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Edition 1.0 2023-05

TECHNICAL REPORT

colour inside

Nuclear facilities – Instrumentation and control, and electrical power systems – Artificial Intelligence applications



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IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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Nuclear facilities – Instrumentation and control, and electrical power systems – Artificial Intelligence applications

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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NUCLEAR FACILITIES – INSTRUMENTATION AND CONTROL, AND ELECTRICAL POWER SYSTEMS – ARTIFICIAL INTELLIGENCE APPLICATIONS

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IEC TR 63468 has been prepared by subcommittee 45A: Instrumentation, control and electrical power systems of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
45A/1458/DTR	45A/1472/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

a) Technical background, main issues and organization of the technical report

Artificial intelligence(AI) is transforming many fields including nuclear industry drastically. It has been explored and deployed for many years in the nuclear industry and recent advances in AI have enabled many more potentials. Wide adoption of AI calls for standardization efforts to minimize the risks and optimize the efficiency in developing and deploying AI applications. Due to its nature as an enabling technology, the topic of AI applications will cross-cut with almost all working groups within SC 45A, which entails discussions on the setting up of a new working group to dedicate to this new technical field.

This technical report overviews AI technologies from a nuclear perspective, and summaries potential AI application scenarios in nuclear facilities. Based on these inputs, a three-tiered structure for nuclear AI standards within the framework of SC 45A is proposed, and development priorities are discussed. This document then moves on from technical discussions to the organizational challenges in SC 45A. It analyses the cross-cutting nature of AI applications in nuclear facilities and makes the recommendation the setting-up a new working group, whose title and scope are also proposed. Possibility of SC 45A liaison with other technical subcommittees is explored and recommendation is given accordingly.

b) Situation of the current technical report in the structure of the IEC SC 45A standard series

The technical report IEC TR 63468 is a fourth level IEC SC 45A document. This document overviews the fundamentals of artificial intelligence (AI) and its potential applications in nuclear facilities to foster better understanding and adoption of AI technologies within such facilities. It also proposes a structure for future SC 45A standard series on nuclear AI applications.

For more details on the structure of the SC 45A standard series, see item d) of this introduction.

c) Recommendations and limitations regarding the application of this technical report

This document is the first of its kind within SC 45A, intended to pave the road for extensive and systematic efforts in the standard development activities with regard to AI applications. It helps stakeholders to understand the main benefits and challenges of AI from a nuclear perspective. More documents are expected to follow in this direction in the coming years.

It is important to note that a technical report is entirely informative in nature, and it establishes no requirements.

d) Description of the structure of the IEC SC 45A standard series and relationships with other IEC documents and other bodies documents (IAEA, ISO)

The IEC SC 45A standard series comprises a hierarchy of four levels. The top-level documents of the IEC SC 45A standard series are IEC 61513 and IEC 63046.

IEC 61513 provides general requirements for instrumentation and control (I&C) systems and equipment that are used to perform functions important to safety in nuclear power plants (NPPs). IEC 63046 provides general requirements for electrical power systems of NPPs; it covers power supply systems including the supply systems of the I&C systems.

IEC 61513 and IEC 63046 are to be considered in conjunction and at the same level. IEC 61513 and IEC 63046 structure the IEC SC 45A standard series and shape a complete framework establishing general requirements for instrumentation, control and electrical power systems for nuclear power plants.

IEC 61513 and IEC 63046 refer directly to other IEC SC 45A standards for general requirements for specific topics, such as categorization of functions and classification of systems, qualification, separation, defence against common cause failure, control room design, electromagnetic compatibility, human factors engineering, cybersecurity, software and hardware aspects for programmable digital systems, coordination of safety and security requirements and management of ageing. The standards referenced directly at this second level should be considered together with IEC 61513 and IEC 63046 as a consistent document set.

At a third level, IEC SC 45A standards not directly referenced by IEC 61513 or by IEC 63046 are standards related to specific requirements for specific equipment, technical methods, or activities. Usually these documents, which make reference to second-level documents for general requirements, can be used on their own.

A fourth level extending the IEC SC 45 standard series, corresponds to the Technical Reports which are not normative.

The IEC SC 45A standards series consistently implements and details the safety and security principles and basic aspects provided in the relevant IAEA safety standards and in the relevant documents of the IAEA nuclear security series (NSS). In particular this includes the IAEA requirements SSR-2/1 , establishing safety requirements related to the design of nuclear power plants (NPPs), the IAEA safety guide SSG-30 dealing with the safety classification of structures, systems and components in NPPs, the IAEA safety guide SSG-39 dealing with the design of instrumentation and control systems for NPPs, the IAEA safety guide SSG-34 dealing with the design of electrical power systems for NPPs, the IAEA safety guide SSG-51 dealing with human factors engineering in the design of NPPs and the implementing guide NSS42-G for computer security at nuclear facilities. The safety and security terminology and definitions used by the SC 45A standards are consistent with those used by the IAEA.

IEC 61513 and IEC 63046 have adopted a presentation format similar to the basic safety publication IEC 61508 with an overall life-cycle framework and a system life-cycle framework. Regarding nuclear safety, IEC 61513 and IEC 63046 provide the interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. In this framework, IEC 60880, IEC 62138 and IEC 62566 correspond to IEC 61508-3 for the nuclear application sector.

IEC 61513 and IEC 63046 refer to ISO 9001 as well as to IAEA GSR part 2 and IAEA GS-G-3.1 and IAEA GS-G-3.5 for topics related to quality assurance (QA).

At level 2, regarding nuclear security, IEC 62645 is the entry document for the IEC/SC 45A security standards. It builds upon the valid high level principles and main concepts of the generic security standards, in particular ISO/IEC 27001 and ISO/IEC 27002; it adapts them and completes them to fit the nuclear context and coordinates with the IEC 62443 series. At level 2, IEC 60964 is the entry document for the IEC/SC 45A control rooms standards, IEC 63351 is the entry document for the human factors engineering standards and IEC 62342 is the entry document for the ageing management standards.

NOTE 1 It is assumed that for the design of I&C systems in NPPs that implement conventional safety functions (e.g. to address worker safety, asset protection, chemical hazards, process energy hazards) international or national standards would be applied.

NOTE 2 IEC TR 64000 provides a more comprehensive description of the overall structure of the IEC SC 45A standards series and of its relationship with other standards bodies and standards.

NUCLEAR FACILITIES – INSTRUMENTATION AND CONTROL, AND ELECTRICAL POWER SYSTEMS – ARTIFICIAL INTELLIGENCE APPLICATIONS

1 Scope

This document overviews the fundamentals of artificial intelligence (AI) as it could potentially be applied within nuclear facilities and identifies proven or potential applications, with the objective to foster better understanding and adoption of AI technologies within such facilities. With the objective of supporting future standard development work of IEC SC 45A in this technical area, this document takes the initiative to propose a structure for SC 45A standard series on nuclear AI applications, and recommends setting up a new dedicated working group to be responsible for and coordinate standard development efforts in this particular area, taking into account its cross-cutting nature.

As some technical aspects of AI are still evolving, and the regulatory framework from nuclear regulators is not yet established, this document focuses on AI applications in nuclear facilities that are non-safety related. However, this approach does not necessarily exclude the applicability of AI technologies in safety applications in nuclear facilities where the technology itself and the related regulatory framework support such potentials.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61513, *Nuclear power plants – Instrumentation and control important to safety - General requirements for systems*

IEC 63046, *Nuclear power plants – Electrical power system – General requirements*

IEC TR 63400, *Nuclear facilities – Instrumentation, control and electrical power systems important to safety – Structure of the IEC SC45A standards series*

ISO/IEC 22989:2022, *Information technology – Artificial intelligence – Artificial intelligence concepts and terminology*

ISO/IEC 23053, *Framework for Artificial Intelligence (AI) Systems Using Machine Learning (ML)*

ISO/IEC TR 29119-11, *Software and systems engineering – Software testing – Part 11: Guidelines on the testing of AI-based systems*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
artificial intelligence
AI
research and development of mechanisms and applications of AI systems

Note 1 to entry: This definition is further expanded in Clause 5 of ISO/IEC 22989.

Note 2 to entry: For the purpose of this document, this definition can be supplemented by the definition given in Wikipedia, where Artificial Intelligence is defined as “intelligence—perceiving, synthesizing, and inferring information—demonstrated by machines, as opposed to intelligence displayed by animals and humans”.

[SOURCE: ISO/IEC 22989:2022, 3.1.3]

3.2
artificial intelligence system
AI system
engineered system that generates outputs such as content, forecasts, recommendations or decisions for a given set of human-defined objectives

[SOURCE: ISO/IEC 22989:2022, 3.1.4]

3.3
autonomy
autonomous
characteristic of a system that is capable of modifying its operating domain or goal without external intervention, control or oversight

[SOURCE: ISO/IEC 22989:2022, 3.1.5]

3.4
automatic
automation
automated
pertaining to a process or system that, under specified conditions, functions without human intervention

[SOURCE: ISO/IEC 22989:2022, 3.1.7]

3.5
Bayesian network
probabilistic model that uses Bayesian inference for probability computations using a directed acyclic graph

[SOURCE: ISO/IEC 22989:2022, 3.3.1]

3.6
continuous learning
continual learning
lifelong learning
incremental training of an AI system that takes place on an ongoing basis during the operation phase of the AI system life cycle

[SOURCE: ISO/IEC 22989:2022, 3.1.9]

3.7
data mining
computational process that extracts patterns by analyzing quantitative data from different perspectives and dimensions, categorizing them, and summarizing potential relationships and impacts

[SOURCE: ISO 16439:2014, 3.13, modified – “identifies” has been replaced by “extracts”]

3.8
data sampling
process to select a subset of data samples intended to present patterns and trends similar to that of the larger dataset being analyzed

Note 1 to entry: Ideally, the subset of data samples will be representative of the larger dataset.

[SOURCE: ISO/IEC 22989:2022, 3.2.4]

3.9
dataset
collection of data with a shared format

Note 1 to entry: Datasets can be used for validating or testing an AI model. In a machine learning context, datasets can also be used to train a machine learning algorithm.

[SOURCE: ISO/IEC 22989:2022, 3.2.5]

3.10
decision tree
model for which inference is encoded as paths from the root to a leaf node in a tree structure

[SOURCE: ISO/IEC 22989:2022, 3.3.2]

3.11
declarative knowledge
knowledge represented by facts, rules and theorems

Note 1 to entry: Usually, declarative knowledge cannot be processed without first being translated into procedural knowledge.

[SOURCE: ISO/IEC 22989:2022, 3.1.12]

3.12
deep learning
deep neural network learning
<artificial intelligence> approach to creating rich hierarchical representations through the training of neural networks with many hidden layers

Note 1 to entry: Deep learning is a subset of ML.

[SOURCE: ISO/IEC 22989:2022, 3.4.4]

3.13
expert system
AI system that accumulates, combines and encapsulates knowledge provided by a human expert or experts in a specific domain to infer solutions to problems

[SOURCE: ISO/IEC 22989:2022, 3.1.13]

3.14
general AI
artificial general intelligence
AGI
type of AI system that addresses a broad range of tasks with a satisfactory level of performance

Note 1 to entry: Compared to narrow AI.

Note 2 to entry: AGI is often used in a stronger sense, meaning systems that not only can perform a wide variety of tasks, but all tasks that a human can perform.

[SOURCE: ISO/IEC 22989:2022, 3.1.14]

3.15
label
target variable assigned to a sample

[SOURCE: ISO/IEC 22989:2022, 3.2.10]

3.16
life cycle
evolution of a system, product, service, project or other human-made entity, from conception through retirement

[SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.23]

3.17
long-short-term-memory network
LSTM
type of neural network that processes sequential data with a satisfactory performance for both long and short span dependencies

[SOURCE: ISO/IEC 22989:2022, 3.4.7, modified – “long-short-term” has been replaced by “long-short-term-memory”]

3.18
machine learning
ML
process of optimizing model parameters through computational techniques, such that the model's behavior reflects the data or experience

[SOURCE: ISO/IEC 22989:2022, 3.3.5]

3.19
machine learning model
mathematical construct that generates an inference, or prediction, based on input data or information

[SOURCE: ISO/IEC 22989:2022, 3.3.7]

3.20
model
physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, process or data

[SOURCE: ISO/IEC 18023-1:2006, 3.1.11, modified –"or data" added]

3.21
narrow AI
type of AI system that is focused on defined tasks to address a specific problem

Note 1 to entry: Compared to general AI.

[SOURCE: ISO/IEC 22989:2022, 3.1.24]

3.22
neural network
neural net
artificial neural network
NN
network of one or more layers of neurons connected by weighted links with adjustable weights, which takes input data and produces an output

Note 1 to entry: Neural networks are a prominent example of the connectionist approach.

Note 2 to entry: Although the design of neural networks was initially inspired by the functioning of biological neurons, most works on neural networks do not follow that inspiration anymore.

[SOURCE: ISO/IEC 22989:2022, 3.4.8]

3.23
prediction
primary output of an AI system when provided with input data or information

Note 1 to entry: Predictions can be followed by additional outputs, such as recommendations, decisions and actions.

Note 2 to entry: Prediction does not necessarily refer to predicting something in the future.

Note 3 to entry: Predictions can refer to various kinds of data analysis or production applied to new data or historical data (including translating text, creating synthetic images or diagnosing a previous power failure).

3.24
reinforcement learning
RL
earning of an optimal sequence of actions to maximize a reward through interaction with an environment

[SOURCE: ISO/IEC 22989:2022, 3.1.27]

3.25
sample
atomic data element processed in quantities by a machine learning algorithm or an AI system

[SOURCE: ISO/IEC 22989:2022, 3.2.13]

3.26
semi-supervised machine learning
machine learning that makes use of both labelled and unlabelled data during training

[SOURCE: ISO/IEC 22989:2022, 3.3.11]

3.27
sub-symbolic AI
AI based on techniques and models that use an implicit encoding of information, that can be derived from experience or raw data.

Note 1 to entry: Compared to symbolic AI. Whereas symbolic AI produces declarative outputs, sub-symbolic AI is based on statistical approaches and produces outputs with a given probability of error.

[SOURCE: ISO/IEC 22989:2022, 3.1.34]

3.28
supervised machine learning
machine learning that makes use of labelled data during training

[SOURCE: ISO/IEC 22989:2022, 3.3.12]

3.29
symbolic AI
AI based on techniques and models that manipulate symbols and structures according to explicitly defined rules to obtain inferences

Note 1 to entry: Compared to sub-symbolic AI, symbolic AI produces declarative outputs, whereas sub-symbolic AI is based on statistical approaches and produces outputs with a given probability of error.

[SOURCE: ISO/IEC 22989:2022, 3.1.33]

3.30
test data
evaluation data
data used to assess the performance of a final model

Note 1 to entry: Test data is disjoint from training data and validation data.

[SOURCE: ISO/IEC 22989:2022, 3.2.14]

3.31
training
model training
process to establish or to improve the parameters of a machine learning model, based on a machine learning algorithm, by using training data

[SOURCE: ISO/IEC 22989:2022, 3.3.15]

3.32
unsupervised machine learning
machine learning that makes only use of unlabelled data during training

[SOURCE: ISO/IEC 22989:2022, 3.3.17]

3.33
validation data
development data
data used to compare the performance of different candidate models

Note 1 to entry: Validation data is disjoint from test data and generally also from training data. However, in cases where there is insufficient data for a three-way training, validation and test set split, the data is divided into only two sets – a test set and a training or validation set. Cross-validation or bootstrapping are common methods for then generating separate training and validation sets from the training or validation set.

Note 2 to entry: Validation data can be used to tune hyper-parameters or to validate some algorithmic choices, up to the effect of including a given rule in an expert system.

[SOURCE: ISO/IEC 22989:2022, 3.2.15]

4 Abbreviated terms

AI	Artificial Intelligence
BWR	Boiling Water Reactor
CAP	Corrective Action Program
CFD	Computational Fluid Dynamics
CNN	Convolutional Neural Network
CRDM	Control Rod Drive Mechanism
CV	Computer Vision