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A Behavioral Scientific Proposal to Revise the Multi-Unit Probabilistic Risk Assessment for Improving Risk Communication and Public Acceptance on Nuclear

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1. INTRODUCTION

The belief on the nuclear safety nowadays seems to confront a strong reluctance and challenge from the public and especially ecologists after Fukushima accident. Korea established an implementation plan of post-Fukushima action items after 2011, which by the amount of up to a billion dollars investment looks vigorous enough to cope with all the safety issues afterwards. It includes many additional scenarios and profound safety considerations. New scenarios are expanded up to very rare postulated events of beyond DBA such as fire and multiple events as well as seismic, flooding, and loss of all power of neighboring/multi-unit NPPs that was experienced in Fukushima. And new considerations go from the safety culture and HOFs (human and organizational factors) and security issues far to the impact issue of the dependancy among multi-units. Korea has accomplished or on the way of an exhaustive stress test and complementary implementations on all the action items. It seems that multi-unit safety issue is one of main action items for public acceptance, since there are many works and review on MUPRA/PSA under-going.

This paper describes the limits of the existing concept of risk and risk assessment to represent the risk practically perceived in public when especially applied in multi-unit events in term of PSA/PRA, and proposes a revised concept of risk based on the behavioral science perspective and a few further considerations to revise the risk calculations of MUPRA/PSA for enhancing risk communication and public acceptance.

2. TRADITIONAL RISK CONCEPT AND ITS LIMITS TO SAFETY PERCEIVED

Safety has been traditionally understood by the risk of the system and the applying technologies. The risk can be assessed by the probabilistic approach such as PRA/PSA as well as the deterministic approaches based on various technical disciplines. The quantitative risk measure obtained by PRA/PSA has contributed to representatively deliver the overall figure of the system safety, and has widely persuaded the public about the details of the safety decisions with confidences of rather clear values and the concrete scenarios.

Traditionally risk value has been obtained by simply multiplying the consequential loss of an event and its probability. And it could be accumulated hopefully to all the risks of plausible failure scenarios.

Risk: Expected Loss = Loss x Prob. System Risk (R) = Σ (Loss x Prob.)	(1)

It has incorporated the classical perspective on the rational decision making so-called EUT (expected utility theory) by Neuman and Morgenson in 1944. The risk values summarized by PRA/PSA after WASH-1400 has been believed as rather clear and objective criteria when the base probability data might be obtained to represent the every failure to be happened in a system including HOF behaviors, digital and S/W processes, common caused failure situations, and other tricky phenomena in practice.

Nowadays the risk communication based on the EUT, however, frequently raises uproars due to the disagreements to the risk perceived, and confronts a strong reluctance/protest/conflict among people in the different sides each other especially opposed to the technology-oriented specialties. The risk values obtained by the large and exhaustive efforts to capture the details of system failure and its basic probability data sometimes are not accepted by public. People especially outside from a discipline is reluctant to accept the basic assumptions and data, and stands asking different perspectives on risk to represent their feelings in practice. A few emerging trial has been conducted by applying the game-theory-based approach such as famous "*Prisoner's Dilema*" (2019 Kim) and exhaustive consensus approach to the policy decision making processes on the demanding nuclear tasks and public issues. Limits may come from the basic assumptions to the non-mechanical characteristics in digital and software based recent systems as well as the HOFs, and more come from the traditional concept of risk due to no consideration on the human perceptions(2018 Lee).

The traditional concept of risk can be revised by mainly the behavioral science perspective that has been prevailing after 1980's in financial and economic disciplines. The new perspective can help to figure out a plausible way to resolve the current conflicts and enhance the low level of risk communications among the interest parties.

Cognitive science studies during the last century has raised many interesting observations and phenomena of human behaviors that sometimes go beyond the rationality assumption. It was 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 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 base 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.

3. THREE CONSIDERATIONS TO RISK (*R'*)

There are several aspects on the traditional definition of risk measure (1972 Thygerson, 1977 Tarrant) that could be discussed and modified by incorporating the behavioral science perspective (2018 Lee).

At first, risk is extended to more than the traditional interpretation of expected loss. It can be re-interpreted into the subjective utility and the different values to the perspective applied (2003 Rasmussen). For example the loss can be extended more from the damage to the system investment to the negative happens and propagations beyond the system and the crew involved (1997 Reason).

Plausible Loss > Loss postulated in R of Eq.(1)
Plausible Prob. > Prob. postulated in R of Eq.(1)

Secondly, the real value of risk needs to be re-interpreted into a utility value rather than the objective cost and/or the investments. It means that the all the losses and their probabilities should be transformed by their own characteristics curves. Logistics curve is a typical one shown in following figure.

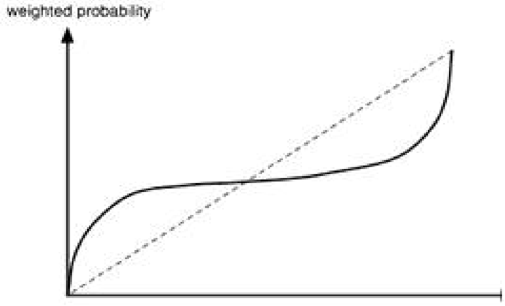

Fig. 1. Typical Transformation of Probability [3]

Thirdly, the postulated additivity on the risk accumulation may not applicable to the subjective utilities rather than the objective values of each risk. System risk can not be calculated by the simple arithmetics.

System Risk (R') $\neq$ Σ (Loss x Prob.)

The risks in terms of utilities obtained from the persons and population groups show strong dependencies on their psychological and cognitive behavior. They are described from the early study on the Allias' paradox (1954) to the rather recent studies in behavioral science. 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). A study to demonstrate the utility perceptions was concluded by the name of "*Prospect Theory*" (1979, Kahneman & Tversky) and the following simple graph (refer Fig. 2).

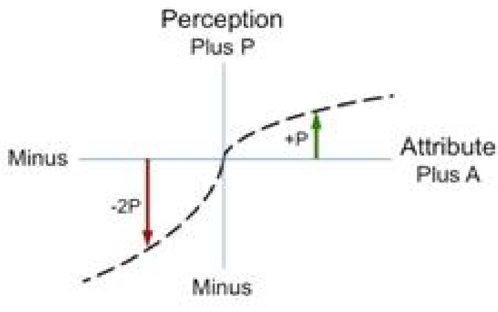

Fig. 2. Asymmetry of Gain/Loss [3,4,12]

In addition to the asymmetry of gain and loss, followings are the typical cognitive considerations from behavioral science perspective.(1992 Wickens)

- insensitivity near the extreme ranges
- anchoring to the first
- availability bias due to the recency and primacy
- marginality to the change

Nowadays the utility interpretation on the expected values related to all decision makings in practice has become mandatory rather than recommended to various fields and people. Dr. Kahneman profoundly has contributed to behavioral science of the changes and its prevailing applications after 1980's, and got a Nobel Prize in 2002 (2011, Kahneman).

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.

Following revised equation can show a proposed modification from the traditional risk quantification (*R*) to the new one (*R'*) by incorporating the behavioral science perspective to the definition of risk. (2018 Lee)

Perceived Risk (R')=*f*({u(Loss)$_i$ x π(Pro.)$_j$ }$_k$)
✓u(Loss)$_i$ = utility value of Loss$_i$
✓π(Prob.)$_j$ = weighted prob. of Pro$_j$
✓*f*(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.
- ∫ means the integral of risks rather than simple additive calculation.

4. CONSIDERATIONS IN RISK CALCULATIONS PROPOSED TO MUPRA/PSA

The risk(*R'*) from the behavioral science may become rather complicated by quantifying a further transformations of the engineering risk value(R) with utility curves and weighting functions about the interest parties to be involved to the risk. Five considerations during its re-calculation of R into R' can be summarized as followings in practice.

- temporal discount : current≒future≒past
- subjectivity of parties : mine≒your≒our≒**their**
- asymmetry of gain and loss : beh. discount
- uncertainty effect : certain risk≒uncertain risk
- conditional prob. : risk in A≒risk in B

Fig. 3. Five basic considerations to Revised Risk

The calculations may be trivial after obtaining the base curves. 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 surveys, observations, and experiments on the risk behavior. (2019 Lee)

For example the risk of more-than one unit of NPPs can neither be simple-additive from the one unit risk nor considerable with Boolean logics about the redundancies and dependencies among the equipments (2019 Jung) and HOFs (2019 Kim) any more if MUPSA/PRA is intended to represent the perceived risk.

p(/U1*/U2*/U3) = 1 - p(U1 + U2 + U3)

- p(U1*/U2*/U3) = p(U1) - p(U1*U2) - p(U1*U3) + p(U1*U2*U3) = p(U1) - p(U1*U2 + U1*U3)
- p(/U1*U2*/U3) = p(U2) - p(U1*U2) - p(U2*U3) + p(U1*U2*U3) = p(U2) - p(U1*U2 + U2*U3)
- p(/U1*/U2*U3) = p(U3) - p(U1*U3) - p(U2*U3) + p(U1*U2*U3) = p(U3) - p(U1*U3 + U2*U3)
- p(U1*U2*/U3) = p(U1*U2) - p(U1*U2*U3)
- p(U1*/U2*U3) = p(U1*U3) - p(U1*U2*U3)
- p(/U1*U2*U3) = p(U2*U3) - p(U1*U2*U3)
- p(U1*U2*U3) = p(U1*U2*U3)

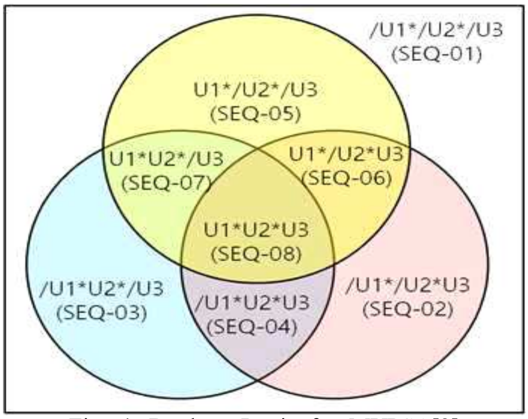

Fig. 4. Boolean Logic for MUPSA[2]

The concept of *marginal risk* applied already in economics may show the basic concerns of public to the multi-unit NPPs comparing a single unit NPP. Though the perceived risk of existing NPPs has remained no-concern under the marginal limit, however, the aggregated risk of multi-unit NPPs may give rise a uproar to the public. The risk is neither continuous nor simple-additive any more during MUPRA/PSA.

The measure of *risk premium* applied already in insurances and finances can be adopted to measure the discrepancy between the calculated risk and the perceived one by easily obtaining 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 = $Loss_{Expected}$ − $Cost_{Paid}$
✓ Loss $_{Expected}$: amount calculated by data ✓ Cost $_{Paid}$: total amount paid for the risk

The quantified value of risk premium can help to explain the discrepancies and understand the positions among the interest parties settled in risk communications. Additionally, it can reveal the differences among the groups and according to the types and detail items of risk. It also can trace the changes according to the time-line and behavior of various variables influencing to the risk premium. A surrogate variable can be selected to interrupt the changes among the influencing factors and the risk premium.

5. DISCUSSIONS AND CONCLUSIONS

The considerations for the representation of perceived risk from the traditional concept of risk are proposed based on mainly the behavioral science perspective. The new revised risk concept 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. The five considerations on the risk calculation and the new measures such as marginal risk and risk premium are proposed. They may result into the changes to the assessment process to MUPRA/PSA rather than the calculation if it intended to enhance the risk communications and public acceptance in practice after Fukushima accident.

The two measures of *Marginal Risk* and *Risk Premium* are proposed to help to capture the differences among risk perspectives on MUPRA/PSA, and to compromise during risk communications and risk decision makings. They will work in practice only when the details on the base data in nuclear are to be obtained by further studies and application projects. It might help to update the current positions on the risk of multi-unit project and to find some surrogate variables to resolve the discrepancy among interest parties.

The proposed concept of risk can be implemented for MUPRA/PSA only with postulated conversion functions of the loss and the probability into the utility and decision weight for representing public perceptions about NPPs. Base data and curves for them can be incorporated further especially in case of big data techniques.

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