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A Revisit to the Risk Concept and Approach based on Behavioral Science Perspective for Risk Communication and Public Acceptance of Nuclear Safety

Yong-Hee Lee
Nuclear ICT Research Division, Korea Atomic Energy Research Institute (KAERI)
Daedeok-daero 989-111, Daejon, Korea, 34050
✉ yhlee@kaeri.re.kr

1. Risk and Risk Communications in Nuclear

Nuclear safety has been perceived by the risk of the system applying nuclear technology. The risk can be assessed by probabilistic approach such as PRA/PSA as well as deterministic approaches from various technical disciplines. The risk measure base on PRA/PSA has contributed to deliver an overall figure of the nuclear safety and persuaded the details of safety confidence with clear values and their concrete scenarios after WASH-1400. The risk values summarized by PRA/PSA has been believed as rather clear and objective criteria if the base probability data could be obtained to represent the every failure to be happened in nuclear systems including human and organizational behaviors, digital and S/W processes, common caused failure situations, and other tricky phenomena in practice.

The risk value has been obtained by multiplying simply the amount of loss of an event and its probability traditionally. PRA/PSA has accumulated hopefully all the risks of plausible failure scenarios. It has incorporated the classical perspective on the decision making so-called EUT (expected utility theory) summarized by Neuman and Morgenson in 1944. Nowadays the risk communication based on the EUT, however, frequently raises conflicts and confronts a reluctance of people in the opposite side to the technology-oriented experts. The risk value based on EUT is sometimes not accepted to the people though it is obtained by huge efforts and exhaustive detail of system failure and its probability. People especially outside a discipline is asking different perspectives on the risk and the safety to represent their feeling in practice.

This paper describes the arguments for the revision to the traditional concept of risk based on mainly the behavioral science perspective prevailing after 1980's. And I will propose a new risk concept and a new approach with modifications beneficial to the traditional risk assessment. It could help to compromise the different perspectives during risk communications and risk decision makings, especially in nuclear.

2. Characteristics of Nuclear Risk and the Traditional Risk Concept

2.1 Arguments on the Characteristics of Nuclear Risk in Risk Communications

Nuclear risk has been expressed by the risk value obtained by the EUT perspective. EUT perspective has worked good enough to explain many judgments and decision makings on various human behaviors including risk-related behaviors until now. There are many discussions and arguments that differentiated and explain the characteristics of nuclear risk from others (2011, 2013, 2015 Y.H. Lee, et. al.).

Nuclear risk is basically related to radiation effect that is invisible and unfamiliar to public, and has been believed not-well-known and mostly irreversible in the aspect of damages. The radiation effects seems biologically long-lasting and genetic to the next generations. This characteristic means more reluctant and fearful to public. It also is large-scale and can become catastrophic socially when an accident happens in application systems, especially, such as nuclear power plants. Additionally, it gives feeling of "not-involved" and "beyond my control" simply because the nuclear technology is not familiar and the application systems are settled and managed a part from public access.

Although some of them mean rather a fear to wellness over the risk to safety, it might be true that all the characteristics of nuclar risks are not included in the current risk value representing the nuclear safety by PRA/PSA. It may help to understand the current changes on nuclear related decisions and improve the risk communication required for public acceptance of nuclear risk.

2.2 Discussions on the Concept of Risk and Calculation in Nuclear

Cognitive science studies has raised many interesting observations and phenomena of human behaviors that were sometimes irrational during

the last century. Followings are a short list of those irrational behaviors as examples.

- primacy/recency biases
- anchoring and conjunction fallacy
- hindsight effect, halo effect, etc.
- availability and representation decision
- causality on the temporal sequences
- various over confidences and unbalance choice

They have been summarized by "Bounded Rationality" that uttered by H. Simon with a Nobel prize in 1971, and it gives birth a new discipline named in "Behavioral Science", since it changed the fundamental base to explain the human behavior of choice and decision making. The base of rationality hypothesis on the judgement and decision making was re-considered after 1980's, and the behavioral science perspective has drastically changed the foundation to human behaviors from the normative model to the descriptive model of human behavior. Risk obtained by incorporating the descriptive model from the behavioral science perspective could be more communicative and acceptable to people during risk communication and related decision makings. Following simple equations have been accepted traditionally during the assessment of risk in practice.

Risk : Expected Loss = Loss x Prob.
System Risk (R) = Σ (Loss x Prob.)

There are several aspects on the traditional definition of risk measure that could be discussed and modified by incorporating behavioral science perspective.

Firstly, the loss consequenced by a failure event and its probability have been represented mainly by the mean values. However they would be distributed on the large horizon of the value rather than the representative point values. The representative values can be selected differently from various perspectives, as median, minimum, maximum, weighted other values as well as the mean value according to the perspective. The risk of expected loss can be scrutinized by the arguments that have been discussed in cognitive studies on the fallacies in decision making (1982, Wickens), the paradox in gambling choices (1954, Allais), and the heuristic and biases in judgments under risk (1974, Tversky and Kahneman). Especially the probability of an event could not be sensitive enough to be rational during the decision making. The perceived probability can be frequently under-estimated near the horizon of extreme values(or it sometime can be over-estimated contradictorily). Figure 1 shows typical shape of weighted estimation of the risk probability.

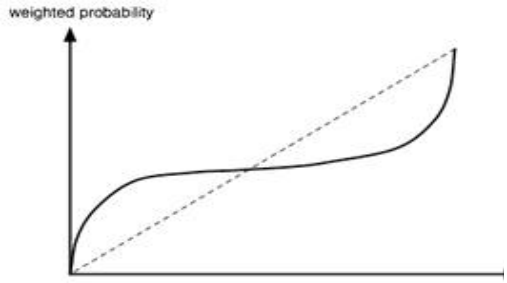

Fig. 1. Typical Transformation of Probability

Secondly, the risk of expected loss could become more realistic if the values of the loss and the probability were to be interpreted by the utility that might be closer to the values perceived by people. The current utility differs from the future utility, and this discrepancy sometimes requires discount rate to compromise. The utility of loss would be more sensitive than the utility of gain in general. The asymmetric discrepancy between the loss and the gain may give rise to the many behaviors that can be explained by only the descriptive model of bounded rationality. A study to demonstrate these irrational utility perceptions was concluded by the name of "Prospect Theory"(1979, Kahneman and Tversky) and the following simple graph (see Figure 2).

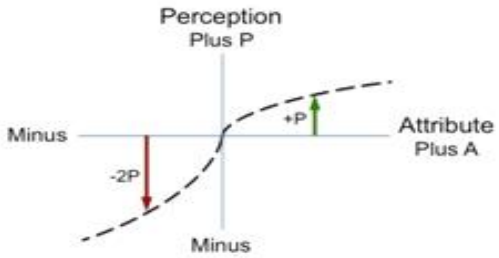

Fig. 2. Asymmetric Perception of Gain and Loss

Nowadays the utility interpretation on the expected values and decision weights related to all decision makings in practice has become mandatory rather than recommended to various fields involving human behaviors. (Dr. Tversky had contributed to safety science and its applications, but he was gone early. Dr. Kahneman got a Nobel Prize in 2002, and summarized the prevailing changes after 1980's with many its applications based on his concept and proposed approach (2011, Kahneman).

Finally, the calculation of risk that is traditionally believed as simply-additive would be complicated by the risk perception behavior in practice. The risk values could not be simply additive anymore especially during the risk decision makings and judgments. NIMBY shows the big discrepancy among the risk values perceived by me and others.

3. A Revised Approach to Risk Quantification from Behavioral Science Perspective

3.1 A Risk Quantification Revised by Behavioral Science Perspective

Following equation can show a proposed modification to the traditional risk quantification in order to consider the arguments on the nuclear risk. The new one incorporates the behavioral science perspective to the definition of risk and its calculation in practice.

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

'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. And ∫ means the integral of risks rather than simple additive calculation of risk values. The quantification of risk value from the behavioral science may become rather complicated by additionally introducing further transformations of the engineering values.

3.2 How to Obtain the Base Curves for the Interest Parties to Nuclear Safety

The basic directions of utility and value transformations can be obtained according to the general S shapes of curves from behavioral science and its applications after 1980's. The calculations may be trivial after obtaining the base curves from the interest parties. The critical details for the risk communications in nuclear, however, may not become easily given without base data. The data might be obtained from the following approaches for surveys, observations, and experiments on the risk behavior.

- **Data I** : Risk Behavior Survey(Public) based on SD (semantic differential) Method
- **Data II** : Observations & Experiments on the risk decision making, heuristics and biases, the responses to the risk due to the preferences & cognitive dissonance.
- Quantification by AHP (analytic hierarchical process) and pair-wise comparison of risk types and items.

Figure 3 shows the curves obtained from the various fields and their thematic variables by observations, surveys and experiments on human behaviors in practice.

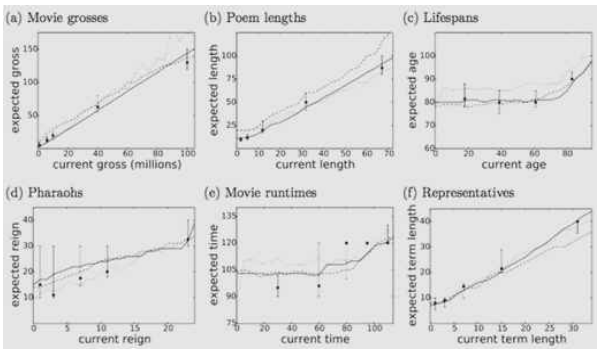

Fig. 3. Curves obtained from Behavioral Science

3.3 A Quantification of Risk Premium and Marginal Risk for the Application to Risk Communications

The concept of risk premium has been already applied in insurance and easily obtained from the difference between the expected value and the price to be paid in practice. They might represent the normative model of rationality and the descriptive model of bounded rationality on the loss and probability in the future accidents.

Risk Premium $= \text{Loss}_{\text{expected}} - \text{Cost}_{\text{paid}}$

- ✓ $\text{Loss}_{\text{expected}}$: amount calculated by data
- ✓ $\text{Cost}_{\text{paid}}$: amount paid by client for the risk

Another measure to explain the risk behavior is marginal risk. Marginal means the increment and/or decrement of the original measure. So, the marginal risk explains the practical responses to the change of the risk. People has been accustomed with a certain level of risk in everyday life, and mostly reluctant to the change, especially incremental, though the change is too small to impact the real life. However, the marginal risk is frequently critical to the risk behavior and risk decision making as we have ever confronted with NIMBY. Nobody can stand that I am not egoistic to the risk.

The values of risk premium and the marginal risk proposed can help to understand the various positions settled in risk communications and quantify the discrepancies among the interest parties. Additionally, it can quantitatively reveal the differences among the groups according to the types and items of risk. They also can trace the changes to the time-line and the behavior of included variables and their various influencing to the risk premium and the marginal risk.

In case with those information on the risk behaviors, surrogate variables can be selected to interrupt the changes among the influencing factors to the risk premium and marginal risk (2010, Lee and Shin).

4. Applications and Further Works

The revisit to the traditional concept of risk are discussed based on mainly the behavioral science perspective. And I proposed a new risk concept and a revised approach with additional interpretations by introducing utility function and decision weight to the risk, and a quantitative integration of risks into risk premium and marginal risk. They include the changes to the assessment process such as PRA/PSA especially in nuclear as well as the fundamental concept itself to facilitate the risk communications in practice.

The proposed concept and quantified approach with risk premium and the marginal risk can help to compromise the different perspectives among the interest parties during risk communications and risk decision makings, however, only when the details on the base data in nuclear are to be obtained by further basic studies of survey and experiments, and further development of applications to the nuclear risk.

The risk communication can be facilitated if the proposed approach is applied in practice. For example, the responses of residents in a multi-unit site as well as the other interest parties can be more easily understood with the proposed approach and the quantitative measures in the risk assessment of multi-unit PRA/PSA.

It can help to update the current positions on the nuclear risk and find a surrogate variables to resolve the discrepancy and conflicts. More promising applications of risk-informed decision makings, especially in case with recent big data techniques, can be incorporated further.

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