A Few Alternative Criteria of Risk Assessment and Safety Decision Making for Improving Risk Communication and Public Acceptance on Nuclear

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1. INTRODUCTION

It becomes more connected and intelligent by virtue of the emerging technologies of ICT such as AI. We hope to be more productive but become sensitive to the technologies, since the intelligence could mean vulnerability and the connectedness could make it more fragile to so-called *Big-One and Event-X*. Nowadays the confidence on the scientific and technological safety becomes not effective any more. Nuclear safety is suffering from a strong public challenge especially after Fukushima accident.

The traditional approach to the safety for public has been a scientific assessment with a best set of evidences. To ensure the safety primarily a deterministic approach has satisfied all the rules and requirements that have been prescribed ahead and explicitly conservative from the most disciplines. However it was not sufficient to ensure that they provided a balanced approach to achieve the risk accepted by public in practice. Public shows a strong reluctance to the nuclear risk due to the experiences of astonishing disasters such as TMI, JCO, Chernobyl, and Fukushima. The concept of risk seems to be changed to public in spite of the enthusiastic and scrutinized quantification on the risk from PSA and others.

The risk has been quantified traditionally by equation (1), since the PSA has been developed in 1970 and is now accepted as a mature criterion to the safety. It can be obtained relatively simply by multiplying the consequential loss of an event and its basic probability, and accumulating all the risks of every plausible failure scenario. Various safety decisions might be made consistently based upon this approach to minimize the risk and/or satisfy some criteria prescribed.

$$\text{Risk: Expected Loss} = \text{Loss} \times \text{Prob.} \qquad \text{System Risk (R)} = \Sigma\,(\text{Loss} \times \text{Prob.}) \quad (1)$$

Postulated that the quantified basic data could be available to all the aspects of risk perceived by all of interest parties, most decisions on seem to be easily acceptable in the aspect of safety at least. However there are a few basic limitations on this approach for straight-ward acceptance.

Firstly, the data available to calculation should be falling behind the risk in the future. They mostly can be obtained from the past experiences of components and system in operation.

Secondly, it becomes worse to get a failure data when they are extremely reliable. The statistical significance should not be enough with rare cases in failure. Sometimes uncertainty goes over the estimation by data, and no meaning to the conclusive decisions.

Thirdly, the technology and working environment is changing rapidly. It makes the meaning of the accumulated data heterogeneous and doubtful among different groups involved in safety decision makings.

Finally, the most fundamental and important change on the risk calculation happens to the differences on the basic understandings of the two risk items, i.e., loss and probability. The scope of loss is being expanded to the decrease of various utilities and values beyond investments and human fatality.

In this paper I discuss the traditional concept of risk that has been applied in nuclear, and propose a few modifications to the risk quantification approach and new measures complementary to the most safety decisions made to maintain eventually the nuclear safety.

2. RISK SCOPE EXTENDED TO THE PERCEIVED BY PUBLIC

IAEA and other nuclear societies look very eager to suggest a sound approach to safety decision makings with a robust concept of risk and a concrete calculation method around the nuclear. Following figure can show a typical example of the exhaustive efforts to include all of the available scope of risk considerations in terms of KEs (key elements) and CFs (constituent factors). (refer to IAEA-TECDOC -1909, as a most recent I-RIDM (integrated risk informed decision making) method)

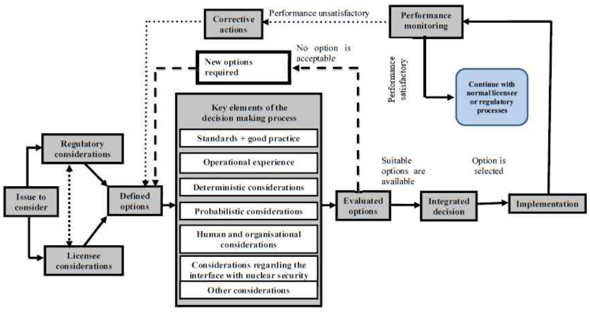

Figure 1. Main Components of the Integrated RIDM Process (adopted from IAEA, 2020)

I-RIDM suggested currently does not go beyond the typical accumulation of weighted values to be contained in various aspects of risk. It could be utilized during *exhaustive consensus approach* to the policy decision making processes on the demanding public issues. A few emerging trial can be added by applying the game-theory-based approach such as "*Prisoner's Dilema*" (2019 Kim).

However the basic scope of two risk elements, i.e., loss and probability can be extended further to cover the perceived practically by the interest groups. The loss perceived by public could go beyond the traditional scope of engineering objects and human fatality to the inconveniences and annoyance in everyday life and long-term concerns on genetics according to the options and changes in nuclear. R' and R* in eq. (2) for these new kinds of losses can be calculated into the risk complementary to the traditional R for the loss of investment and fatality.

$$\begin{gathered} Risk(i): Expected\ Loss(i) = Loss(i) \times Prob.(i) \\ Alternative\ Risk\ (R'\ or\ R^*) = \Sigma\ R(i) \end{gathered} \quad (2)$$

Item i can not be predetermined into a list of candidates but be selected by interest groups with respect to the types of issues and safety decisions, and added to the total risk value by the different aspects of losses in practice. (1972 Thygerson, 1992 Rasmussen)

There can be a various kinds of risks to a single issue and the same system. Sometimes they can be accumulated easily into a single value. But frequently they need to treat respectively each other. Security is a typical example of separated risk, and others also may come from the psychological reasons such as mental accounts.

3. ARITHMETIC CONSIDERATIONS TO RISK CALCULATIONS

Studies from cognitive psychology and others after the last century has raised many interesting observations on human decision behaviors especially under risk that sometimes go beyond the rationality assumption. The "*Allias' Paradox*" "*Bounded Rationality*" and "*Prospect Theory*" uttered respectively, however, were proved as a different kinds of systematic human behaviors.

It can be a new discipline named "Behavioral Science(or Behavioral Economics)", though all of heuristic and biases are not summarized into an exhaustive set of human behavior. By virtue of the new perspective from behavioral science (or behavioral economics), followings can be suggested just as a few examples to revise the risk calculations that might be beneficial in order to practically represent the risk perceived by public.

Firstly, the terms should be re-interpreted from the engineering results into the values perceived. Data obtained statistically from the engineering practice can be converted into the value through the conversion functions such as market utility and decision weight. The conversion function typically has a form of logistics curve shown in figure 2, however the details should be calibrated by the reference anchored and magnitudes of change.

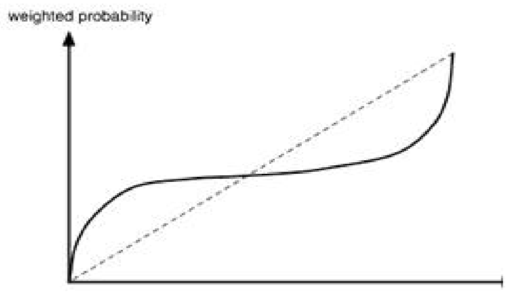

Figure 2. Typical Form of Conversion Function

Secondly, further detailed considerations to revise the risk data conversion, if especially applied in calculations by virtue of PSA/PRA, has more emphasis to the following discounts due to heuristic and biases to risk perception. (2020 Lee)

- temporal discount : current>future/past
- subjectivity of parties : mine>your, our>**their**
- anchoring of reference : relative to current
- uncertainty effect : certain risk>>uncertain risk
- asymmetry of Gain/Loss : loss>>gain

In addition to the above discounts, followings are the typical modifications from behavioral science perspective. (1992 Wickens, 2019 Lee)

- insensitivity near the extreme
- availability by previous experience/information
- recency and/or primacy
- prominency by features
- marginality to the change from reference pt.

These behavioral re-interpretations has become mandatory to risk decision makings in practice but the details related to the values rather recommended according to various fields and people. Many experts such as Kahneman, Thaler and others profoundly has contributed to *Behavioral Science* and its prevailing applications to *Economics* after 1980's (2011, Kahneman).

4. NEW CRITERIA TO RISK ASSESSMENT AND SAFETY DECISIONS

For the purpose of risk communication and public acceptance, the engineering calculation of risk looks not sufficient to consider the perceived reality on risk among interest groups. The risk calculation has been traditionally believed as simply-additive arithmetically. However it would be rather complicated by incorporating various risk perception behavior in practice (more than suggested above). The risk values could be neither simply-additive nor representative to the risk perceived anymore, especially during the risk decision makings and judgments. There might be different kinds of measures of risk values, that can be suggested as new criteria to support the risk informed decision makings.

Firstly, total amount of risk (R') can be revised from the traditional risk (R) by applying following revised equation (3) for incorporating further considerations described above.

Perceived Risk (R') $= f(\{u(\text{Loss})_i \times \pi(\text{Pro.})_j\}_k)$ ✓ $u(\text{Loss})_i$ = utility value of Loss_i ✓ $\pi(\text{Prob.})_j$ = weighted prob. of Pro_j ✓ $f(\text{Risk}_k)$ = integration of Risk_k	(3)

- 'u' means utility function that might be convex for gain and concave for loss along the reference point selected by people in risk perceptions and decisions.
- 'π' means decision weight that may be a typical s-shape curve of conservatism.
- ∫ means the integral of risks rather than simple additive calculation.

The postulated additivity on the accumulation of risk by rather objective engineering values of each risk items may not applicable to the subjective utilities and real values perceived. So total risk can not be obtained by the simple arithmetics of Σ(Loss.xProb.) any more. The calculation itself may be trivial after obtaining the conversion curves on the loss and probability, however, the details may not become easily given without base data for risk communications among interest groups. The base data for the conversion curves might be obtained from further surveys, observations, and experiments on the risk behavior of interest groups. (2019 Lee) The risks in terms of utilities and values obtained from the population groups show strong dependencies on their cognitive and psycho-social behavior.

Secondly, new measures supportive the total amount of risk can be suggested as followings (just two examples to R and/or R')

- *marginal risk* (or risk sensitivity)
- *risk premium*
- total accumulated amount of *risk preservations*

The concept of m*arginal risk* is a sensitivity value to the expected change from the current status of risk. It varies according to the types of risks as well as the interest groups. *Marginal risk* is a good measure of practical decisions rather than total risks and can be applied to recent nuclear issues such as new construction of spent fuel storages and safety of multi-unit NPPs since it has already long experience in economics.

The concept of *risk premium* is the same in insurance, and rather straight-forward to obtain in a quantitative value by applying the following equation (4).

Risk Premium = $\text{Loss}_{\text{Expected}} - \text{Cost}_{\text{Paid}}$ ✓ $\text{Loss}_{\text{Expected}}$: amount calculated by data ✓ $\text{Cost}_{\text{Paid}}$: total amount paid for the future	(4)

Risk preservations can be obtained by the accumulation of total historical acceptances. It can be applied to the relative evaluation of risk premiums among interest groups to the personal and social risks over the years.

It may include more various and descriptive risk perceptions more than the temporal and personal discounts to the engineering risk. NIMBY (Not-In-My-Back-Yard) and PIMFY(Please-In-My-Front-Yard) found frequently during the safety decisions could be figured out with these quantitative measures and more systematic manner by the discrepancies among the risk perceived by me/others and here-and-now/there-and-then.

5. DISCUSSIONS AND CONCLUSIONS

The scope extension to the traditional risk concept and a few additive modifications to be incorporated to risk calculation are proposed to incorporated the risk perceived over the objective engineering risk by interest groups. A few new measures are also suggested as just examples to enhance the power of risk assessments and further applications to RIDM and integrated RIMD, and eventually to facilitate the risk communications and public acceptance in nuclear. The new revised risk concept based on mainly the behavioral science perspective is resulted in re-calculation into the utility and decision weight risk (*R'*) from the traditional risk (*R*), and further integrations of risks with a few additional considerations.

Nowadays the risk even given in a quantity is neither continuous nor simple-additive any more. The safety decisions and risk communication based on the normative model of risk frequently reveal a strong reluctance and conflict, and sometimes confront uproars due to the fundamental discrepancy to the risk perceived among people in the different sides each other, especially opposed to the technology-oriented specialties.

The quantified value of risk can help to explain the discrepancies among interest groups, and understand the respective positions settled in risk communications. Risk values can intermediate the differences among the groups according to the types and detail items of risk. Furthermore, we can investigate the temporal changes and various variables influencing and interrupting to the risk perceptions.

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