UCRL-JC-126175
PREPRINT

Risk Ranking Methodology for Radiological Events

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This paper was prepared for submittal to the
1997 Safety Analysis Workshop
7th Annual Energy Facility Contractors Group Safety Analysis
Working Group Workshop
Oakland, CA
June 9-13, 1997

March 1, 1997

Lawrence Livermore National Laboratory

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Risk Ranking Methodology for Radiological Events*

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Introduction

Risk ranking schemes have been used in safety analysis to distinguish lower risk accidents from higher risk accidents. This is necessary to identify those events that might warrant additional study/quantitative analysis and to ensure that any resources allocated for risk reduction are properly directed.

A common method used for risk ranking utilizes risk matrices. These are typically 3x3 or 4x4 matrices, having event consequences along one axis and event frequency along the other. Each block on the risk matrix represents some level of risk, and blocks presenting similar risk are often grouped together into one of 3 or 4 risk regions. Once a risk matrix has been identified, events are placed on the matrix based on an estimate of the event consequence and event frequency. Knowing how the blocks on the risk matrix relate to one another with respect to risk, the relative risk of the events will be known based on where they are placed on the matrix.

In most cases, the frequency axis of the matrix has some numerical values associated with it, and this typically spans several orders of magnitude. Often, the consequence axis is based on a qualitative scale, where consequences are judgment based. However, the consequence scale generally has implicit qualitative values associated with it, which may or may not be recognized. Risk regions are often arbitrarily assigned (or assigned on the basis of symmetry). This presents a problem in that if the blocks of the risk matrix are incorrectly grouped, then incorrect conclusions can be drawn about the relative risk presented by events at a facility.

This paper first describes how risk matrices have typically been established in the past. Problems associated with these risk matrices are identified and discussed. A methodology for logically establishing risk matrices, with specific application to radiological risk is provided. The paper provides guidance on how matrices should be tailored to their specific application, and then closes with some summary remarks.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Qualitative Risk Matrices and Relative Risk

A common method used for risk ranking utilizes risk matrices. A risk matrix plots accident frequency along one axis and accident consequences along the other axis, with each axis typically divided into from 3 to 5 discrete bins. Each combination of a frequency bin and a consequence bin forms a risk block. Each block on the risk matrix represents some level of risk. Once a risk matrix has been established, events can be placed on the matrix based on an estimate of the event frequency and event consequence. All events falling into a particular risk block will have approximately the same risk. If we know how the blocks on the risk matrix relate to one another, the relative risk of the events can be known based on where they are placed on the matrix. Unfortunately, with a qualitative risk matrix, this is not always possible.

Three types of risk matrices are commonly used. A purely qualitative risk matrix will have its bins defined in descriptive or qualitative terms. A purely quantitative risk matrix has its bins defined in measurable or quantitative terms. Relative or absolute numerical scales are used on quantitative matrices; scales on qualitative matrices are relative but not numerical. The third type of risk matrix is a hybrid: a semi-quantitative matrix with one scale (usually frequency) expressed quantitatively, while the other scale is expressed qualitatively.

Risk is defined as the product of frequency and consequence. For a risk matrix, the risk for each block is the product of the frequency bin value (or range) and the consequence bin value (or range). For a quantitative matrix, the risk is then simply expressed as a numerical value or range. The risk for a given block can then be directly compared to the risk for any other block, and regions of similar risk can be defined containing groups of blocks with similar numerical values for risk. These regions might be correlated to acceptance criteria. For example the lowest risk region may be deemed "acceptable", an intermediate risk region deemed "marginal", and the highest risk region deemed "unacceptable". However, this must be done with care and with a clear understanding of the risk ranges represented on the risk matrix.

For qualitative and semi-quantitative matrices, the risk for each block cannot be expressed numerically, but is simply the combination of the frequency bin description or value, and the consequence bin description. For these matrices, the risk for a given block can only be directly compared with some, but not all of the other blocks. A relative risk comparison can be made between block A and block B only when there is an unambiguous relationship between them. An ambiguous relationship exists whenever A has a greater frequency bin than B, and a smaller consequence bin than B, or whenever A has a greater consequence bin than B and a smaller frequency bin than B. For these ambiguous situations, meaningful conclusions cannot be drawn regarding the risk that these blocks present with respect to one another.

Figure 1 shows a hypothetical qualitative risk matrix. The risk blocks connected by arrows can be directly compared to each other, and the arrows are shown to progress in the direction of increasing risk. Any block that can be reached along the paths of the arrows can be compared to any other along that path. A risk comparison is ambiguous for blocks that cannot be connected by the arrows. For example, how can we compare the risk of an accident with a frequency of "definite maybe" and "minor" consequences to one having a frequency of "once in a blue moon" with "major" consequences? Or try comparing a frequency of "probably not" and "minor" consequences, with a "once in a blue moon" chance of "bad news" consequences.

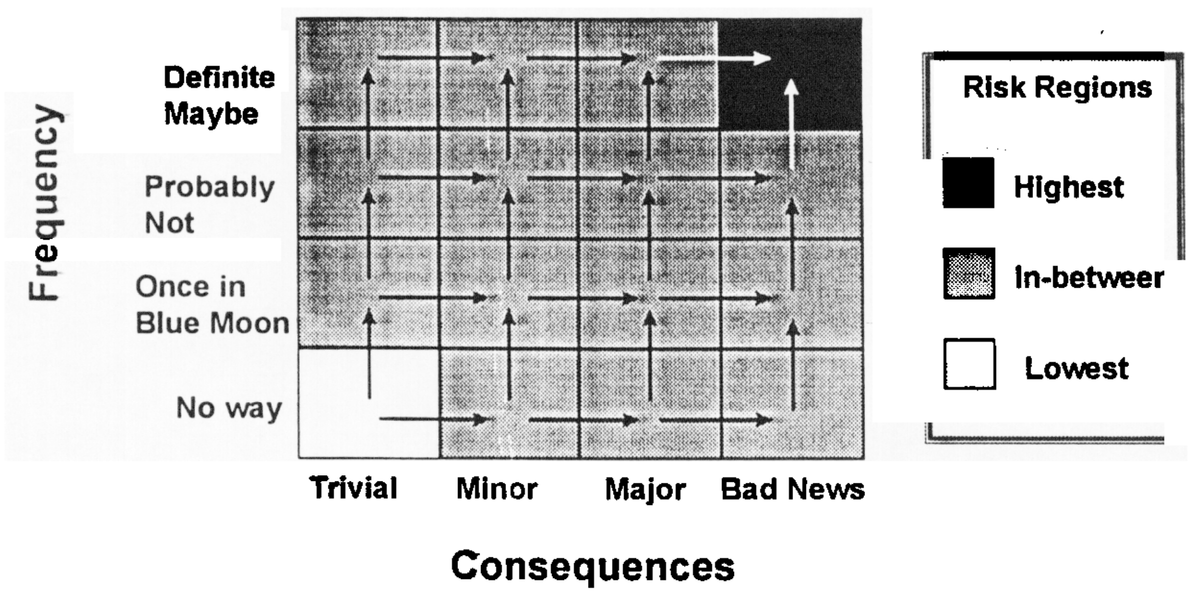

Figure 1. A 4x4 Risk Matrix: arrows show relationships of increasing risk.

Because of the limitations in making risk comparisons, qualitative and semi-quantitative matrices have very limited value. It makes no sense to attempt risk groupings of the blocks, as the only logical grouping is the obvious one shown in Figure 1: the lower left corner is the lowest risk group, the upper right corner is the highest risk group, and everything else is in the middle. Any subdivision of the middle group is fraught with peril, as blocks having lower risk will be grouped with others having higher risk, and other blocks in a group may be higher or lower since any comparison among them is ambiguous. There is no other way to logically group the blocks for the qualitative and semi-quantitative matrices.

Problematic Risk Matrices

Although the only logical way to group blocks on a qualitative risk matrix, given the information provided thus far, is as shown in Figure 1, many unfounded variations have been applied. Consider the example in Figure 2. This semi-quantitative risk matrix has been used to evaluate the risk from postulated accidents. There is no distinction as to the type of accident or facility it might be best applied to. Although there are four risk regions defined, there is no logical basis for those groupings. The diagonal pattern used to group the blocks may be visually appealing, but it is devoid of logic and misleading when applied to risk analysis. For example, consider accidents having a high frequency but extremely low consequences. That block is grouped in the region of low risk, and considered acceptable. Then there are accidents that may occur with medium frequency having medium consequences. That block is grouped in the region of medium risk, and considered unacceptable. However, based on the previous discussion these two blocks cannot be directly compared. There is no basis for placing one block in the medium risk category and the other in the low risk category. Yet decisions have been made on the acceptability of the risk, based on this unfounded grouping.

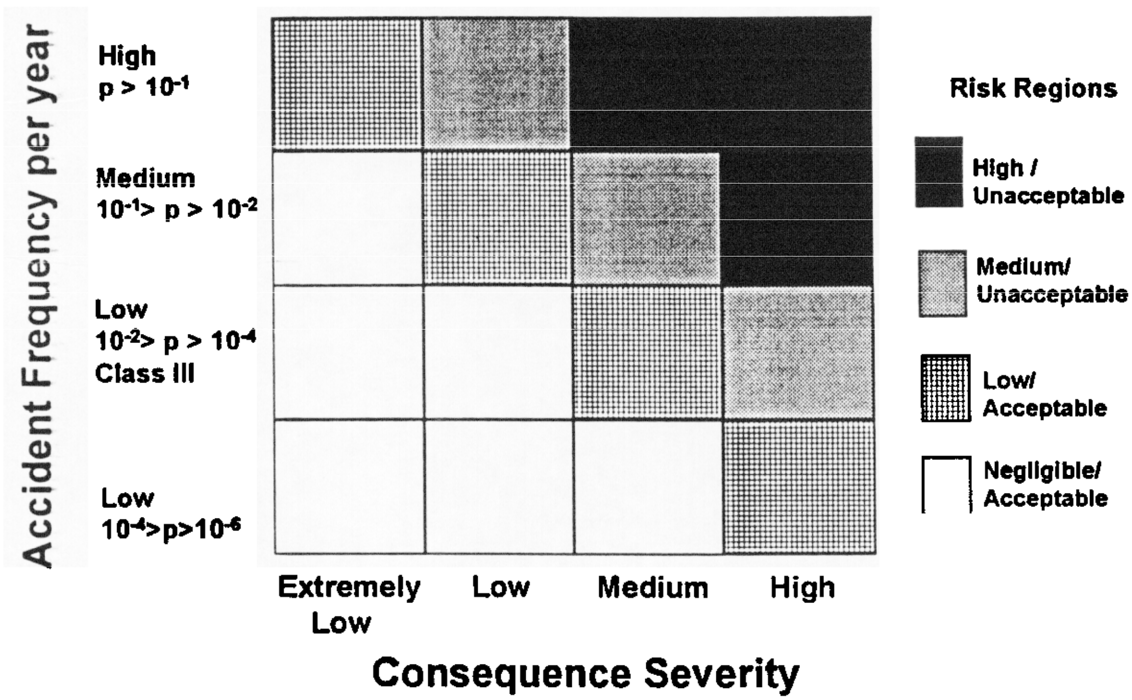

Figure 2. An example of a risk matrix with arbitrary risk groupings.

There are other problems with the risk matrix in Figure 2. There is no discrimination as to what type of accidents or facilities it should be applied to. Consider an application to an experimental high explosives facility. At this facility, conventional high explosives are routinely handled by personnel in large enough quantities that an inadvertent explosion caused by a drop of a charge or an impact on a charge could result in death to a worker. This risk is inherent to the operation. Such a consequence would typically be considered "High". Let's consider this type of accident, and assume it might occur with a frequency of 10^{-2} to 10^{-4} per year. This is quite reasonable for a scenario initiated by human error, with many operations being performed over a year, and thus many chances for an explosion. Furthermore, extensive operational data is insufficient to justify placing this accident in a lower frequency bin. Placing this accident on the matrix in Figure 2, we find that it falls in the region of medium risk, and would be considered unacceptable.

Let's consider what is really being concluded here: it is unacceptable to run the risk of an accident that might kill one worker over a mean time frame of from 100 to 10,000 years.

One hundred years is longer than the lifetime of the facility, and 10,000 years is longer than all of recorded human history. This implies placing a value on a worker's life that is unprecedented. (They should be getting astronomical salaries if they are worth that much.) This outcome is the direct result of applying an arbitrary risk matrix that is not based on logic. Management is led to an incorrect conclusion by the improper establishment of the original groupings on the matrix, or by the unreasonable judgment labels attached to risk regions. It also presents management with the dilemma of how to keep the facility operating, thereby continuing to accept risks and the associated liability, which have been deemed "unacceptable" by risk analysis.

Establishing Useful Relative Risk Matrices

If we are to make any sense out of this semi-quantitative risk matrix from Figure 2, we must understand the underlying quantitative scales that are implied by the risk groupings. In Figure 3, we have assigned relative numerical values to the consequence scale, converting the semi-quantitative matrix of Figure 2 to a quantitative matrix. These values are dimensionless, serving to establish the relative importance of each bin. The maximum risk for each block is easily calculated as the product of the upper limit of the range on the frequency bin and the value of the consequence bin. These values are relative to each other, and cannot be compared to risk values from some other risk matrix (i.e., they do not represent absolute risk values).

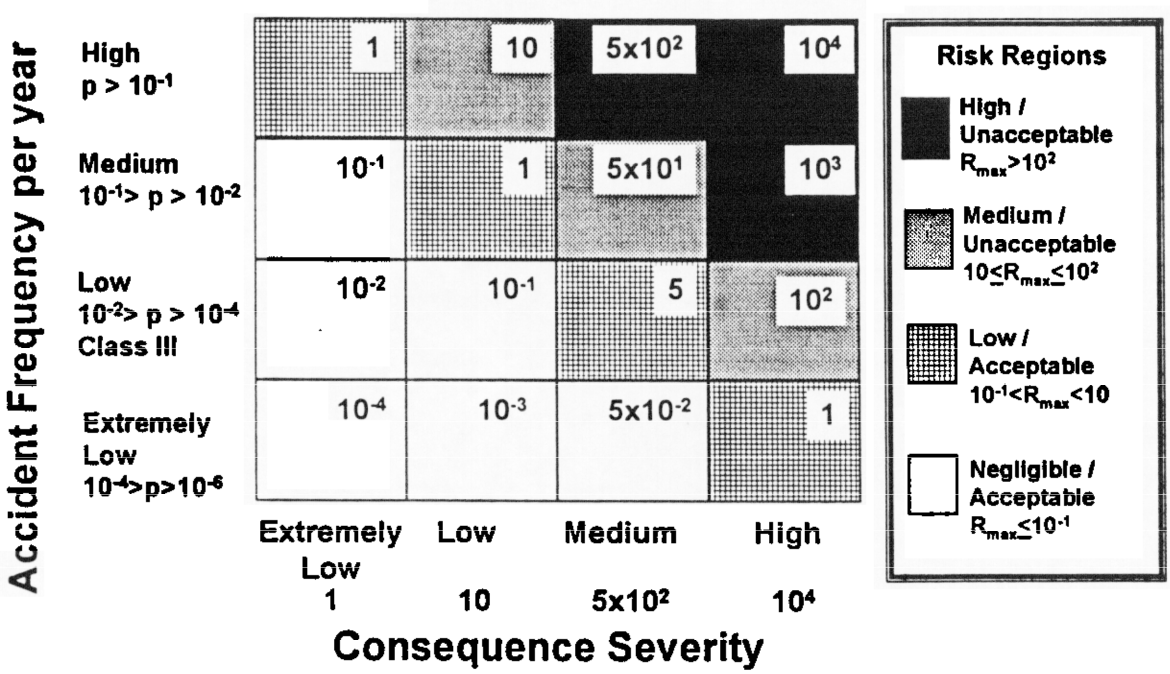

Figure 3. An example of an implied quantitative consequence scale associated with Figure 2.

The maximum risk associated with each block is shown in each upper right corner. Now, logical criteria for establishing risk can be derived. For example, High Risk must have a maximum in each block greater than 100, Medium Risk must have a maximum for each block between 10 and 100 inclusive, Low Risk must have a maximum for each block between .1 and 10, and negligible risk is less than or equal to .1 . By carefully selecting the consequence scale, the original risk groupings are now based in logic. However, these values have not been related to the actual descriptions of the consequences for this matrix, and may not be appropriate for analysis of particular facilities or operations. It should also be noted that risk regions are relative to one another and do not necessarily represent absolute risk. For that reason, it may be best to eliminate judgmental labels describing risk regions and to identify them using objective labels (i.e., instead of Negligible Risk, call it Risk Region 1; instead of High Risk, call it Risk Region 4).

A risk matrix approach has value to decision making only when it is based on quantitative information, and derived to be used with specific facilities or operations. A general purpose risk matrix may work for some analyses, but will be inappropriate for others. To establish a useful risk matrix, the previous process must be applied in reverse. That is: (1) define the frequency and consequence scales quantitatively; (2) establish the criteria for grouping blocks into risk regions; (3) group the blocks into risk regions, based on the product of frequency and consequence for each block, and the established criteria. Defining the frequency bins is straightforward, and common practice is to use wide bins of about 2 orders of magnitude. Defining the consequence bins can be more challenging. The consequence bins must be relevant to the intended analysis. Most desirable are absolute values for the bins, such as dose ranges in rem for radiological accidents. If absolute values cannot be assigned, then relative values must be used. These can be derived through a process of expert elicitation, based on qualitative descriptions for each consequence bin, and one's willingness to tradeoff a certain number of accidents of a lower consequence, for an accident of higher consequence. Then the risk or risk range for each block can be calculated, and meaningful groupings of blocks can be logically determined.

Application to the National Ignition Facility

Successful examples of this approach are documented in the Device Assembly Facility Nuclear Explosive Safety Master Study[1], and in the National Ignition Facility Preliminary Safety Analysis[2] (NIF PSAR). For NIF, two risk matrices were developed for radiological events: one for workers and one for the public. Each is a 4x4 matrix and the one developed for the public is shown in Figure 4. In order to determine the relative risk presented by each of the 16 blocks of the risk matrix, numerical values were assigned to the frequency and consequence axes. The product of the numerical values of frequency and consequence gave a range of numerical values defining the risk for each block. For example, the consequence bins for the public were established as follows: Category 1: dose $\leq$ 0.001 rem (thought to be a negligible dose); Category 2: 0.001 rem < dose $\leq$ 0.1 rem (public routine exposure limit); Category 3: 0.1 < dose $\leq$ 1 rem (threshold for offsite emergency planning); Category 4: 1 < dose $\leq$ 25 rem (siting requirement).

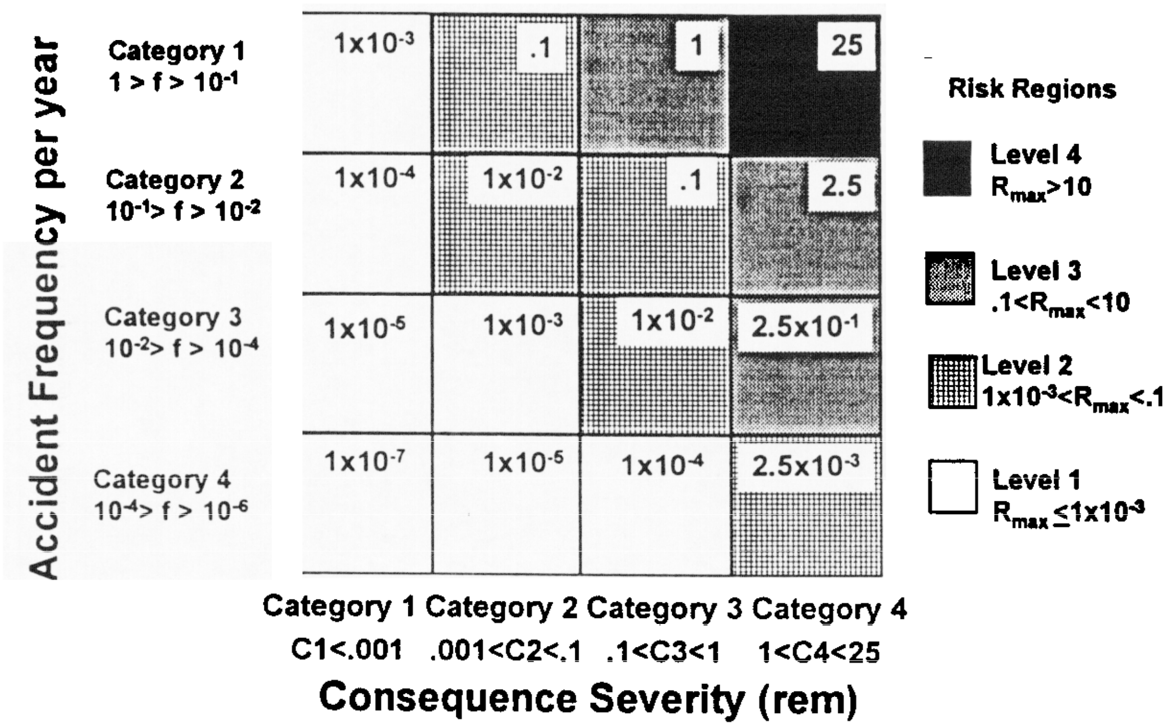

Figure 4. Quantitative risk matrix for public radiological exposure developed for NIF.

Given the quantitative definition of the axes, the risk range for each block in the matrix can be expressed in rem/yr. The maximum value for each block is shown in Figure 4. Blocks of similar risk can then be grouped together for the purposes of simplifying the presentation of the results and structuring a logical decision-making process. In this example, four risk regions were defined. Risk Level 1 was selected to include all blocks on the matrix presenting similar (or less) risk than that associated with a dose to the public of 0.001 rem/yr. (Frequency Category 1, Consequence Category 1 event). The second premise for establishing risk regions was derived from the companion matrix for workers. It defined the highest region of risk to include events of risk greater than or equal to an event potentially occurring during the lifetime of the facility (Frequency Category 2), resulting in death to a worker (Consequence Category 4). The numerical value assigned to the consequence of death to a worker from acute radiation effects was 1,000 rem (there is a high probability of death if exposed to this level of radiation). The threshold for this risk region would be 0.01 x 1000 = 10 rem/yr. Applying this criterion to the public matrix sets a lower bound for Risk Level 4, and defines risk in the same way for workers and the public. Risk Levels 2 and 3 were then selected to fit evenly between these two bounds. Therefore, Levels 2 and 3 each span a risk range of two orders of magnitude.

Once the risk regions have been established on the risk matrix, the analyst needs only to know the frequency and consequences associated with an event well enough to place the event into a frequency and a consequence bin. The event can then be placed on the matrix, and the relative risk level for the event will be known.

Tailoring Risk Matrices

The approach just outlined can be followed to establish radiological relative risk matrices. However, useful information on the relative risk of events may not always result. For example, after reviewing the radiological events identified for a facility, the analyst may find that all events fall into the same risk region. It may be sufficient to know this, or the analyst may want to adjust the consequence scales to more closely cover the range of potential consequences at the facility. A finer scale should allow greater distinction among events.

Closing Remarks

A risk matrix can be a useful tool to present the results of simplified risk analysis, helping one to gain insight into the relative risks of various scenarios that might be encountered in a given system. When developed quantitatively with axes constructed to be relevant to the facility and operations being studied, risk evaluations can be defined logically. Logic-based risk evaluations can facilitate management decisions such as the authorization of operations. It can also help optimize resources by showing where to concentrate efforts for more detailed analysis or for risk reduction activities.

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