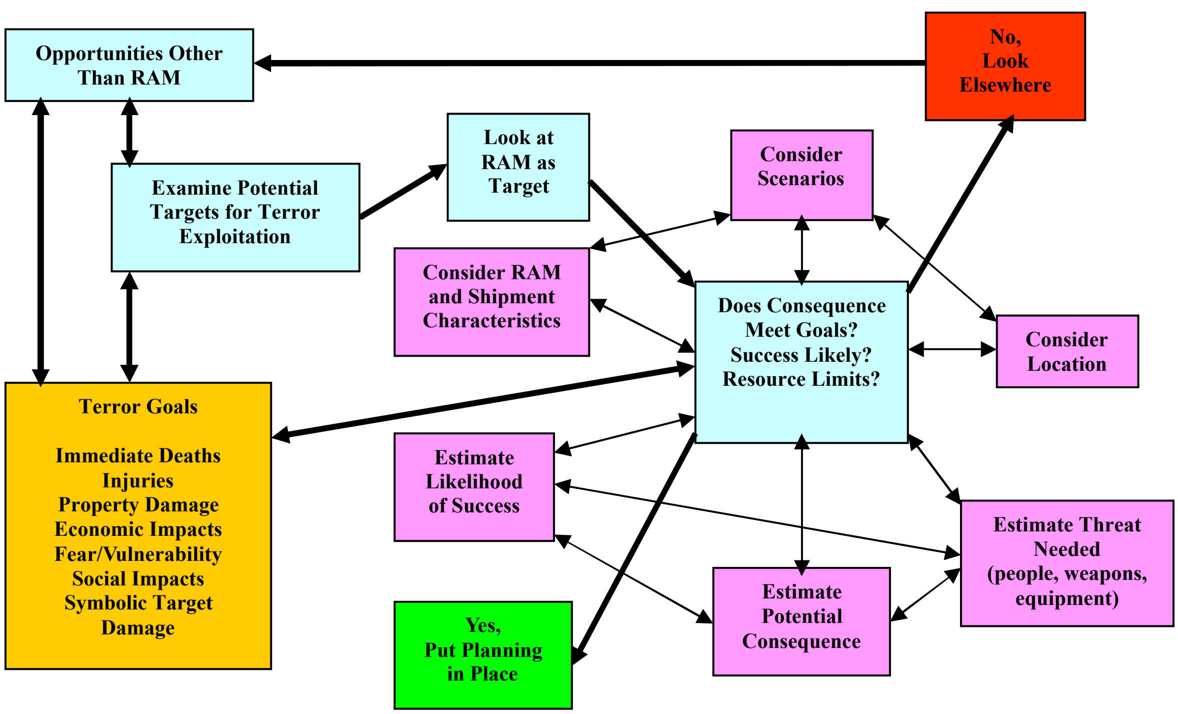

Figure 1: Conceptual Model of Terrorist Selection Process

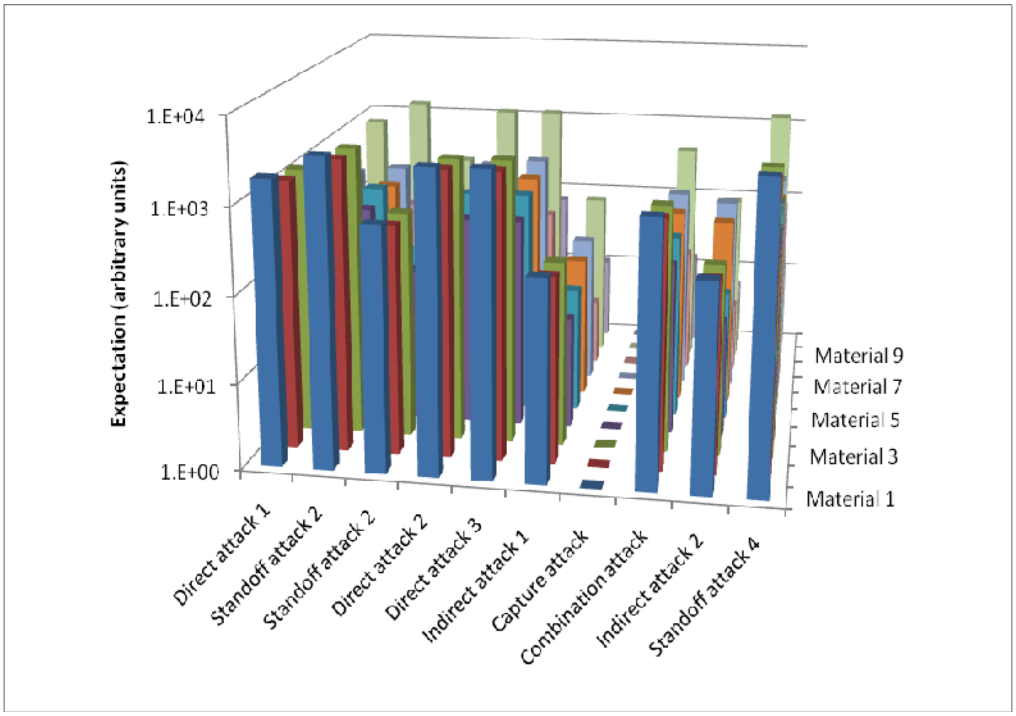

Figure 2: Expectation Matrix

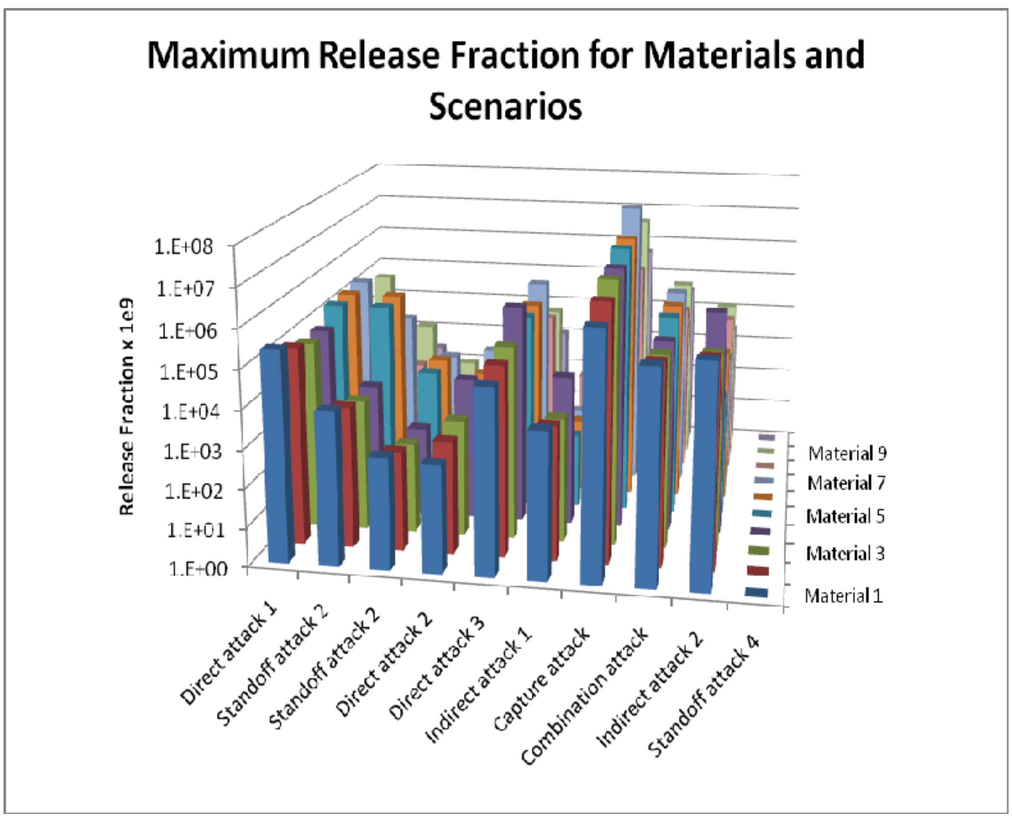

Figure 3: Maximum Release Fraction

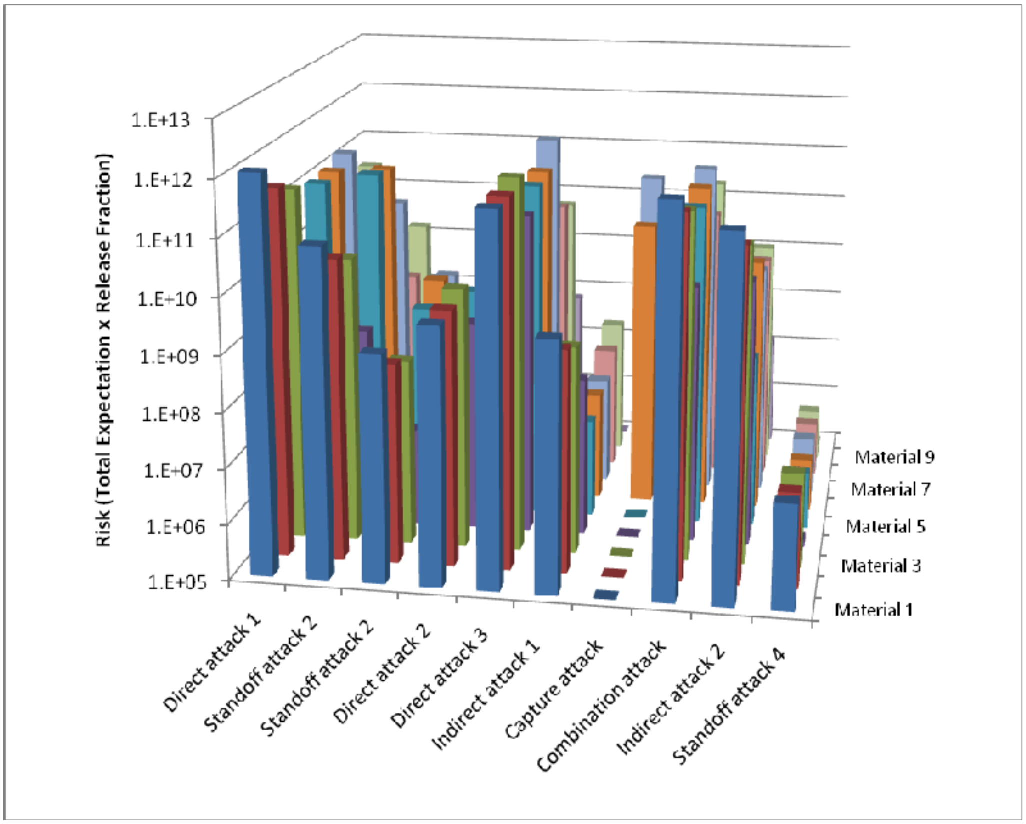

Figure 4: Risk for Materials and Scenarios (arbitrary units)