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# Safety Principles Revisited to Identify AI Applications to Nuclear Industry

Hyeonil Kim [a*], Seung Geun Kim[b], Yong Gyun Yoo [b]
[a] *Korea Atomic Energy Research Institute, Versatile Reactor Technology Development Div.,*
*111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon*
[b] *Korea Atomic Energy Research Institute, Artificial Intelligence Application & Strategy Team,*
*111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon*

[*] *Corresponding author: hyeonilkim@kaeri.re.kr*

## 1. Introduction

Artificial Intelligence (AI) is not a new technology in industries any more. AI gives productivity in business such as smart phones, entertainment, financials, and so on. Being selected as a promising tool for handling space shuttles and submarines, which is critical to viability, AI is.

Strictly speaking, using a terminology, AI, is misleading us into thinking that intelligence is realized in a machine for science and technology. This can give a strong negative view that AI cannot be used or is of no use especially in nuclear industry, supported by rigidly established rules and regulation, because of the prejudice about the intelligence. Since the term, AI, is broadly used even if it is meant to be data-driven computational science such as deep learning and machine learning in reality, it is also used in this paper keeping in mind that AI means to be data-driven approaches facilitating uncertainty quantification, optimization, automation, decision support, solution acceleration, design, etc.

AI is a somewhat new tool in nuclear industry and the expectation for AI is different from other industries: trigger innovation phase for nuclear industry and slope of enlightenment phase for aerospace and automotive, and productivity for SMART phones, for instances. Moreover, AI is still changing fast and wide in a flood of information in science and technology as well as global business environments. Thus a well-organized approach is necessary to identify what applications should be handled by using AI and what requirements on AI should be imposed for using AI in nuclear industry.

We revisited, therefore, to the safety principles [1-2] with interrelationship to the fundamental concepts of defense in depth (DID) and safety culture. Both the specific safety principles and defense in depth concept can give a good guideline such that performance and safety of nuclear facilities and activities including nuclear power plants over lifetime can be fulfilled in a comprehensive and systematic manner. This will be used as a basis for constructing strategy of AI applications to nuclear industry.

## 2. Challenge and Change to Nuclear Industry

Nuclear reactors need to increase safety and decrease cost. For instance, UK nuclear sector deal calls for 30% reduction in the cost of new build projects by 2030. Only 57% of projects finish within their initial budgets and probability of delivering a major project on time, cost and benefits is only 0.5%. 95% of project data is not used (used once then never used again). AI could deliver a 10% increase in UK GDP in 2030 [3]. This means that it is necessary to transform how we use data not just only for specifically designing a thing but also for managing a project to design the thing.

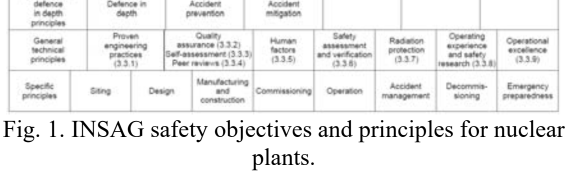
Industry 4.0, which can be found about 700 million searches on Google, is revolutionizing the way companies manufacture, improve and distribute their products throughout their operations due to increasing interconnectivity and smart automation. This change will give a much higher standard and demand on efficiency and effectiveness by a set of integrated knowledge based on digital transformation over all related fields. To nuclear industry this is not exceptional.

The challenge and the change to nuclear industry definitely implies a direction that cost should be the first goal to a product/project and the product/project should be well managed with a set of integrated knowledge over lifetime.

## 3. Safety Principles Revisited

Safety principles are revisited to identify AI(data-driven) applications to nuclear industry such that research and development programs be in the line of the direction.

The structure and the categorization of safety objectives and principles applicable to nuclear plants, expressed in a technologically neutral way, are summarized as shown in Figure 1 [1].



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|---|---|---|---|---|---|---|---|---|
| Objectives | General nuclear safety objective | Radiation protection objective | Technical safety objective | | | | | |
| Fundamental safety management principles | Safety culture | Responsibility of operating organization | Regulatory control and verification | | | | | |
| Fundamental defence in depth principles | Defence in depth | Accident prevention | Accident mitigation | | | | | |
| General technical principles | Proven engineering practices (3.3.1) | Quality assurance (3.3.2) Self-assessment (3.3.3) Peer reviews (3.3.4) | Human factors (3.3.5) | Safety assessment and verification (3.3.6) | Radiation protection (3.3.7) | Operating experience and safety research (3.3.8) | Operational excellence (3.3.9) | |
| Specific principles | Siting | Design | Manufacturing and construction | Commissioning | Operation | Accident management | Decommis-sioning | Emergency preparedness |

Fig. 1. INSAG safety objectives and principles for nuclear plants.

Figure 2 is a conceptual framework for the specific safety principles showing their interrelationship to the fundamental concepts of defense in depth(DID) and safety culture for realizing safety objectives as shown in Fig. 1. From top to bottom on the left hand side of Figure 2, all the principles are related to the levels of defense, whose detail are shown in Table 1, in order of increasing threat to safety, from normal operation to off-site and emergency response, indicating the provisions in design and operation that need to be made to address the challenges a plant could face. The horizontal order of the specific safety principles indicates their application during the main stages of a nuclear project, from its beginning to the end of plant lifetime as follows:

- Siting
- Design
- Manufacturing and construction
- Commissioning
- Operation
- Accident management
- Decommissioning
- Emergency preparedness.

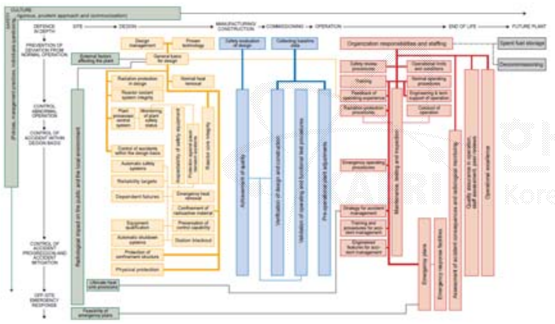

Fig. 2. Schematic presentation of the INSAG specific safety principles showing their coherence and their interrelations.

Table I: Levels of Defense in depth in existing plants.

| Levels | Objective | Essential means |
|---|---|---|
| Level 1 | Prevention of abnormal operation and failures | Conservative design and high quality in construction and operation |
| Level 2 | Control of abnormal operation and detection of failures | Control, limiting and protection systems and other surveillance features |
| Level 3 | Control of accidents within the design basis | Engineered safety features and accident procedures |
| Level 4 | Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents | Complementary measures and accident management |
| Level 5 | Mitigation of radiological consequences of significant releases of radioactive materials | Off-site emergency response |

For instance, a design can be enhanced by:

- DID Level 1: reducing uncertainties using data, improving quality in construction using projects data, improving quality in operation supported by data,
- DID Level 2: reducing off-normal conditions by anomaly detection by data-driven decision support, strengthening preventive maintenance by data-driven aging management,
- DID Level 3: reducing uncertainties using data, improving quality in operation supported by data
- DID Level 4: reducing uncertainties using data, improving quality in operation supported by data
- DID Level 5: improving quality in response by using integrated information around a region or regions

## 4. Conclusions

A feasible set of solutions to meet the challenge and change around nuclear industry can be prepared by integrating information over the life cycle of nuclear products based on digital transformation supported by a new promising technology, artificial intelligence (data-driven things) [4]. The first thing to do was to revisit the safety principles. Each contribution of the specific safety principles to cost and management is, however, not clearly known. Thus it is necessary to devise an index to express cost and asset management of a nuclear facility.

## ACKNOWLEDGMENTS

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