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Automation systems and integration — Industrial data — Nuclear digital ecosystem specifications

Systèmes d'automatisation et intégration — Données industrielles — Spécifications de l'écosystème numérique nucléaire

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Foreword

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This document was prepared by Technical Committee ISO/TC *184*, *Automation systems and integration*, Subcommittee SC 04 *Industrial data*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of this document is to bring all current knowledge together about standardization of information on nuclear installations in the nuclear industry.

This document provides orientations for how the concept of an industrial digital ecosystem can be realised for the nuclear industry, its installations and practices. These orientations are based on surveys of the state of the art for the adoption of digital methods and technology for the nuclear sectors by the participating members of ISO/TC 184/SC 4 and a review of the current state of the standards for the digital representation of engineering data that are the responsibility of ISO/TC 184/SC 4 and international standards from other TCs/SCs from ISO, IEC, CEN and some de-facto international industry standards.

The objective is to provide the nuclear industry with a common framework to address the intertwined aspects to manage digital information based on standards and related to nuclear facilities and materials.

The nuclear facilities are composed of all the physical structures, systems, and components: mining, fuel manufacturing, nuclear material transport, nuclear power plants (NPPs), reprocessing plants, waste management and disposal facilities.

This document aims to support operational processes in a nuclear ecosystem using digital tools to produce, manage and share information.

It is based on the experience and skills of experts with generic competencies in standards for industrial data, developed during the past years in the edition of standards for product modelling, plant modelling and construction modelling associated with some specific experience of some members in nuclear facilities lifecycle, the corresponding information and records management in the lifecycle.

This document will be updated when new technological advances become available, as many initiatives in the field of the "Industry of the future" are underway, the most relevant of which is the development of the digital twin (DT). The corresponding outcomes can be integrated in a viable roadmap with steps to effectively guide practitioners of the nuclear ecosystem in implementing methodologies and technologies to make effective the benefit of the proposed standards.

This document does not provide answers to all of the issues but does raise questions and identifies barriers for successful implementation which will be addressed to create a digital ecosystem in the nuclear industry. It does provide a simple conceptual framework and a roadmap to guide the actors of the nuclear ecosystem.

To consolidate this perspective, this document has taken into account nuclear technology and the constraints on the nuclear industry. Developing a standardization framework for the nuclear industry could also be useful in order to face long standing issues met in conventional industries regarding information management.

Radioactivity structures all of the activities in the nuclear industry and strongly impacts the needs and the way of modelling facilities and of organising information to support the business processes.

Innovation and standardization will enable a nuclear digital ecosystem (NDE), which could be downsized for conventional industries with specific lighter requirements.

This methodology offers the best guarantee to meet the specific needs of a nuclear ecosystem and to reuse generic models, relationships, and standards already available or prepare their adaptation or extension for the future.

Automation systems and integration — Industrial data — Nuclear digital ecosystem specifications

1 Scope

This document provides:

— a review and summary of the adoption of digital methods and technology in the national nuclear sectors;

— a summary of the state of the art of some of the standards supporting the digital representation and interoperability of industrial data;

— orientation on the use of these standards for model-based systems engineering (MBSE) in order to achieve a nuclear digital ecosystem (NDE);

— a high-level roadmap of the stages by which this ecosystem can be achieved, taking into account the maturity of the actors of the ecosystem, their relationships and the added value of using advanced standards.

NOTE The complete reports from the participating entities are presented in Annexes A to G.

This document includes the following:

— the systems composing the nuclear facilities and their input, output, and other products resulting from interactions in the nuclear system or with its environment;

— the material accounting and the corresponding requirements;

— waste management: all types of nuclear waste produced during processes and activities, and their properties are considered for a seamless management of information in the whole value chain of the nuclear ecosystem.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 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:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
asset
item, thing or entity that has potential or actual value to an organization

[SOURCE: ISO/TS 18101:2019]

3.1.2
information
knowledge concerning objects, such as facts, events, things, *processes* (3.1.13), or ideas, including concepts, that within a certain context has a particular meaning

[SOURCE: ISO/IEC 2382:2015, 2121271, modified — Field of application and notes to entry have been removed]

3.1.3
data
reinterpretable representation of *information* (3.1.2) in a formalized manner suitable for communication, interpretation, or processing

[SOURCE: ISO/IEC 2382:2015, 2121272, modified — Notes to entry have been removed]

3.1.4
data element
member of a *data set* (3.1.5)

3.1.5
data set
logically meaningful group of data

[SOURCE: ISO/TS 18101-1:2019]

3.1.6
data quality
degree to which a set of inherent characteristics of data fulfils requirements

Note 1 to entry: Examples of requirements for quality data also include data integrity, data validation, data portability, data synchronization and the data provenance record.

[SOURCE: ISO 8000-2:2022, 3.8.1, modified — Note 1 to entry has been modified.]

3.1.7
digital ecosystem
distributed, adaptive, open, socio-technical system with properties of self-organisation, scalability and sustainability inspired from natural ecosystems

[SOURCE: ISO/TS 18101-1:2019]

3.1.8
digital representation
manner in which information is stored for interpretation by a machine

[SOURCE: ASME Y 14.47 – 2019]

3.1.9
domain
field of special knowledge, which can be further subdivided according to requirements to support a higher level of specialized detail

[SOURCE: ISO/TS 18101-1:2019]

3.1.10
information model
formal model of a bounded set of facts, concepts or instructions to meet a specified requirement

Note 1 to entry: In this context, the description of *domain* (3.1.9) entities in a *digital ecosystem* (3.1.7) addressing lifecycle *asset* (3.1.1) management.

[SOURCE: ISO/TS 18101-1:2019]

3.1.11
interoperability
capability of two or more entities to exchange items in accordance with a set of rules and mechanisms implemented by an interface in each entity, order to perform their specific tasks

Note 1 to entry: Examples of entities include devices, equipment, machines, people, processes, applications, computer firmware and application software units, data exchange *systems* (3.1.17) and enterprises.

Note 2 to entry: Examples of items include services information, material in standards, design documents and drawings, improvement projects, energy reduction programs, control activities, *asset* (3.1.1) description and ideas.

Note 3 to entry: In this context, entities provide items to, and accept items from, other entities, and they use the items exchanged in this way to enable them to operate effectively together.

[SOURCE: ISO/TS 18101-1:2019]

3.1.12
nuclear digital ecosystem
NDE
digital ecosystem (3.1.7) specialised for application to nuclear power facilities and related activities

Note 1 to entry: The objective is to provide principles, methodologies and technologies to enable sharing of shared resources across nuclear industry and beyond, and their specialization in each specific domain and discipline.

Note 2 to entry: There is a trend to name these shared resources "Commons"

3.1.13
process, noun
set of interrelated or interacting activities that use inputs to deliver an intended result

[SOURCE: ISO 9000:2015, 3.4.1, modified — Notes to entry have been removed.]

3.1.14
property
named measurable or observable attribute, quality or characteristic of a system

3.1.15
reference data library
RDL
managed collection of reference data

[SOURCE: ISO 15926-1:2004]

3.1.16
requirement
need or expectation that is stated, generally implied or obligatory

[SOURCE: ISO 9000:2015, 3.6.4, modified — Notes to entry have been removed.]

3.1.17
system
combination of interacting elements organized to achieve one or more stated purposes

Note 1 to entry: A system is sometimes considered as a product or as the services it provides.

Note 2 to entry: In practice, the interpretation of its meaning is frequently clarified by the use of an associative noun, e.g. aircraft system. Alternatively, the word "system" is substituted simply by a context-dependent synonym, e.g. aircraft, though this potentially obscures a system principles perspective.

Note 3 to entry: A complete system includes all of the associated equipment, facilities, material, computer programs, firmware, technical documentation, services and personnel required for operations and support to the degree necessary for self-sufficient use in its intended environment.

Note 4 to entry: A system is also interacting with its environment.

3.1.18
system element
member of the combination of elements that constitutes a *system* (3.1.17)

3.2 Abbreviated terms

AI	artificial intelligence
ALARA	as low as reasonably achievable
ANN	artificial neural network
APR	advanced pattern recognition
BIM	building information model (see ISO 16739-1)
BWR	boiling water reactor
CAD	computer aided design
CAE	computer aided engineering
CDE	common data environment
CDF	core damage frequency
CFIHOS	Capital Facilities Information Handover Specification
CM	configuration management
CNS	Convention on Nuclear Safety
DMS	document management system
DT	digital twin
EAM	enterprise asset management
EPC	engineering, procurement and construction
ERP	enterprise resource planning
eSOMS	electronic shift operations management system
ESPN	nuclear pressure equipment (equipement sous pression nucléaire)
FAIR	findable, accessible, interoperable end reusable
HLW	high-level waste
HVAC	heating, ventilation and air conditioning
ISDC	International Structure for Decommissioning Costs (ISDC) of the OECD
IAEA	International Atomic Energy Agency
IFC	industry foundation classes (see ISO 16739-1)
IIoT	industrial internet of things

IVV	integration, verification and validation
K-PIM	knowledge-centric plant information model
LD	linked data
LLW	low-level waste
LOTAR	long term archiving
LTKR	long term knowledge retention
MBSE	model-based systems engineering
MR	micro reactor
NIST	National Institute of Standards and Technology (USA)
NLP	natural language processing
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission (USA)
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OO	owner and operator
O&M	operations and maintenance
PIM	plant information model
PLM	product lifecycle management plant lifecycle management
PWR	pressurized water reactor
RDF	resource description framework
RDL	reference data library
SMR	small modular reactor
SNF	spent nuclear fuel
SSC	structure system component
SSoT	single source of truth
SW	semantic web
WANO	World Association of Nuclear Operators
WBS	work breakdown structure

4 Overview of the nuclear industry

4.1 Nuclear fuel cycle

The nuclear industry can be analysed starting with the fuel cycle,[1] and includes all activities from the uranium mining, fuel fabrication, construction of the nuclear installations, O&M of the nuclear installations, decommissioning, fuel reprocessing, waste management and waste disposal.

Whilst reprocessing of nuclear fuel is possible, with facilities to manage the valuable material and the waste produced during the whole fuel cycle, which prefigures a circular economy, it is currently not regularly practiced in a large fraction of the world's NPP fleet.

An integrated management of the data produced during all the fuel cycle and in all the facilities involved in this cycle will bring a clear added value.

The lack of interoperability of data along this cycle is conservatively estimated from 1 % to 3 % of the cost of investment of all of these facilities.[2] At an international level, this represents tens of billions of Euros. Data interoperability and traceability is moreover a regulatory requirement for the nuclear industry.

With the extended use of digital tools at every step of the cycle, it is of the utmost importance that standards support the interoperability of data which must be accessible for reuse for time spans of more than 100 years.

Sharing a global understanding of the situation of the nuclear industry as a system of systems is key.

Systems engineering combined with MBSE in a digital environment offer the best available framework of a global understanding.

Standards to support interoperability of the nuclear ecosystem are numerous and various and concern plants, products, buildings, material, fuel, waste and the environment. The governance of these standards is managed locally by subject matter experts to support specific needs of the actors.

4.2 Nuclear power plant (NPP) safety leadership and management

Safety is a critical issue in the nuclear industry, and the prime public concern of the 1986 Chernobyl accident and the 2011 Fukushima I accident confirmed the concerns. This is reflected in IAEA CNS [73]:

— New NPPs are to be designed, sited, and constructed, consistent with the objective of preventing accidents in the commissioning and operation and, should an accident occur, mitigating possible releases of radionuclides causing long-term off-site contamination and avoiding early radioactive releases or radioactive releases large enough to require long-term protective measures and actions.

— Comprehensive and systematic safety assessments are to be carried out periodically and regularly for existing installations throughout their lifetime to identify safety improvements that are oriented to meet the above objective. Reasonably practicable or achievable safety improvements are to be implemented in a timely manner.

— National requirements and regulations for addressing this objective throughout the lifetime of NPPs are to consider the relevant IAEA Safety Standards and, as appropriate, other good practices as identified inter alia in the Review Meetings of the CNS.

Safety in this clause focuses on key radiation-related aspects of NPP O&M safety, namely nuclear safety, radiation protection and radioactive waste management. Safety data is essential for safety management.

When considering safety in relation to nuclear facilities there are a number of different domains to be considered (both nuclear industry specific and general) including: nuclear safety supervision according to regulations and operation license documents, change management of safety justification basis for the license extension (e.g. change of safety related SSCs, change of operating limits and conditions). Nuclear safety inspection requires the recording data of NPP operation Limiting Condition for Operation (LCO), periodic test data related to safety, parameters of safety system, the defect reporting data, etc.

Radiation protection: the goal of NPP radiation protection is to ensure that O&M personnel are exposed to doses below the limits, and to maintain the radiation at reasonable and feasible levels, and to protect the public and the environment. The main work of radiation protection includes radiation work management, radiation dose control, radiation pollution control, radioactive material control, radiation monitoring, all of which require Radiation Work Permit (RWP) data, ALARA, radiographic testing permit, individual dose record, personnel RP (radiation protection) certificate, etc.

Radioactive waste management: The principles of radioactive waste management are radioactive waste minimization and radioactive effluent optimization. Radioactive waste management requires continuous monitoring data of the effluents, the sampling analysis data, etc.

Safety leadership and management requires the involvement and active participation of all parties and benefits from a system engineering approach. The ISO 8000 series is an important standard which helps to improve NPP safety data quality.

IAEA has provided a series of safety standards as well as international cooperation to ensure that high safety performance is attained. All countries with operating NPPs report on the implementation of their obligations under CNS for international peer review. WANO also has programs to help improve safety.

Digital technology has been implemented to help improve NPP safety, as NPP safety management is still largely paper-based. In China, blockchain technology is used for personal exposure data management. In France, a unique collaborative ‘ESPN digital’ platform centralizes safety requirement management for all stakeholders. In the Pallas project in the Netherlands blockchain principles are adopted by means of attaching a digital signature to each digital statement in the project repository [common data environment (CDE)] which defines meta data such as provenance, access rights, confidentiality, and when applicable, the replace chain (history) of each statement (as per ISO/TS 15926-11).

A few data interoperability barriers hinder NPP safety, for example, the lack of an international standard for the safety classification of equipment, as shown in Table 1.

Table 1 — Illustration of the framework for safety management — Source [74]:

<table>
<tr><th colspan="2">Organizations or countries</th><th colspan="6">Safety classification of I&C functions and systems in nuclear plants</th></tr>
<tr><td colspan="8">Main international standards organizations</td></tr>
<tr><td colspan="2" rowspan="3">IAEA safety glossary</td><td colspan="5">Items important to safety</td><td rowspan="5">Items not important to safety</td></tr>
<tr><td rowspan="2">Safety systems</td><td colspan="4">Safety-related items</td></tr>
<tr><td></td><td colspan="3">Safety features (for DEC)</td></tr>
<tr><td rowspan="2">IAEA SSG-30</td><td>Function</td><td>Safety category 1</td><td colspan="3">Safety category 2</td><td>Safety category 3</td></tr>
<tr><td>System</td><td>Safety class 1</td><td colspan="3">Safety class 2</td><td>Safety class 3</td></tr>
<tr><td rowspan="3">EC 61226</td><td></td><td colspan="5">Systems important to safety</td><td>Systems not Important to Safety</td></tr>
<tr><td>I&C function</td><td>Category A</td><td colspan="3">Category B</td><td>Category C</td><td>Non-categorized</td></tr>
<tr><td>I&C system</td><td>Class 1</td><td colspan="3">Class 2</td><td>Class 3</td><td>Non-classified</td></tr>
<tr><td colspan="2" rowspan="2">IEEE</td><td colspan="5">Systems important to safety</td><td rowspan="2">Non-safety-related</td></tr>
<tr><td colspan="3">Safety-related</td><td colspan="2"></td></tr>
<tr><td>EUR</td><td>Safety level of functions / I&C systems</td><td>1</td><td colspan="3">2</td><td>3</td><td>NS
(non-safety)</td></tr>
<tr><td colspan="8">Selected states with nuclear power programs</td></tr>
<tr><td colspan="2">Canada</td><td>Category 1</td><td colspan="3">Category 2</td><td>Category 3</td><td>Category 4</td></tr>
<tr><td colspan="2">China</td><td>F1A</td><td colspan="3">F1B</td><td>F2</td><td>Non-classified</td></tr>
</table>

Table 1 *(continued)*

Finland		Class 2	Class 3	EYT/ STUK	EYT (Classified non-nuclear)
France		Class 1	Class 2	Class 3	Non-classified
Germany	I&C function	Category 1	Category 2	Category 3	Non-classified
	I&C equipment	E1		E2	
India		IA	IB	IC	NINS
Japan		PS1/MS1	PS2/MS2	PS3/MS3	Non-nuclear safety
Korea		IC-1	IC-2	IC-3	Non-classified
Russia	I&C function	Category A	Category B	Category C	Non-categorized
	I&C system	Class 2		Class 3	Class 4 (Systems not important to safety)
South Africa		Level 1 Direct influence on safety performance	Level 2 Products important to nuclear safety	Level 3 All products of the nuclear installation	Non-safety or availability related
Switzerland		1	2	3	Non-classified
UK		Class 1	Class 2	Class 3	Non-classified
USA		System important to safety			(Not specified)
		Safety related			

4.3 Differences between nuclear industry and other industries

The nuclear industry is a modern industry; the first power plant, Calder Hall, in the United Kingdom, opened on 17 October 1956.

Nuclear energy has great potential, considering the increase of electrical power in the future, to satisfy the needs of the global population with low carbon emissions. Nuclear energy is characterized by its compactness: a 1 000 MWe power plant uses 27 tons of enriched uranium per year when an equivalent thermal power plant uses 1 500 000 tons of fossil fuel per year.

The nuclear industry is a capital-intensive industry, which is sensitive to financial costs. Thus, it is key, during the lifecyle of the power plant and nuclear fuel cycle, to share data of quality, reduce the design, construction and commissioning duration and costs as well as the periods of shut down for maintenance and inspection because of the availability of the required data for the actors.

Fission produces heat by splitting fissile material and producing radioactive elements. When storing and handling fissile material, care is required to respect mass and geometric constraints to avoid unexpected chain reactions. The different types of radiation interact with the environment, components of the NPP, the atmosphere which results in specific issues for the reliability of the equipment in an environment with high levels of radiation.

The nuclear industry is a strictly controlled industry with high requirements on the traceability of the materials and of the activities.

There are some limitations on the ability to share information on nuclear topics, especially when this crosses national boundaries as with export control regulations.

The activities linked to safety classified equipment complies with regulations on the information management.

Otherwise, common principles are shared globally through rules and orientations edited by the IAEA. However, national regulations are often specific and there is a lack of international standardization in some domains, e.g. the classification of nuclear waste.

Some forms of fuel cycles are adopted for the economic operation of NPPs, such as MOX fuels, by reprocessing the spent UOX fuels. The amount of the final disposal of the spent nuclear fuel (SNF) and the high-level waste (HLW) differs among which types of fuel cycles are used. Therefore, financial planning is important for the management of SNF and HLW during the NPP operations.[1)]

In the decommissioning phase, there is large amount of low-level waste (LLW) by dismantling NPPs. The cost structure of decommissioning NPPs is well summarised by the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD).[75] In this document, the scope of decommissioning cost estimates among European countries and the US is described and there are differences for estimation items between countries due to the different regulations of each country.

Beyond these specificities, the nuclear industry has commonalities and shares the following common concerns with other industries:

— The initial safety philosophy was partially inherited from the aerospace and chemical industries.

— The nuclear industry uses complex calculation codes and simulation tools similar to other advanced industries.

— Nuclear engineering has developed tools for 3D representation to support the design activities.

— A NPP has mechanical equipment, heat exchanger, piping, air conditioning and other systems with similarities with equipment involved in other process industries.

— Nuclear engineering has commonalities with other process industries, and uses P&IDs, other functional schemas and data sheets as in the oil and gas industry.

— Buildings and concrete for biological protection are important components of a NPP or a fuel reprocessing plant and civil works have strong interaction with process and corresponding equipment with periodic data exchange between the corresponding teams.

— The work breakdown structure (WBS) into the international structure for decommissioning costs (ISDC) format, as summarised by OECD/NEA can be a guidance document for the decommissioning phase of NPPs.

— As for all other industries, the nuclear industry encourages the opportunities brought by use of new information technologies and to organize its digital transformation.

In summary, the nuclear industry brings together various domains of manufacturing, process plants and construction and has an interest in the corresponding standards for industrial data and their interoperability.

5 Review of national reports

5.1 General

Descriptions of the current state of digitization in the nuclear sectors of China, France, Japan, Republic of Korea, the Netherlands, the United Kingdom (UK), and the United States of America (USA) are presented for information. These examples can be regarded as a sample from the 20 participating members and 8 observing members of ISO/TC 85/SC6 (Nuclear energy, nuclear technologies, and radiological protection — Reactor technology). The complete reports are reproduced in Annexes A to G. The degree of digitization varies across the sample. Each country has a strategy to increase the use of digitization to an extent that varies according to the distribution of requirements between new build, operations and maintenance (O&M), and decommissioning. The use of advanced digital methods and software technology is increasing amongst all members of the sample.

1) OECD NEA presentation -- TM on FRs and related FC facilities with improved economics characteristics, Vienna, Austria, 11-13 Sep 2013 (iaea.org).