R&D Project

Utilization of Artificial Intelligence in the Analysis of Nuclear Power Plant Requirements

Santeri Myllynen

2 June 2022

SNETP
Sustainable Nuclear Energy Technology Platform

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Biography Santeri Myllynen

- Fortum 08/2018 ->
  - Specialist, Project Planning
    - Project management-related matters, especially time management and progress assurance
    - A part-time project engineer for Posiva in a final disposal of spent nuclear fuel project
  - Design Engineer (Nuclear Safety Design)
    - Systems and requirements engineering as well as configuration, quality and project management
  - Master's Thesis Worker (08/2018 – 04/2019)
    - Thesis: "Utilization of Artificial Intelligence in the Analysis of Nuclear Power Plant Requirements"
- Summer Trainee positions in nuclear and conventional power industry 2014-2017
    - Substitute Manager, Project Assistant, Quality Intern & Technical Trainee
- Education: Master of Science (M.Sc.), Energy Technology
  - Minor: Nuclear Engineering (Korea Advanced Institute of Science and Technology, KAIST)

Fortum in General

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Strong position to drive the energy transition in Europe

3rd largest
power generator
in Europe and Russia

3rd largest
CO_2-free power
generator in Europe

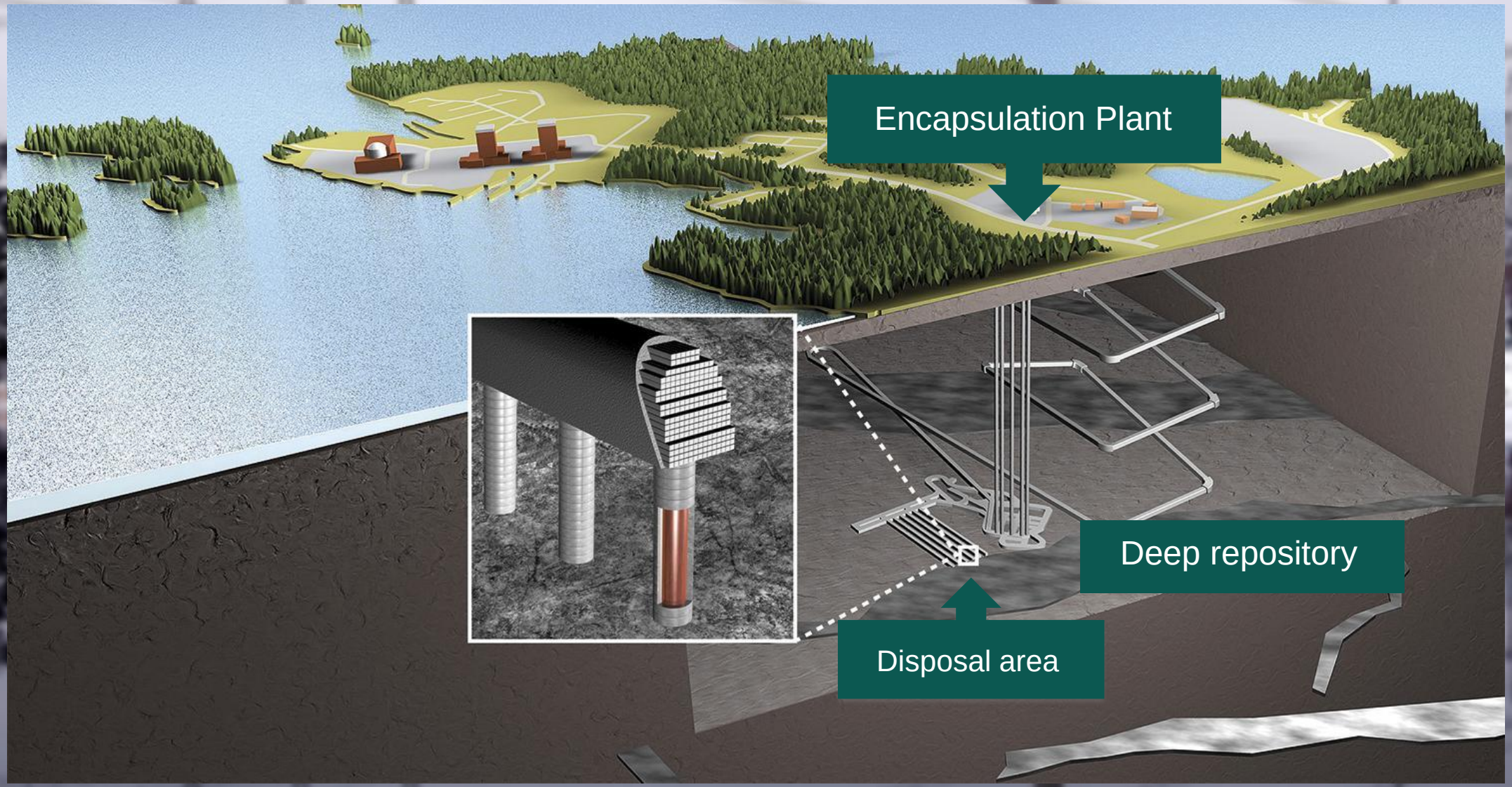
3rd largest
nuclear generator
in Europe

4th largest
gas storage operator
in Europe

Fortum’s and Uniper’s nuclear fleet

Unit	Mwe (net)	Fortum Share %	Uniper Share %
Loviisa 1 Loviisa 2	507 507	100 100	
Olkiluoto 1 Olkiluoto 2 Olkiluoto 3 (newb)	890 890 1600	26.6 26.6 25	
Hanhikivi 1 (newb)	1200	6.6	
Forsmark 1 Forsmark 2 Forsmark 3	988 1120 1172	23.4 23.4 20.1	9.3 9.3 10.8
Oskarshamn 1 Oskarshamn 2 Oskarshamn 3	decom decom 1400	43.4 43.4 43.4	54.5 54.5 54.5
Ringhals 1 Ringhals 2 Ringhals 3 Ringhals 4	881 decom 1063 1103		29.6 29.6 29.6 29.6
Barsebäck 1 Barsebäck 2	decom decom		100 100

Final disposal of spent nuclear fuel



Source: Posiva

Nuclear Services Offering

Newbuild Services
- Owner's engineering services for newbuild,
- Licensing and safety engineering, e.g. ADLAS® concept family

Services for operating nuclear power plants
- Operational support, e.g. trainings
- Maintenance and outage optimization, Procedures
- Owner's engineering for automation renewal and plant modernization projects (e.g. HFE)

Decommissioning and waste management
- Extensive expert services for decommissioning and waste management from strategic level planning to execution of dismantling and waste management activities at site.
- Wide-ranging back-end services, covering strategical consultation and engineering services for radioactive waste disposal (from very low level waste to spent nuclear fuel) including layout design, nuclear expertise and sophisticated radiation safety analyses for long-term safety studies.
- Unparalleled NURES® ion exchange treatment products and system deliveries for treatment and purification of radioactive liquids.

Safety Analysis and safety improvements
- Deterministic Safety Analysis with Apros®, Severe Accident Management, Probabilistic Risk Assessment

Apros® simulator applications for engineering projects
- Apros® dynamic simulation to define technical requirements for new equipment, process and I&C design verification and testing, virtual commissioning

RadEx ®
Radiation Safety Expert Services, including radiation safety trainings, for customers who use radiation sources or radioactive materials in their operations.

SMR
- Research, consulting, business development, licensing

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Introduction to Study

Aalto University | Learning Centre

Aaltodoc → 1b Maisterivaiheen opinnäytetyöt / Master's theses → [dipl] Insinööritieteiden korkeakoulu / ENG → View Item

Utilization of artificial intelligence in the analysis of nuclear power plant requirements

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RESEARCH-ARTICLE

Developing and Implementing Artificial Intelligence-Based Classifier for Requirements Engineering

Santeri Myllynen, Ilpo Suominen, Tapani Raunio, Rasmus Karell, Jussi Lahtinen

Check for updates

+ Author and Article Information

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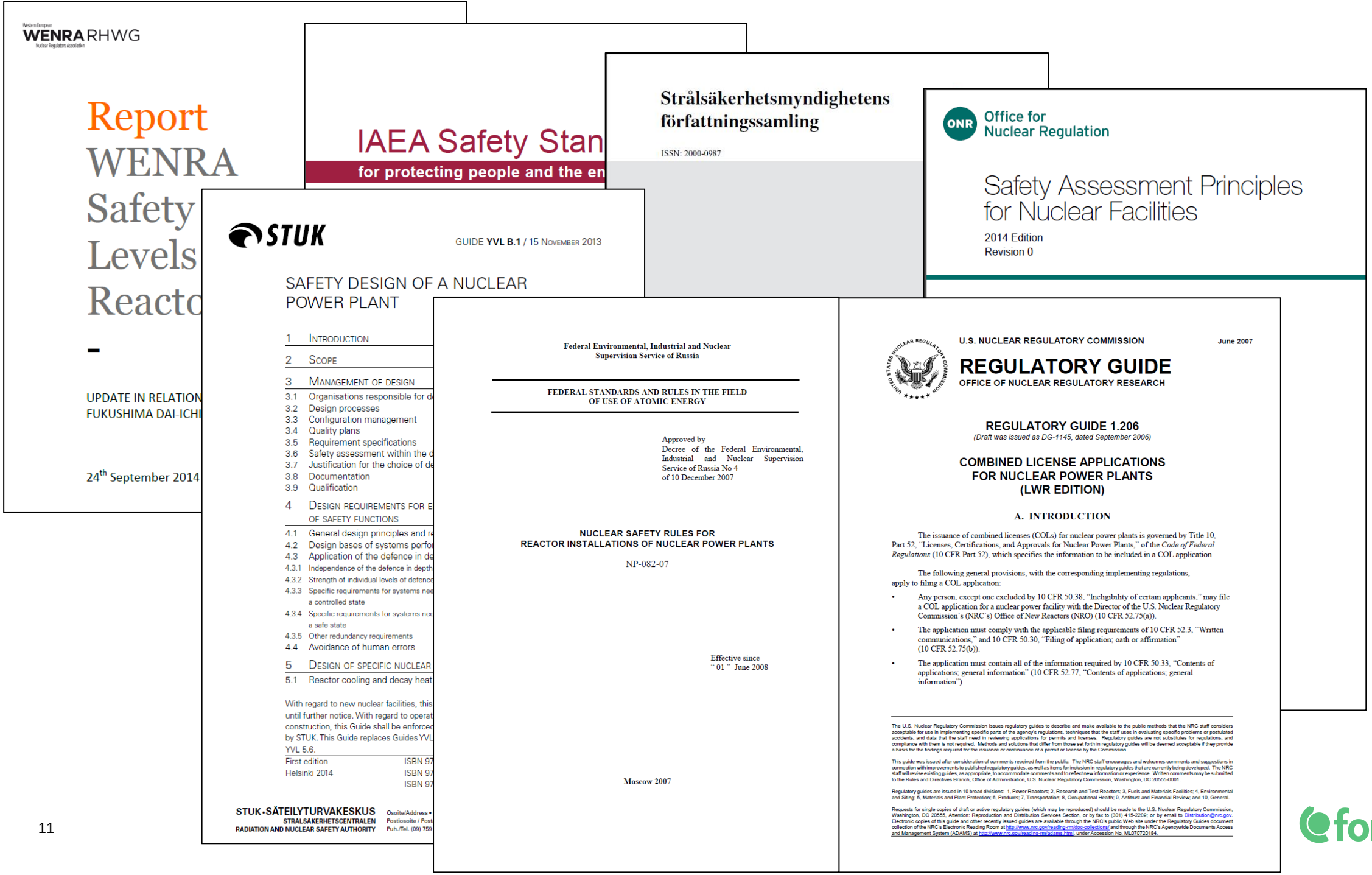

Western European WENRA RHWG Nuclear Regulators Association

Report
WENRA
Safety
Levels
Reacto
–

UPDATE IN RELATION
FUKUSHIMA DAI-ICHI

24th September 2014

IAEA Safety Stan
for protecting people and the en

Strålsäkerhetsmyndighetens författningssamling

ISSN: 2000-0987

ONR Office for Nuclear Regulation

Safety Assessment Principles for Nuclear Facilities

2014 Edition
Revision 0

STUK

GUIDE YVL B.1 / 15 NOVEMBER 2013

SAFETY DESIGN OF A NUCLEAR POWER PLANT

1 INTRODUCTION
2 SCOPE
3 MANAGEMENT OF DESIGN
3.1 Organisations responsible for d
3.2 Design processes
3.3 Configuration management
3.4 Quality plans
3.5 Requirement specifications
3.6 Safety assessment within the d
3.7 Justification for the choice of de
3.8 Documentation
3.9 Qualification
4 DESIGN REQUIREMENTS FOR E OF SAFETY FUNCTIONS
4.1 General design principles and re
4.2 Design bases of systems perfo
4.3 Application of the defence in de
4.3.1 Independence of the defence in depth
4.3.2 Strength of individual levels of defence
4.3.3 Specific requirements for systems nee a controlled state
4.3.4 Specific requirements for systems nee a safe state
4.3.5 Other redundancy requirements
4.4 Avoidance of human errors
5 DESIGN OF SPECIFIC NUCLEAR
5.1 Reactor cooling and decay heat

With regard to new nuclear facilities, this until further notice. With regard to operat construction, this Guide shall be enforced by STUK. This Guide replaces Guides YVL YVL 5.6.

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Federal Environmental, Industrial and Nuclear Supervision Service of Russia

FEDERAL STANDARDS AND RULES IN THE FIELD OF USE OF ATOMIC ENERGY

Approved by
Decree of the Federal Environmental, Industrial and Nuclear Supervision Service of Russia No 4
of 10 December 2007

NUCLEAR SAFETY RULES FOR REACTOR INSTALLATIONS OF NUCLEAR POWER PLANTS

NP-082-07

Effective since
" 01 " June 2008

Moscow 2007

U.S. NUCLEAR REGULATORY COMMISSION June 2007

REGULATORY GUIDE
OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.206
(Draft was issued as DG-1145, dated September 2006)

COMBINED LICENSE APPLICATIONS FOR NUCLEAR POWER PLANTS (LWR EDITION)

A. INTRODUCTION

The issuance of combined licenses (COLs) for nuclear power plants is governed by Title 10, Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," of the *Code of Federal Regulations* (10 CFR Part 52), which specifies the information to be included in a COL application.

The following general provisions, with the corresponding implementing regulations, apply to filing a COL application:

- Any person, except one excluded by 10 CFR 50.38, "Ineligibility of certain applicants," may file a COL application for a nuclear power facility with the Director of the U.S. Nuclear Regulatory Commission's (NRC's) Office of New Reactors (NRO) (10 CFR 52.75(a)).
- The application must comply with the applicable filing requirements of 10 CFR 52.3, "Written communications," and 10 CFR 50.30, "Filing of application; oath or affirmation" (10 CFR 52.75(b)).
- The application must contain all of the information required by 10 CFR 50.33, "Contents of applications; general information" (10 CFR 52.77, "Contents of applications; general information").

The U.S. Nuclear Regulatory Commission issues regulatory guides to describe and make available to the public methods that the NRC staff considers acceptable for use in implementing specific parts of the agency's regulations, techniques that the staff uses in evaluating specific problems or postulated accidents, and data that the staff need in reviewing applications for permits and licenses. Regulatory guides are not substitutes for regulations, and compliance with them is not required. Methods and solutions that differ from those set forth in regulatory guides will be deemed acceptable if they provide a basis for the findings required for the issuance or continuance of a permit or license by the Commission.

This guide was issued after consideration of comments received from the public. The NRC staff encourages and welcomes comments and suggestions in connection with improvements to published regulatory guides, as well as items for inclusion in regulatory guides that are currently being developed. The NRC staff will revise existing guides, as appropriate, to accommodate comments and to reflect new information or experience. Written comments may be submitted to the Rules and Directives Branch, Office of Administration, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001.

Regulatory guides are issued in 10 broad divisions: 1, Power Reactors; 2, Research and Test Reactors; 3, Fuels and Materials Facilities; 4, Environmental and Siting; 5, Materials and Plant Protection; 6, Products; 7, Transportation; 8, Occupational Health; 9, Antitrust and Financial Review; and 10, General.

Requests for single copies of draft or active regulatory guides (which may be reproduced) should be made to the U.S. Nuclear Regulatory Commission, Washington, DC 20555, Attention: Reproduction and Distribution Services Section, or by fax to (301) 415-2289; or by email to Distribution@nrc.gov. Electronic copies of this guide and other recently issued guides are available through the NRC's public Web site under the Regulatory Guides document collection of the NRC's Electronic Reading Room at http://www.nrc.gov/reading-rm/doc-collections/ and through the NRC's Agencywide Documents Access and Management System (ADAMS) at http://www.nrc.gov/reading-rm/adams.html, under Accession No. ML070720184.

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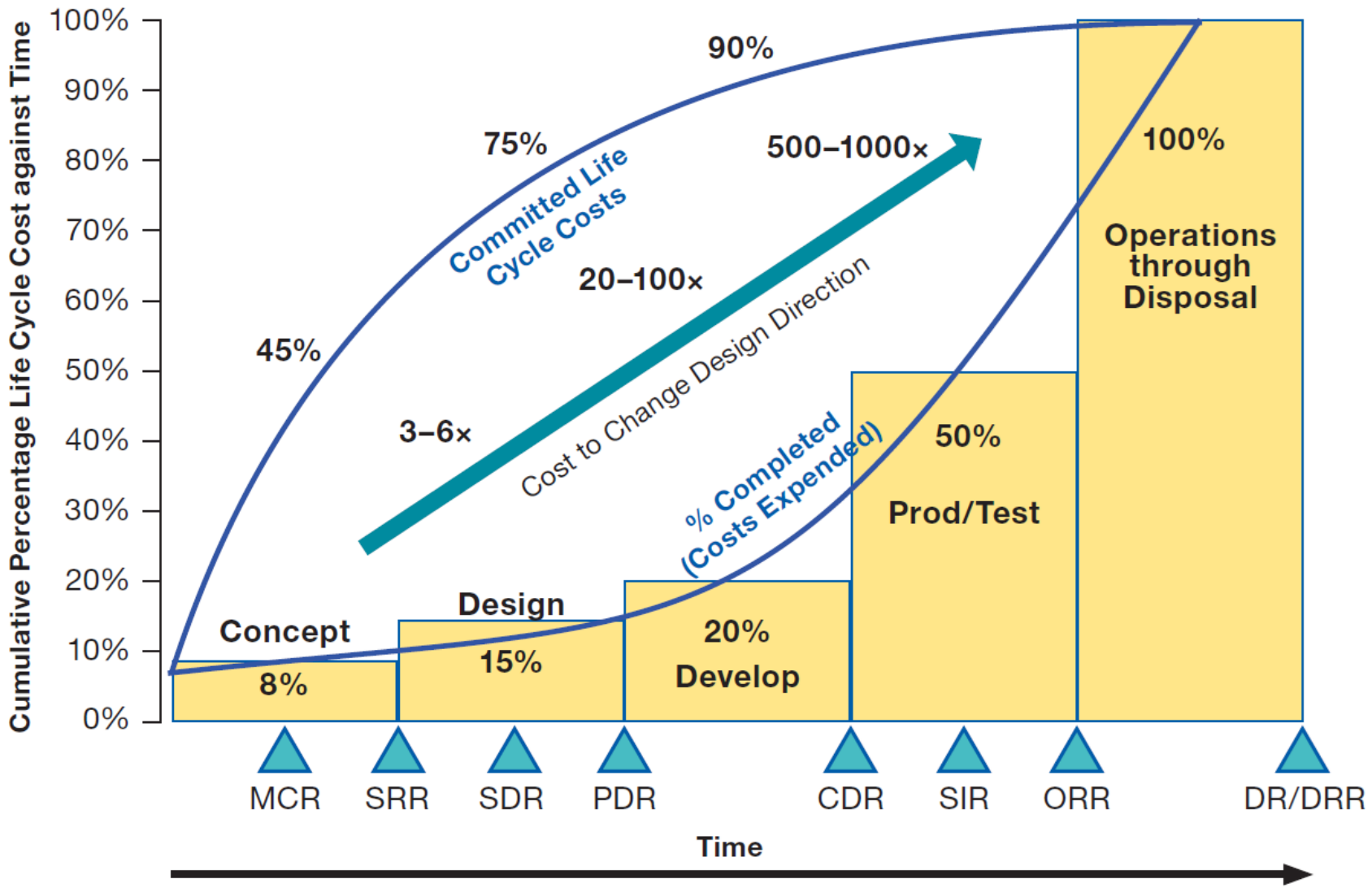
Life-Cycle Cost Impacts from Early Phase Decision-Making



Source: NASA Systems Engineering Hanbook: NASA SP-2016-6105 Rev2 supersedes SP-2007-6105 Rev 1 dated December, 2007.

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http://nihealthcare.com/uu-could-hold-key-to-better-understanding-brain-disorders/

Study

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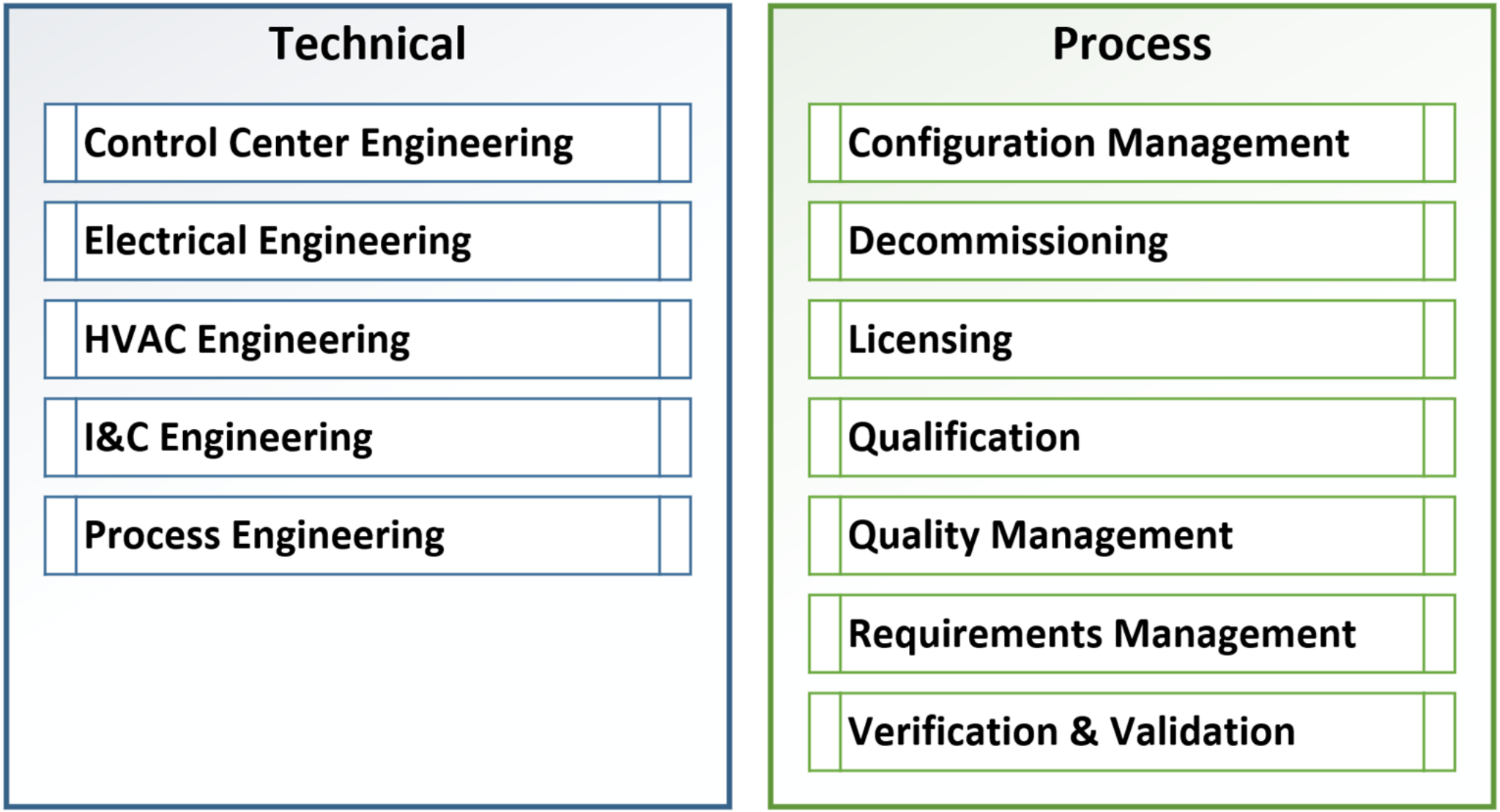
Requirements Classification

Requirements Classes



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Data Collection

YVL Guide	Title
YVL A.3	Leadership and management for safety
YVL A.5	Construction and commissioning of a nuclear facility
YVL A.6	Conduct of operations at a nuclear power plant
YVL A.8	Ageing management of a nuclear facility
YVL A.12	Information security management of a nuclear facility
YVL B.1	Safety Design of a Nuclear Power Plant
YVL B.4	Nuclear Fuel and Reactor
YVL B.5	Reactor Coolant Circuit of a Nuclear Power Plant
YVL B.6	Containment of a nuclear power plant
YVL B.7	Provisions for internal and external hazards at a nuclear facility
YVL C.5	Emergency arrangements of a nuclear power plant
YVL C.6	Radiation monitoring at a nuclear facility
YVL D.4	Predisposal management of low and intermediate level nuclear waste and decommissioning of a nuclear facility

YVL Guide	Title
YVL E.3	Pressure Vessels and Piping of a Nuclear Facility
YVL E.4	Strength Analyses of Nuclear Power Plant Pressure Equipment
YVL E.6	Buildings and Structures of a Nuclear Facility
YVL E.7	Electrical and I&C Equipment of a Nuclear Facility
YVL E.8	Valves of a Nuclear Facility
YVL E.9	Pumps of a Nuclear Facility
YVL E.10	Emergency Power Supplies of a Nuclear Facility

IAEA

IEC International Electrotechnical Commission

ISO

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Examples of Requirements Classification

REQ ID	Requirement	Requirement Classes
YVL-A.3-6.1-604	604. For each process, the necessary inspection, testing, verification, and validation phases, the acceptance criteria for each phase, and the responsibilities for the performance of the activities shall be specified. It shall also be specified if these activities are to be performed by individuals other than those responsible for the process.	Quality Management Verification & Validation
YVL-B.1-4.3.2-439	439. If the redundant parts of a safety system are interconnected for the distribution of electricity or control signals, the safety advantage as compared to a solution without such interconnection shall be justified.	Instrumentation & Control Verification & Validation
YVL-B.1-4.3.2-435	435. The failure of a subsystem in a system executing safety functions shall not cause the failure of another redundant subsystem of the same system or the failure of several subsystems participating in the same safety function.	Process Engineering
YVL-B.1-5.4.2-5425	5425. The plant unit's power supply systems shall be dimensioned to supply sufficient electrical power for the implementation of the safety functions in all plant conditions.	Electrical Engineering
YVL-D.4-4.4.1-432	432. As the decommissioning of the nuclear facility proceeds, the safety classification document shall be updated to reflect the current state of the facility.	Decommissioning

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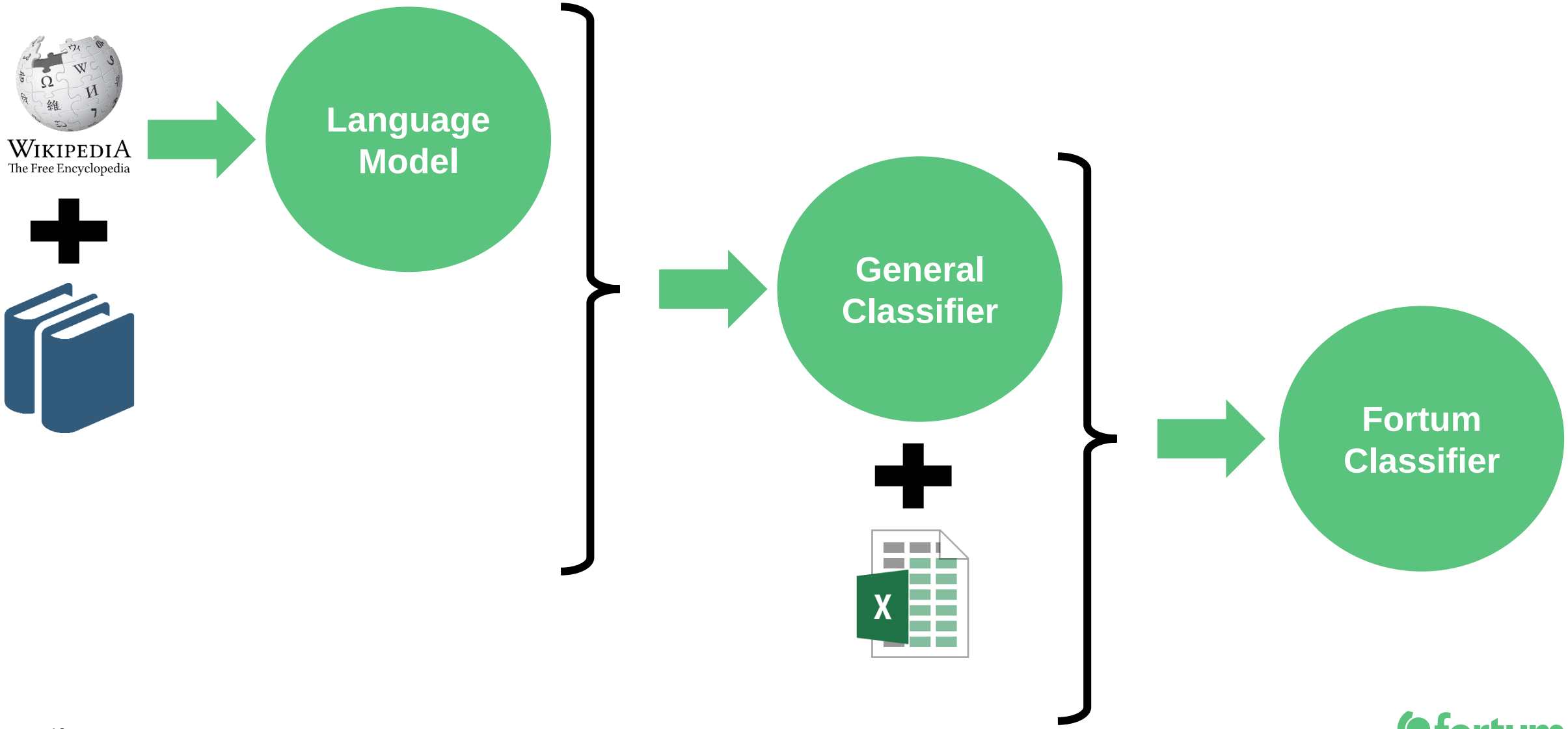
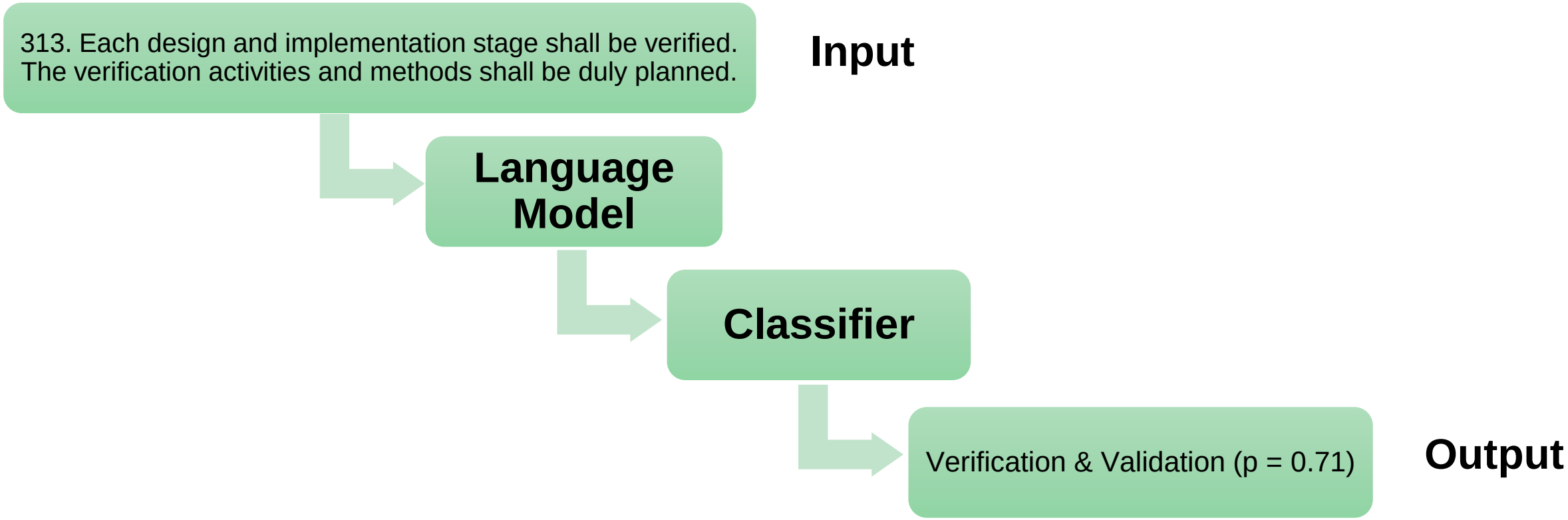
Training Fortum Classifier



Language Model + Classifier



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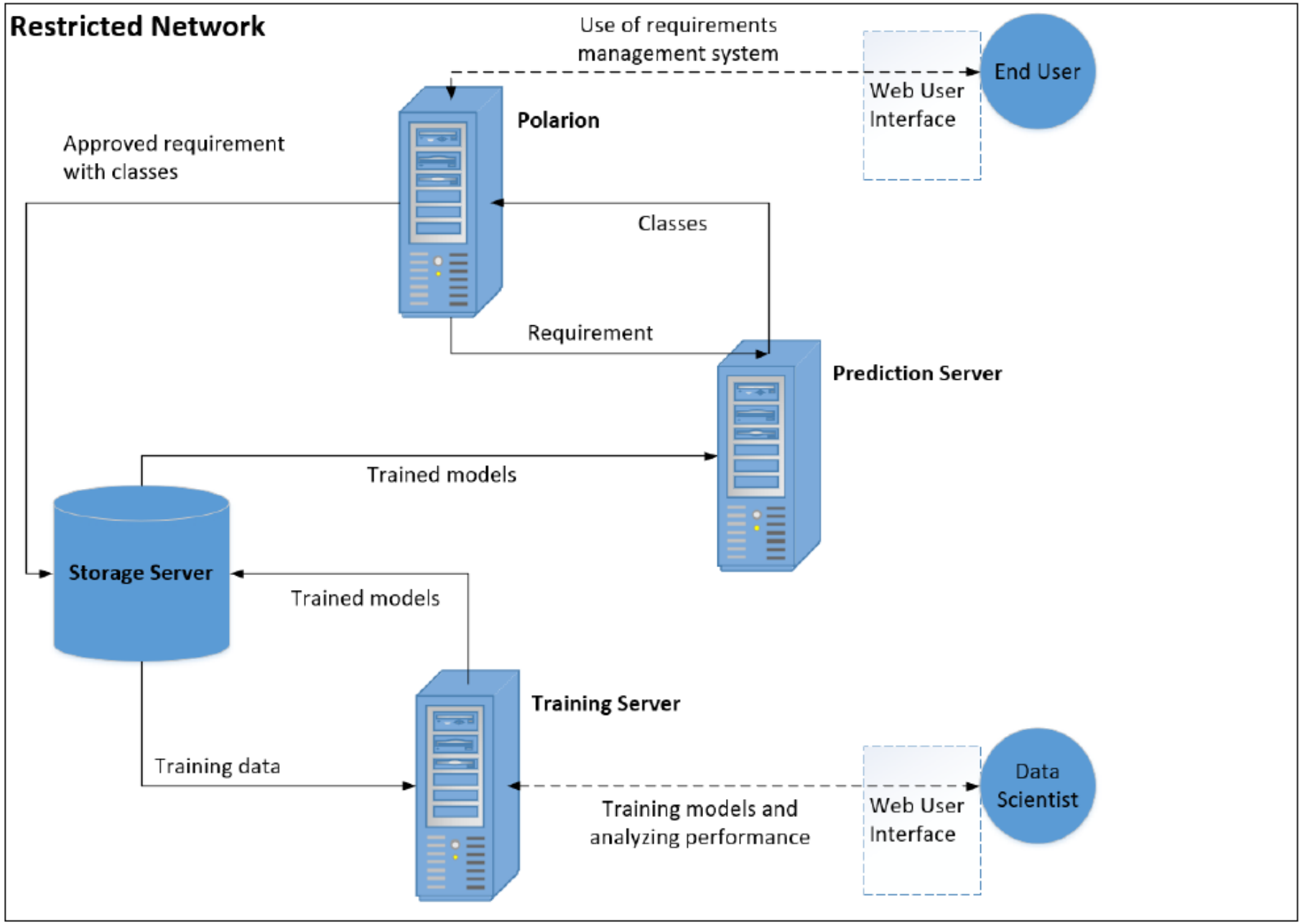
Restricted Network
Use of requirements management system
End User
Web User Interface
Polarion
Approved requirement with classes
Classes
Requirement
Prediction Server
Trained models
Storage Server
Trained models
Training Server
Training data
Training models and analyzing performance
Web User Interface
Data Scientist

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Results

Test dataset (n = 390)

	Accuracy	Match ratio
BERT	0.983	0.869
DistilBERT	0.981	0.849
RoBERTa	0.978	0.821
XLM	0.972	0.734
XLNet	0.980	0.815

Independent test dataset (n = 76)

	Accuracy	Match ratio
BERT	0.906	0.355
DistilBERT	0.902	0.289
RoBERTa	0.914	0.394
XLM	0.898	0.158
XLNet	0.934	0.434

Requirements Atomization

Requirements Atomization

YVL-B.1-3.9 3.9 Qualification

364. The licensee shall evaluate the acceptability of the qualification results and present a justified conclusion drawn from the results.
365. ….
366. ….

Requirements Atomization

YVL-B.1-3.9 3.9 Qualification

364. The licensee shall evaluate the acceptability of the qualification results **and** present a justified conclusion drawn from the results.

364. The licensee shall evaluate the acceptability of the qualification results.

364. The licensee shall present a justified conclusion drawn from the results.

From which results?

Requirements Similarity

Requirements Similarity

Requirement from Law	Requirement Regulatory Guide	Score for Similarity (0 Identical – 10 Dissimilar)
STUK Y.1	**YVL B.1, Chapter 4**	**Score**
Systems, structures and components important to the safety of a nuclear facility shall be available as detailed in the design basis requirements.	411. If shared structures, systems and components important to safety are designed for nuclear power plant units located on the same plant site, it shall be demonstrated by means of reliability assessments that this does not impair the capability of these structures, systems and components to perform their safety functions.	4,616184711
A nuclear power plant shall have the necessary components and procedures for securing the removal of residual heat from the nuclear fuel in the reactor for a period of three days independently of the off-site supply of electricity and water in a situation caused by a rare external event or a disruption in the on-site electrical distributionsystem.	452. The nuclear power plant shall have in place arrangements that can guarantee sufficient cool- ing for the fuel placed in fuel storage facilities during rare external events in accordance with requirement 450. These arrangements shall make it possible to supervise the water level in the spent fuel pools for a minimum of eight hours without recharging the DC batteries. Furthermore, it shall be possible to keep the fuel reliably submerged during the loss of the plant's internal electricity distribution system in accordance with requirement 451. A sufficient inventory of water and fuel and capability to recharge the DC batteries shall exist at the plant site to maintain these arrangements for a period of 72 hours.	4,636093616

Vanilla BERT: https://arxiv.org/pdf/1810.04805.pdf

Discussion

Discussion

- Narrowly defined specific problem – successful even with modest amount of data
- Collecting high-quality training data is a time-consuming process and susceptible to errors
- Algorithms perform well for similar requirements
  - ➢ Challenges to categorize requirements containing new words and/or word orders
- More high-quality data and precise classes are required to better facilitate the needs of systems engineering in nuclear industry

Conclusions

Conclusion

- AI can clearly be utilized in requirements engineering
- AI can save time and money as well as has potential to promote safety when applied correctly
  - Reduces manual error-prone, rather monotonic, time consuming, but still important work
- Algorithms may be further developed for:
  - Atomizing complex requirements containing several classes
  - Recognizing and potentially combining similar requirements
  - Checking requirements syntax
  - Assessing the fulfillment of requirements

Read more: www.fortum.com/nuclear

Santeri Myllynen
santeri.myllynen@fortum.com

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