The Underlying Principles and Quantitative Values of Risk Limits

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Abstract: The purpose of this paper is to clarify the principle that risks imposed on individuals should be limited in their magnitude. The paper also discusses implementation of this risk limitation principle by regulation, including quantitative risk limits. This principle of limits arises when an activity, although beneficial to society, nevertheless imposes some risk of harm on any individual without their consent and not for their benefit. In this case, fairness requires that the magnitude of the risk be limited. If the harm is fatality, then compensation is no remedy, and regulation should limit the risk a priori. This principle of limitation of imposed risk is not the same as the idea that it is desirable to reduce risk in general. The principle to be applied for general reduction of risk is optimization. Optimization considers all impacts, both beneficial and adverse, on all persons to improve net benefits to society collectively. The appropriate magnitude of a quantitative risk limit may vary if the individual has some degree of consent, or benefits from the activity having risk. Thus values recommended for limits on risk have typically differed between workers who benefit from the activity, and members of the general public who do not.

Keywords: Risk Limits, Individual Risk, PRA, Decision Analysis, Regulation

1. INTRODUCTION

Risk is the possibility or probability of harm. Risk to individual persons arises from their own activities, from actions of other persons, and from natural phenomena. Some risks to ourselves arise from actions we choose to take because they are beneficial to us. Some harmful or risky actions by others are maliciously intended as such. Some risks come from nature, and cannot easily be affected by human action. There are many types of risk. This paper is only about unintentional preventable risks arising from activities of benefit to society. Risk refers to the future. Quantitative risk assessment and reliability engineering are the recognition that, despite the good intentions of design and operating procedures, harmful events may happen because we cannot entirely control the future. This paper is about one particular type of risk, and what should be done about it. Some risks to us arise from activities under our own control; other risks are imposed on us by activities that are not under our control, nor for our benefit. The principle clarified in this paper is that this latter type of risk should be limited in magnitude, and, when the harm is irrecoverable, may need to be regulated. The views in this paper on regulation are the author's, and not those of the United States Nuclear Regulatory Commission or its staff.

2. THE PRINCIPLE OF LIMITATION OF RISK IMPOSED ON INDIVIDUALS

The main points to be made about the principle of limitation of risk imposed on individuals are: 1) that the principle applies to certain situations and does not apply in others, 2) that it is not just a practical tool for risk management, but embodies a fundamental principle of equity, that each individual is entitled to, 3) that it is not the same as optimizing societal benefits, such as minimizing collective risk, and 4) that it is not the same as the principle of making risk to individuals as low as reasonably practicable, and 5) risk limits are the upper bound of tolerable, not acceptable, risk. The principle is that there is essentially an ethical obligation to limit imposed risks as a matter of equity. This does not mean that the principle should always be implemented by a requirement to quantify risk to individuals,

and meet quantitative risk limits. This subject of implementation of the principle will be discussed in section 3 below.

2.1 Decision Situations where Risk Limitation Applies

A decision situation is a situation where a decision-maker must choose from among mutually exclusive options. A number of different groups of persons may be affected by these options, including the decision-maker; and there may be various benefits and adverse impacts on these different groups. Many such situations involve options which will cause risks to some persons. The principle of risk limitation applies only to those situations where the options involve an initiating an activity that is beneficial to society as a whole, but imposes some risk on some individuals without compensating benefits to them. There are two keys that define this situation. First the persons who will receive the risk are not the decision-maker. This is what is meant by the term "imposed". Secondly, the persons who will undergo the risk will not receive commensurate benefits from the option. Other situations exist where this principle does not apply. Reference [1] discusses five archetype decision situations that vary depending on who receives the risk, who receives the benefit, and who has control of the decision. For example, there is the situation arising in medical practice where decisions are made that trade off benefits from medical treatment against their risks. There is no limit on the magnitude of risks that might be appropriately taken in such cases. Similarly there is the rescue situation where a person voluntarily enters a risky situation to provide a benefit to others. The risk taken is thus voluntary, not imposed. Warfare also involves situations where the principle of risk limits does not apply.

The typical situations envisioned here are where risk is imposed on members of the public or workers by an activity of considerable economic value to society. The principle is that, regardless of the magnitude of the economic benefit, there is a magnitude of risk that should not be imposed.

2.2 The Issue of Equity in Imposed Risk

This principle that imposed risks should be limited is not new. For radiation doses, and the risk of radiation doses, that arise from activities beneficial to society, the International Commission on Radiological Protection recommends in Reference [2] (ICRP60) that "constraints" be applied. The following is a quote from ICRP 60 paragraph S18 referring to the "procedure" of optimizing protection:

> "This procedure should be constrained by restrictions on the doses to individuals (dose constraints), or the risks to individuals in the case of potential exposures (risk constraints), so as to limit the inequity likely to result from the inherent economic and social judgments."

Thus ICRP explains the principle of limits as an issue of equity. In reference [3], ICRP discusses extension of this principle to include "potential exposures", that is risks of accidental doses rather than routine exposures.

The idea that limiting imposed risks is a matter of equity or fairness is also found in paragraph 119 of the United Kingdom Health and Safety Executive (document "Reducing Risks and Protecting People" (reference [4]).

The point made in these authoritative documents is that, despite careful evaluation that an activity is beneficial to society, and therefore incurring some collective risks or other adverse impacts is justified by those benefits, there is some magnitude of risk that should not be imposed on any individual person. The reason given is that it is a matter of equity. The UKHSE (Ref. 4) notes that there may be exceptional circumstances where this principle might be violated.

Note that section 2.1 above makes it clear that the principle of risk limitation only applies in the specific situation of imposed risk not for the individual's benefit. Even in this situation, in principle, if the benefits to society were sufficiently great, and the imposed risk not too much above a normal limit, some temporary imposed risk might be considered such an "exceptional circumstance". However, in practice, it is almost never necessary to impose high risks long term. If a facility is of such value to society, and individual residents might be at excessive risk, then they could be moved, perhaps involuntarily.

There is also the unusual circumstance where a choice is made such that risk of harm will occur for a few individuals in order to reduce risk to another group that is either larger or would be subject to greater harm. When the risk is unavoidable, this special situation is called an "intervention", and does not constitute "imposed" risk. Excessive imposed risk occurs only when there is the option of avoiding it.

2.3 Limitation Applies to Individual Risk not Collective

The principle of limitation of risk applies to each individual person. Thus in calculating a risk metric, in principle, the risk to each potentially affected person should be calculated separately to see if it is excessive. In practice, this is not done. Instead one typically identifies a restricted group that clearly is at highest risk, called the "critical group"; or alternatively a "reasonably maximally exposed individual". Either of these may be hypothetical bounding cases that are convenient for the purposes of calculating and managing risk, but the principle itself applies to actual individual persons. A typical metric of individual risk is the estimated annual frequency of fatality for that individual due to accidents in a particular facility. Collective risk is a different quantity. For collective risk of fatality due to accidents, the total number of fatalities is calculated for each scenario, and the mean value is calculated by the probability weighted sum over all scenarios. Thus a typical metric of collective fatality risk is mean fatalities, usually per year.

The point here is that the risk to each individual is the quantity of concern, not a sum or average over all affected persons. This is because the issue is one of fairness to each individual. This is a key to understanding the common situation where the risk arises from unintended releases of radioactive or toxic material. In such release scenarios, a particular individual may not be affected at all unless the wind is blowing in his direction. Even when it is, if dispersion by turbulence is high, the dose may not be enough to cause fatality. Thus the probability of fatality depends on the probability of weather conditions. The equation for the frequency of fatality thus includes several factors: 1) the frequency of the release scenario, 2) the probability distributions on the size of the release given each scenario, and 3) the probability distribution on weather conditions. The probability of fatality for one scenario is then the joint integral of the two probability distributions over the domain where fatality occurs. Thus the total average frequency of the consequence to the individual is the sum over all accident scenarios of the frequency of the scenario times the probability of the consequence given that scenario. Note that the probability distribution on weather conditions may be highly conditional on the scenario. For instance, a high wind event may cause failures that lead to release, but there is a high probability that the weather condition is highly dispersive of any release that may occur. Likewise, the presence of individual residents may be conditional on the scenario. For example, many residents around a facility would be evacuated in most flood scenarios, so that releases caused by the flood would not affect them. Thus the risk assessor needs to model locational distributions of persons, variations in weather, and other factors for each scenario.

Typically, for a release large enough to cause fatality, the probability that the wind is blowing toward a particular individual is about 0.1. If the frequency of the release is 0.001 per year, the individual's frequency of fatality is (0.1)(0.001/year) = 0.0001 /year. This point is often misunderstood in that it appears to some inappropriate not to count a release that goes in a direction away from the individual. However, the mathematics is correct, in that all releases are, in fact, considered, but the risk is calculated for each individual person (or group) at a time; and for each individual calculation, risk to other persons is not relevant.

2.4 The Principle of Individual Risk Limitation is not Individual Risk Minimization

The United Kingdom applies a principle that risks to individuals should be made As Low As Reasonably Practicable" (ALARP). ICRP applies a similar concept of optimization or minimization to both routine doses and the risk of accidental doses. The ideas here amount to a recommendation or requirement that individual risk be reasonably reduced. This principle can be implemented by performing an optimization that considers all impacts of each of a set of options to select that yielding the highest net benefit. This principle could be implemented as a regulatory requirement (as it is in the United Kingdom) and applied to minimizing risk to individuals. This is not the same as the principle of risk limitation discussed in this paper. A risk limit would be the highest tolerable value of risk to an individual. Any proposed activity that causes the limit to be exceeded is unacceptable. A requirement to further reduce individual risk below this limit is a separate issue.

2.5 Meaning of Risk Limits

ICRP in Reference [3] and UKHSE in Reference [4] recommend quantitative limits on risk to individuals. The meaning of these values is clearly spelled out as values which are not to be exceeded for the situations to which they apply under almost any circumstances. UKHSE in Reference [4] makes it clear that it regards these risk limits as the boundary between tolerable and unacceptable risk. The term tolerable implies a situation that has some undesirable character, but nevertheless can be allowed. The term "acceptable" is not used by UKHSE until individual risk levels are much lower. In addition, both ICRP and UKHSE endorse the principle of As Low As Reasonably Practicable. Thus one might say that individual risk, as well as collective, is not "acceptable", unless this principle has been satisfied as well. Further, the term "acceptable" raises the question of acceptable to whom. Persons on whom the risk is imposed may not find any imposed risk "acceptable". The principle of risk limits is thus best characterized as a tolerability limit determined by society to prevent large inequities on individuals from activities that are otherwise a net benefit to society.

3. RISK LIMITATION IN DECISION ANALYSIS AND REGULATION

Although the principle of limitation of imposed risk may apply to a regulatory situation, this does not mean that the only way to implement the principle is by quantitative regulatory limits. Both the United Kingdom Health and Safety Executive (UKHSE) and the ICRP in reference [4] provide quantitative risk limits, one for workers and one for the general public. However, the UKHSE limits are not regulatory or statutory requirements. They are guidelines for the regulators. If quantitative risk limits were required, it would imply that the risks be quantified. Regulation involving issues of compliance is better if compliance can be determined accurately and objectively. Accurate objective quantification of risk is a difficult standard to achieve. There are several ways around this difficulty. Risk can be limited by prescriptive measures that have been determined by risk analysis to be reasonably effective in meeting quantitative risk limitation guidelines that are not themselves regulatory requirements. Risk assessment and comparison of results to quantitative risk guidelines can be used in various ways other than as direct regulatory limits. Demonstration that risk limits have been met can also be done not by true risk assessment, but by bounding quantitative risk analysis using conservative assumptions in lieu of data. Another approach is to use standardized pre-approved risk models and data. This would only be practical for a limited range of types of facility and hazards.

Both the ICRP and UKHSE recommend implementation of the principle of risk limitation by two risk limits, one for the public and one for workers. Two limits is not the only possibility, others could be defined. The magnitude of risk that it is fair to impose depends on the degree of control and the amount of benefit that the individual gets from the activity causing the risk (see reference 1). These two factors could vary among different groups of persons. The differences in control and benefit are the reasons that the worker risk limit can be higher than that for the public. The worker derives substantial benefits from the risk taken. The worker also has exercised the choice to undertake the risk to get the benefit. However, worker risk should still be limited in that the degree of control by the

worker is limited. In principle, there could be other groups of persons who, analogous to workers, have some amount of control and/or benefit from the risky activity. Thus, in principle, a variety of risk limits could be established to accommodate these variations in control and benefit.

Some risks that are imposed on individuals, such as property damage, are recoverable, typically through insurance. Irreversible serious health effects and fatality are not recoverable . Thus any mechanism used to assure that imposed risk of these irrecoverable consequences is limited is better done by a priori evaluation, regulation, or standards.

The conclusion here is that although imposed risk should be limited, the mechanisms used to provide such limitation could vary. Risk, however, is inherently a quantitative concept; hence, quantitative guidelines and some form of risk analysis is usually part of the process of determining whether limitation is tolerable.

4. QUANTITATIVE VALUES OF RISK LIMITS

UKHSE uses limits of 10^{-4} per year for the public and 10^{-3} per year for workers as the boundary between tolerable and unacceptable risk of fatality imposed on individuals. ICRP in Reference [3] recommends risk limits on potential exposures to radiation doses that are of the same order of magnitude as its annual limits on routine doses of 20 millisieverts to workers and 1 millisievert to the public. The UKHSE fatality risk limits are consistent with the latent cancer fatality risk from these ICRP dose levels. Thus these two recommendations on limits are consistent with each other. No basis for an exact numerical value for risk limits has been identified. To illuminate whether the recommended limits are reasonable, consider a value 10 times the public limit, namely a risk of fatality of 10^{-3} per year. Over an 80 year life span this would be a risk of fatality of 0.08 imposed on an individual. This seems clearly excessive. On the other hand, if the risk limit were 10^{-5} per year, the risk imposed on the average person in the U. S. by other drivers who are at fault would not meet it. This risk of fatality imposed by other drivers is about $4x10^{-5}$ per year. Thus, to within an order of magnitude, the limits used by UKHSE appear reasonable.

In considering the reasonableness of risk limits, it should be remembered that these limits are maximum tolerable values, not desirable objectives, or negligible risk levels. Negligible individual risk levels are a different concept, and much lower than the limits discussed here.

5. CONCLUSIONS

In conclusion, the principle that risk imposed on individuals not for their benefit should be limited has been recognized by authorities applying it to a wide range of practices. Even though not used as regulatory requirements, quantitative risk limits are recognized as useful. Limits of 10^{-4} per year for risk of fatality to individual members of the public, and 10^{-3} per year for workers, as the boundary between tolerable and unacceptable appear reasonable. Individual risk is not the same metric as the collective risk metric used in cost-benefit optimization to manage risk.

References

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