Adoption of ARCADIA and Capella to Develop an Elimination Process of Radioactive Waste by Melting

A beginner's experience

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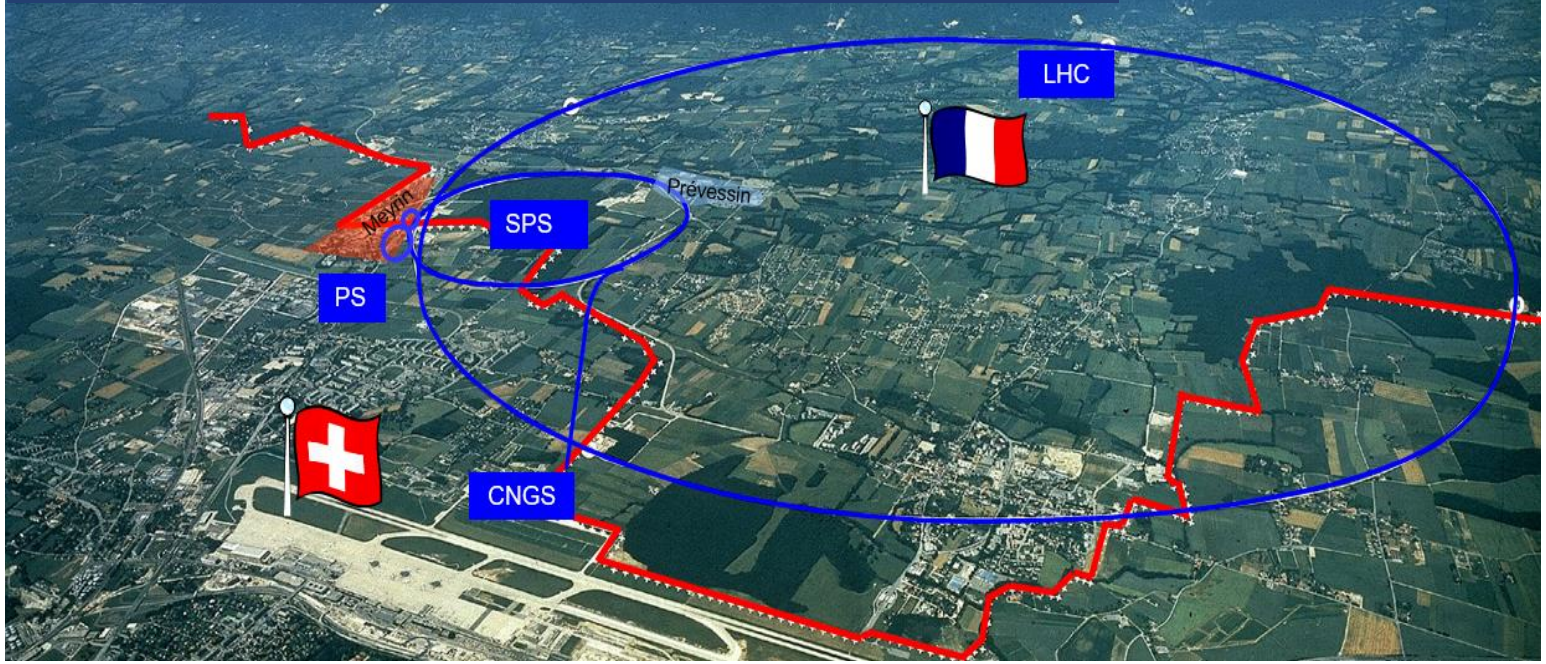
Outline

1. **Introduction**
   - CERN context & facts
   - Managing CERN radioactive waste
2. **Process specification**
   - Limitations of current practices
   - Causes, approaches
   - Proposed solution by ARCADIA and Capella
   - Examples of diagrams in use:
     operational architecture, capabilities, scenario
   - M2Doc
3. **Conclusion**

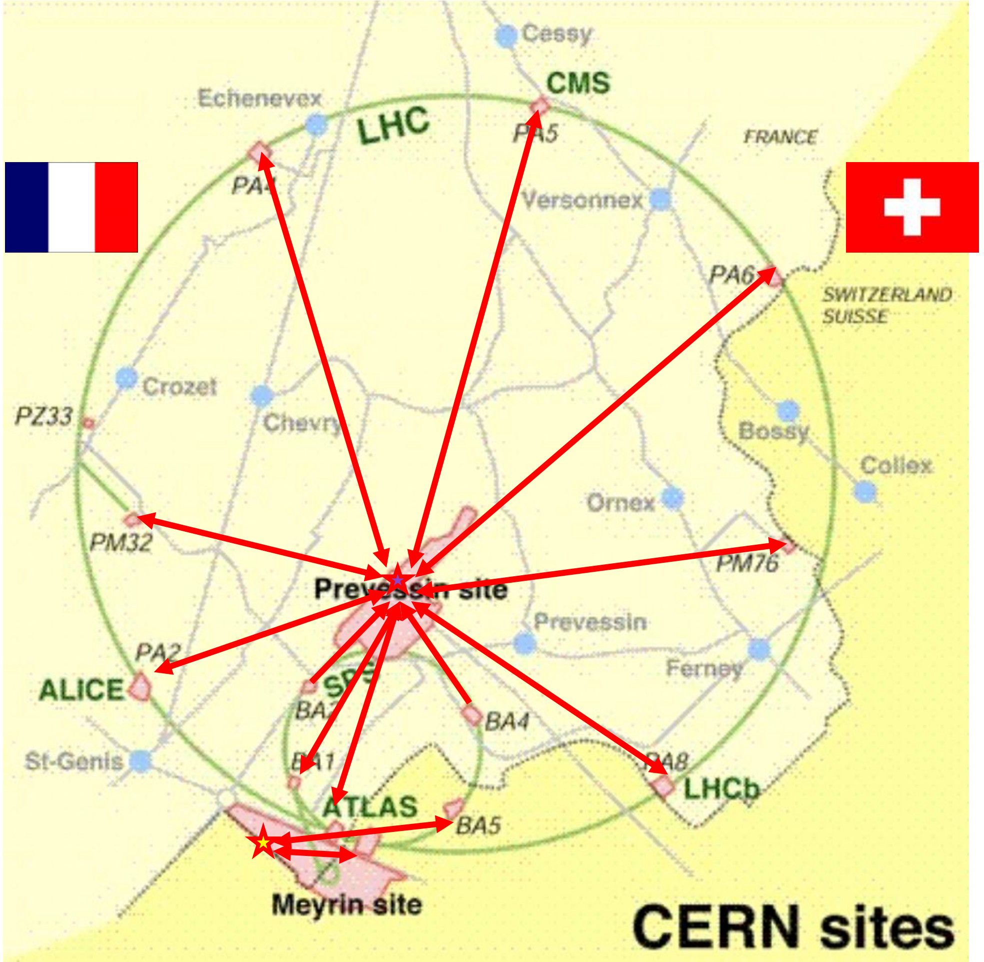
CERN – The European Organization for Nuclear Research

Mission: Foster peaceful collaboration between nations
- 24 member states
>50 agreements with non-member states
~2600 staff, ~ 3500 registered contractors
~12000 registered users from about 100 countries
~10000 radiation workers



- CERN is an ***intergovernmental Organization*** subject not to national but international law.
- ***Right to establish rules*** as necessary for the proper functioning of the Organization:
  - CERN Staff Rules and Regulations;
  - CERN Safety Rules.
- A "**Tripartite Agreement** on Radiation Protection and Radiation Safety" between CERN and its host states provides the legal framework to discuss in a transparent and collaborative way with the host states authorities. The subjects covered are:
  - Export / import and handling of radioactive materials;
  - Transport of radioactive materials;
  - Radioactive waste;
  - Incident declaration;
  - Dosimetry;
  - Environmental monitoring.

CERN Facts



- ~500 m³/year rad. waste
- ~1000 m³/year rad. waste processing facility
- 10.000 m³ rad. waste interim storage facility.
- >160 experiments;
- ~1000 radiation areas
- ~50 km of accelerator infrastructures, mostly located underground (LHC up to 100m);
- Radioactive Ion Beam facility (ISOLDE);
- Spallation neutron source (n-TOF);
- https://home.cern/resources/faqs

In addition to two main sites (Meyrin and Pévessin), CERN has 13 remote sites (11 in France and 2 in Switzerland).

All remote sites are located in a semirural environment and have limited infrastructure and services.

Over the last decades, the number of facilities has more than doubled, while the demographic evolution in the region resulted in the construction of new long-stay buildings,

Challenge: how to manage the radiation-protection risks in accordance with the legislations of the two Host States, France and Switzerland.

Example: the management of radioactive waste: CERN's radioactive waste must be disposed of using the different pathways available in France and Switzerland through the most technically and economically advantageous pathways.

CERN Radioactive Waste (RW)

- Spallation, neutron capture...
- Very-low to intermediate-level rad. waste.
- Mainly β-,γ- emitters.
- Very limited contamination.
- Short to medium lived radionuclides (no long-lived radionuclides, apart from very specific experiments).
- Limited quantities of activated or contaminated liquids.
- Large variety of radionuclides.
- Possible mixed waste (waste presenting a chemical hazard linked to the radiological hazard).

End-of-life stage of CERN radioactive equipment - 1/2

Classification

Candidates for "**clearance**"
0 kCHF/m³, 30.5% of CERN radioactive waste

Elimination as conventional waste

Switzerland

Very-Low-Level RW
~0.9 kCHF/m³, 63.8% of CERN radioactive waste
~25% of elimin. costs over the next 10 years

Packaging & 300y storage in a surface repository

ANDRA (France)

End-of-life stage of CERN radioactive equipment - 2/2

Classification

Short-lived Intermediate- & Low-Level RW
~26 kCHF/m³, 5.5% of CERN radioactive waste
~ 57% of elimin. costs over the next 10 years

Embed in reinf. concrete & 300y storage in a surface repository

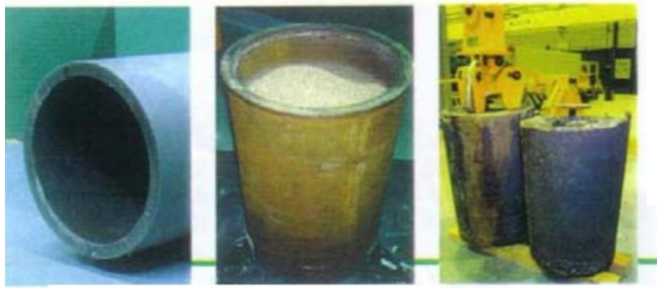
ANDRA (France)

A Team – EDMS 2726591

Long-lived Intermediate- & Low-Level RW
~242 kCHF/m³, 0.2% of CERN radioactive waste,
~18% of elimin. costs over the next 10 years

Dismantling in hot cell, packaging & geological disposal

PSI (Switzerland)



Tube | Conditioned ashes in shielded drum | Ingots

Elimination of Radioactive Waste by Melting

A long journey…

Setup phase

2017-11: **Start** of the **technical market survey** of available technologies and accredited European suppliers capable of processing FMA waste. Technical visits on selected companies in Germany, Sweden, France.

2018-06: **FMA elimination strategy** defined & presented at the 1st RWM St. Board.

2019-05: **FMA elimination program** defined & presented at the 2nd RWM St. Board.

Project phase

2020-05: **FMA elimination project** by melting: **mandate** & **milestone plan** defined.

2021-05: Primary waste batch: **first container filled** & available for characterisation.

2022-06: Primary waste batch **finalised**. **Audit** by the melting company

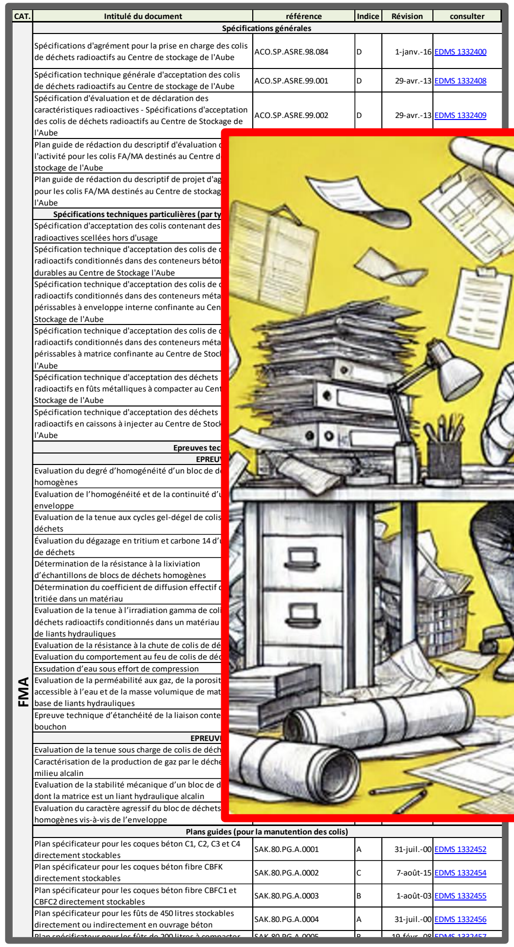
2022-11: **Melting**.

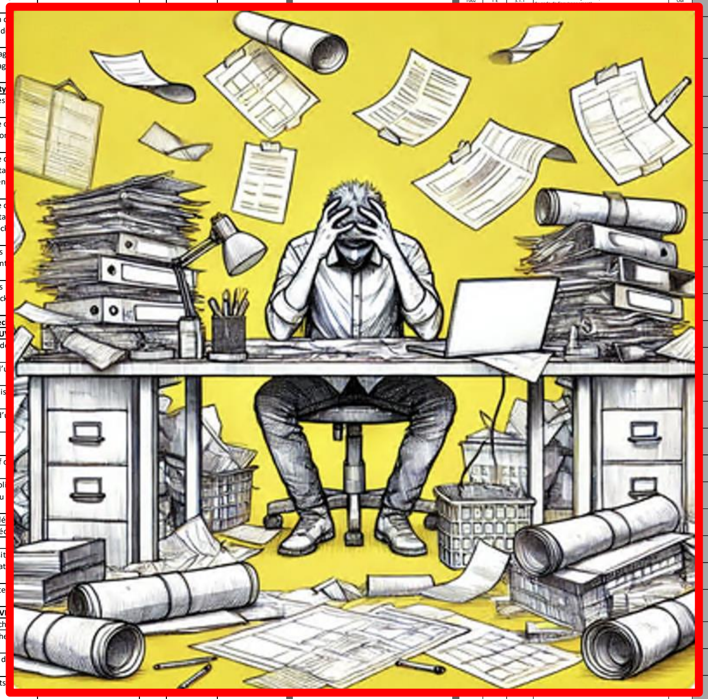
2023-06: **Elimination** of the pilot batch towards the French repository.

2023-10: **Project closure**.

How to eliminate radioactive waste ?

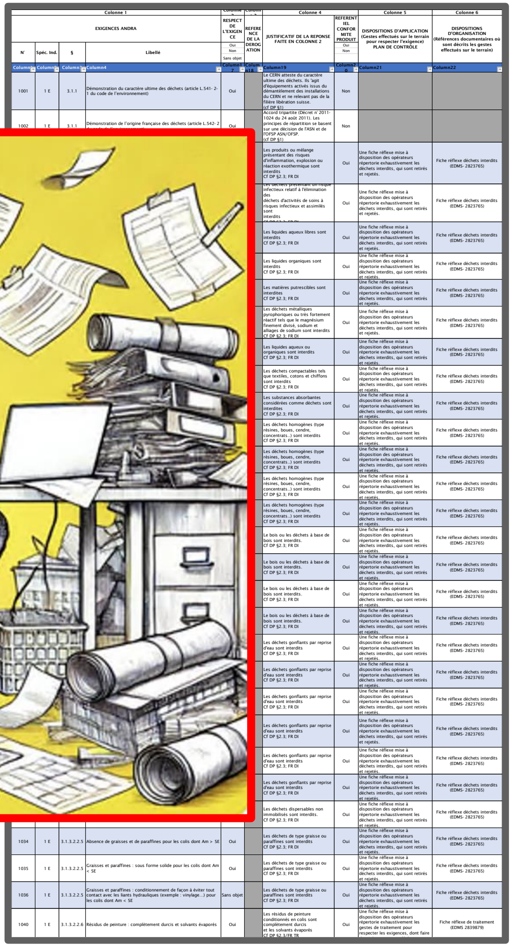
List of the specifications applicable to the elimination of short-lived intermediate- & low-level waste





49 specifications…

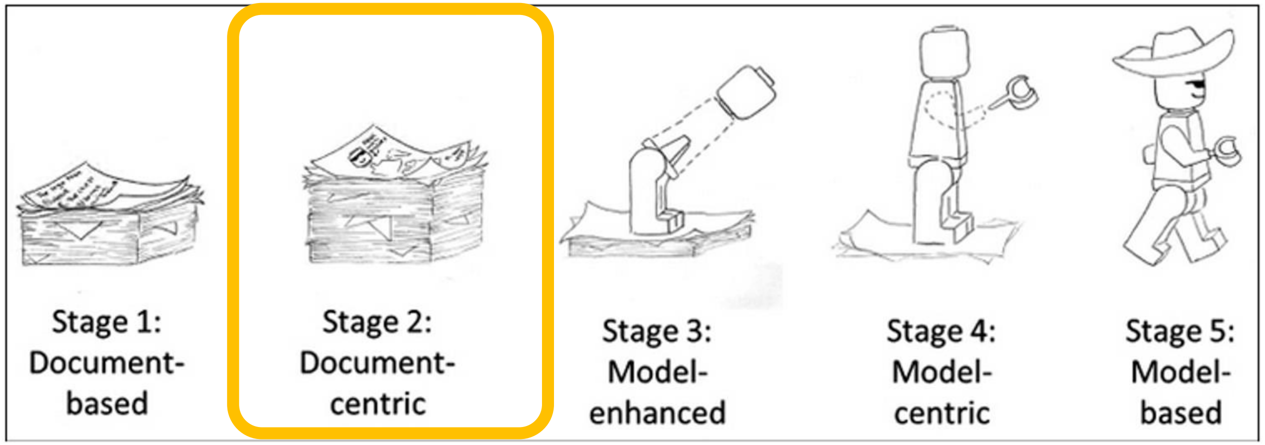
List of high-level requirements extracted from the specifications



241 high-level requirements…

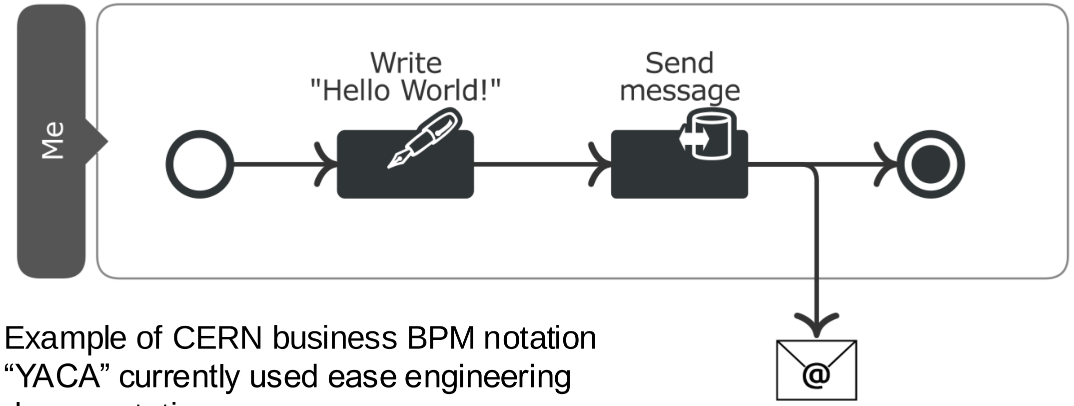
- Within the CERN framework, the knowledge associated with an engineering system is still entirely contained in text documents.
- Engineers use specific graphical notations to produce a set of standardized diagrams supporting the text descriptions.
- Actual drawing packages are used to create these diagrams that form part of the documentation.
- In the case of radioactive waste management, the high-level and hidden requirements approach the “painful” limit of 1000 (Roques & Hetherington 2024).

CERN MBSE maturity



CERN today

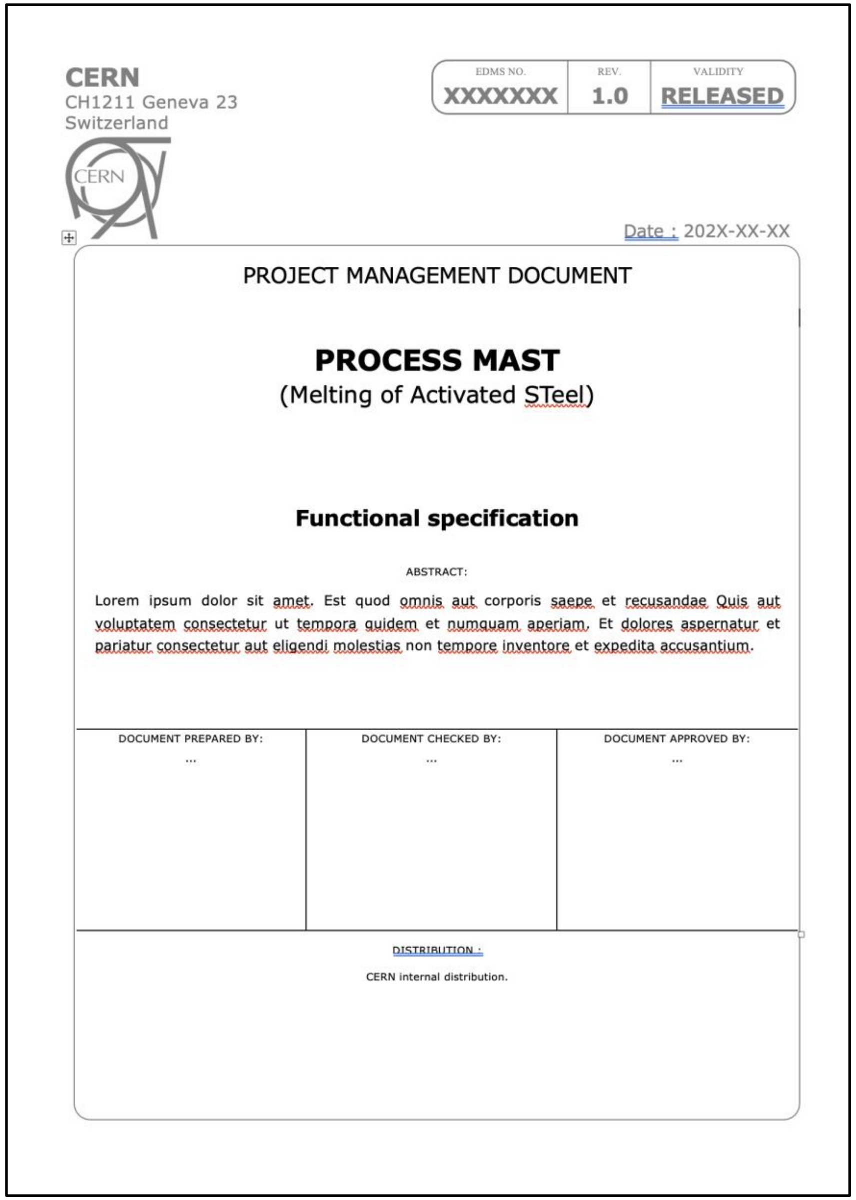
Holt, J.D. & Perry, S.A. (2020) *Implementing MBSE – the Trinity Approach*. INCOSE UK Publishing, Ilminster, UK



Example of CERN business BPM notation "YACA" currently used ease engineering documentation

- CERN has built and manages some of the most complex engineering systems.
- The knowledge associated with these engineering systems is still entirely contained in text documents.
- Since 2015 CERN uses a specific **business process modeling** (**BPM**) notation to produce a set of standardized diagrams supporting the text descriptions:
  ➔ YACA ("Yet Another Charting Approach")
- Drawing packages are used to create these diagrams that form part of the documentation.
  ➔ Draw.IO

Process specification
Current practices and limitations



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Date : 202X-XX-XX

PROJECT MANAGEMENT DOCUMENT

PROCESS MAST
(Melting of Activated STeel)

Functional specification

ABSTRACT:

Lorem ipsum dolor sit amet. Est quod omnis aut corporis saepe et recusandae Quis aut voluptatem consectetur ut tempora quidem et numquam aperiam. Et dolores aspernatur et pariatur consectetur aut eligendi molestias non tempore inventore et expedita accusantium.

DOCUMENT PREPARED BY:	DOCUMENT CHECKED BY:	DOCUMENT APPROVED BY:
...	...	...

DISTRIBUTION :

CERN internal distribution.

Text documents are today the main vector to gather technical information and convey it to the approval/validation bodies and to the development teams.

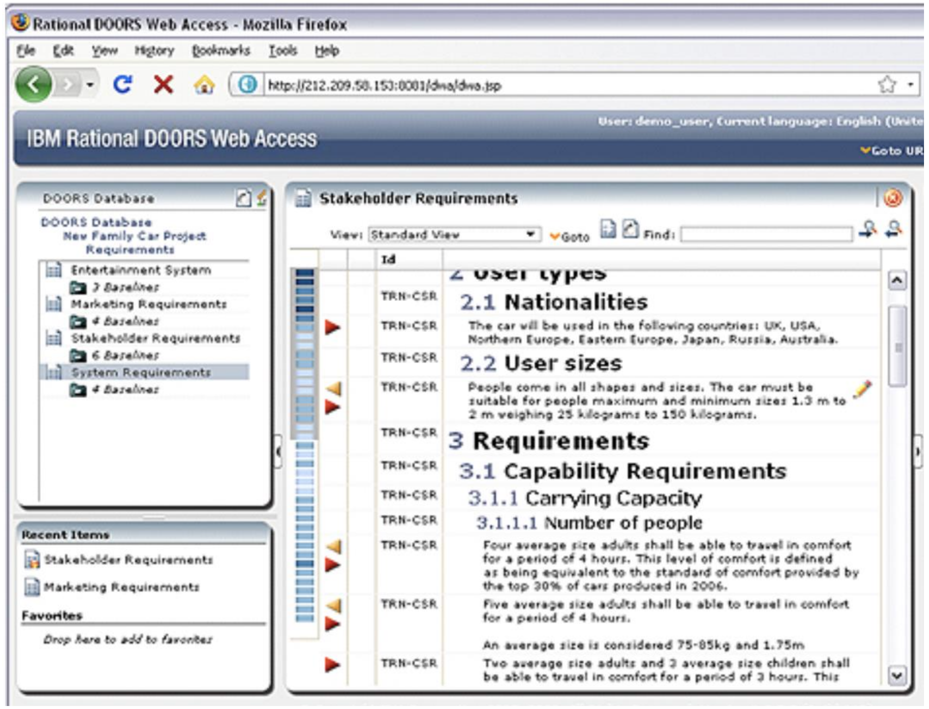
Text documents have limitations:

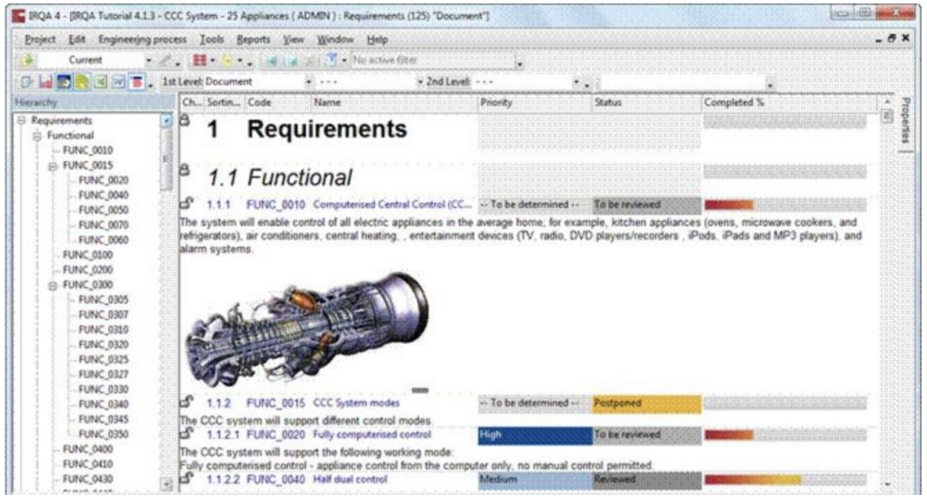
- Complex consistency checks across the document(s);
- Loss of consistency as the specification evolves;
- Fuzzy separation between stakeholders’ expectations, requirements, choices of implementation.

Consequences:

- Time-consuming validation;
- Difficulty to assess and control change requests;
- Poor control of versioning;
- Definition of suppliers' delivery is weak and not sufficient (addendum to contracts / rework).

Engineers have tried to pinpoint the cause of the limitations…

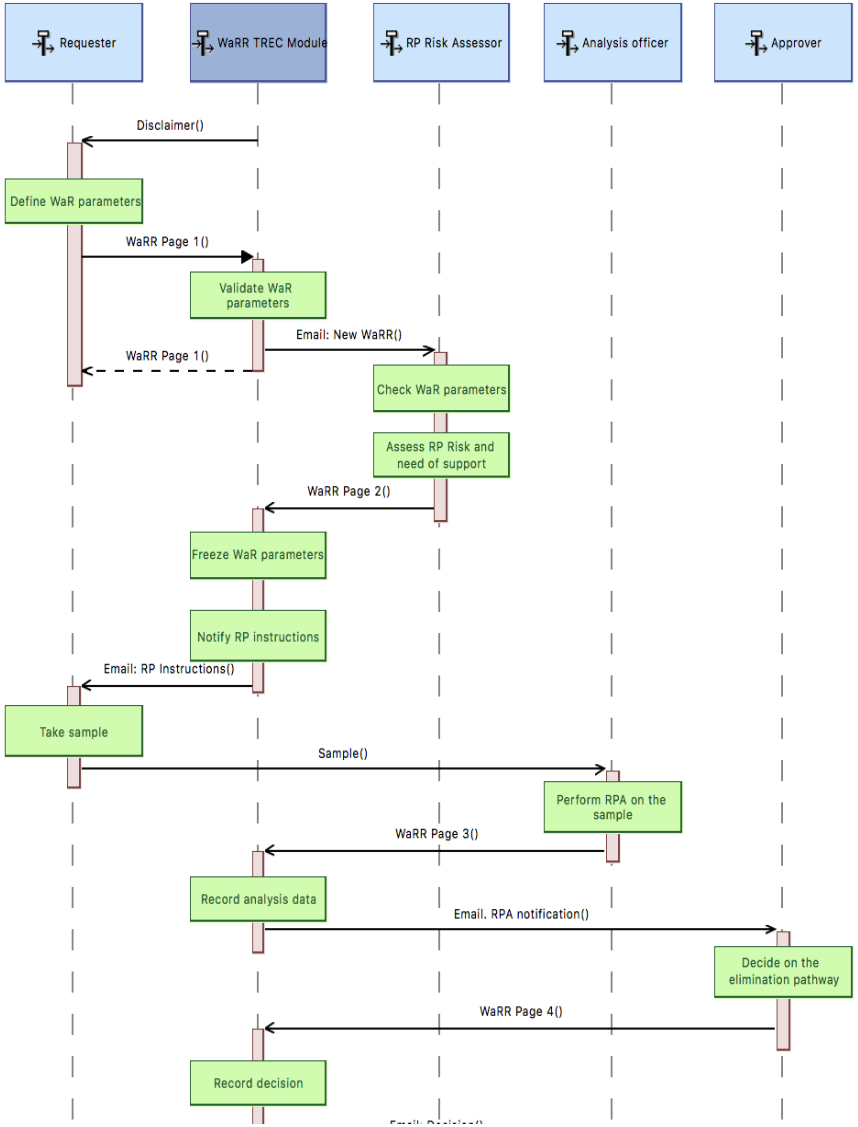




Process specification
Limitation 1

HUMAN MIND

- **Cause**: beyond a given limit, human mind alone is unable to master complex information.
- **Approach**: break down the specification into elementary sentences and thoroughly manage *each one* of them ("requirements engineering" approach).
  Ideally, we should tell which requirements are fulfilled by which part of our system and how to test them. A link should show which test covers which requirement.
- **Solution**: use specific software tools to collect, link, share the sentences and manage their lifecycle.
  Examples: "IBM® Rational® DOORS®" , "ProR®", "Innoslate®".



Process specification
Limitation 2

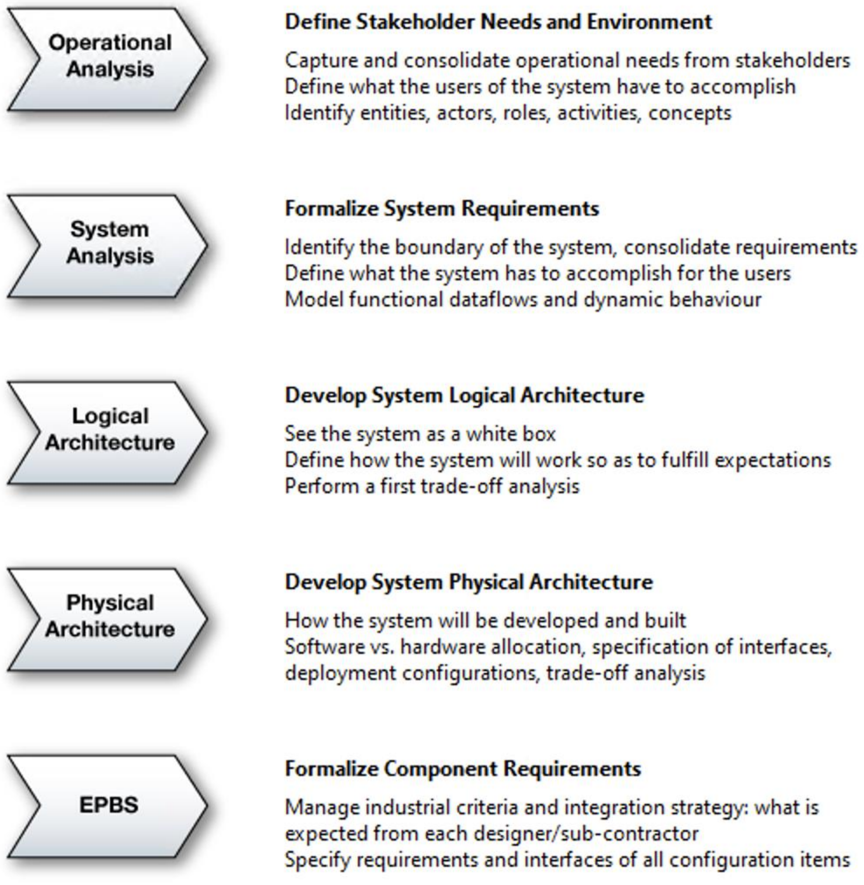
LANGUAGE

- **Cause**: Natural language is inadequate to clearly specify an engineering system.
- **Approach**: use ad hoc artificial notations.
- **Solution**: use a graphical language to capture and communicate engineering requirements.
  Examples: “Universal Modeling Language” (UML), “System Modeling Language” (SysML), “Architecture Analysis Design Language” (AADL).

Process specification
Limitation 3

METHOD

- **Cause**: A specification must describe both the problem that the designed system solves (the need), and the designed system itself (the solution). Unless a rigorous method is followed, these aspects are often muddled up.
- **Approach**: Separate the aspects of the specification to manage a system's complexity; tackle progressively operational, system, logical and physical aspects.
- **Solution**: develop a design method.
  Examples: ARCADIA (ARChitecture, Analysis and Design Integrated Approach).
  Theory textbook : ISBN 978-1-78405-413-7
  Software textbook : ISBN 978-1-78548-168-0
  ISBN 978-1-937468-14-9



“Activity explorer” of Capella

Remarks

Difficulty

Take the initiative, with limited or no assistance of others, in diagnosing the needs, formulating goals, identifying human and material resources, and evaluating outcomes

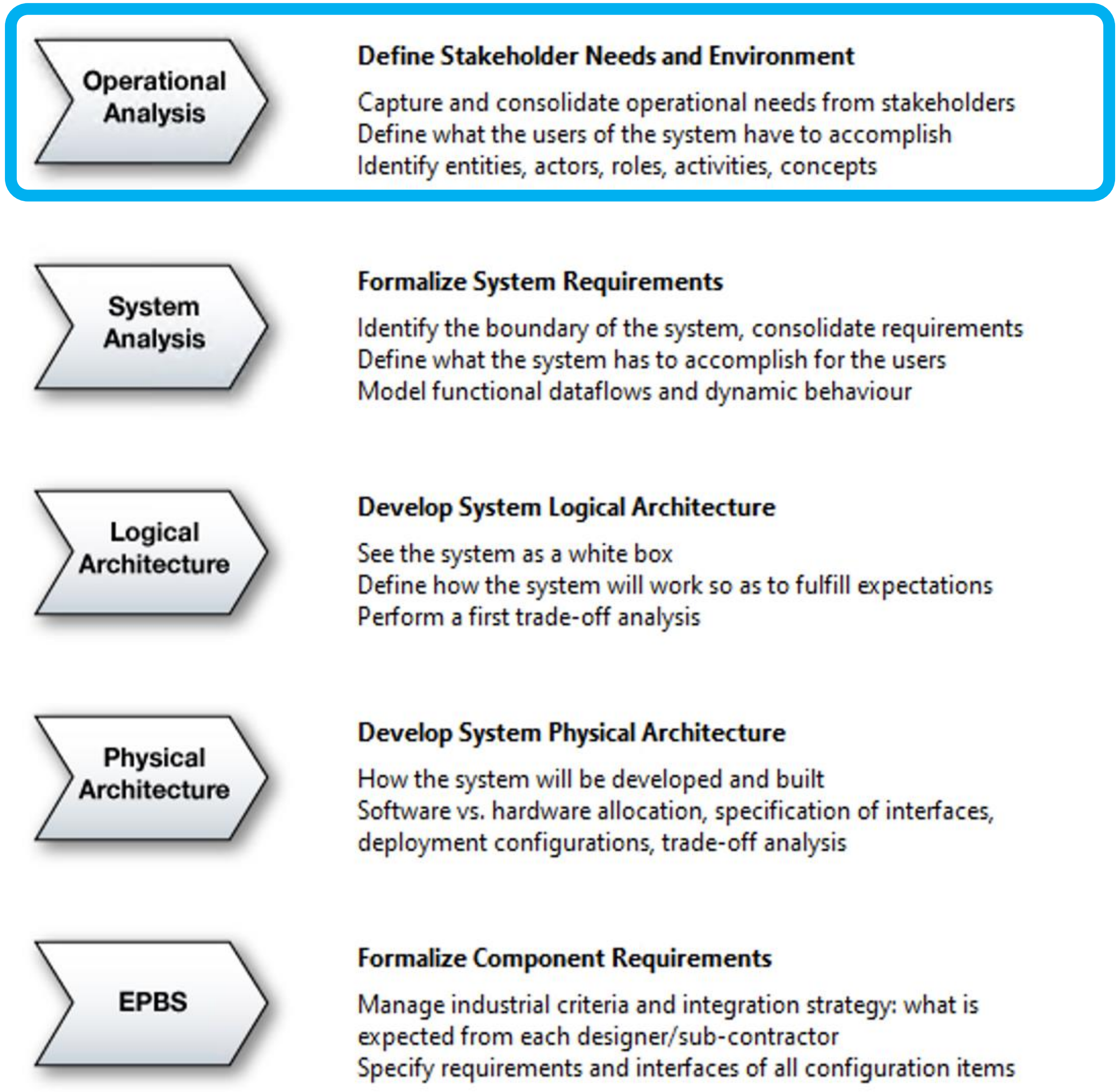
Challenges

- Barriers: Financial (software cost).
- Personal: Learn a new language, method, software.
- Team: Introduce these tools to the colleagues.

Selected approach

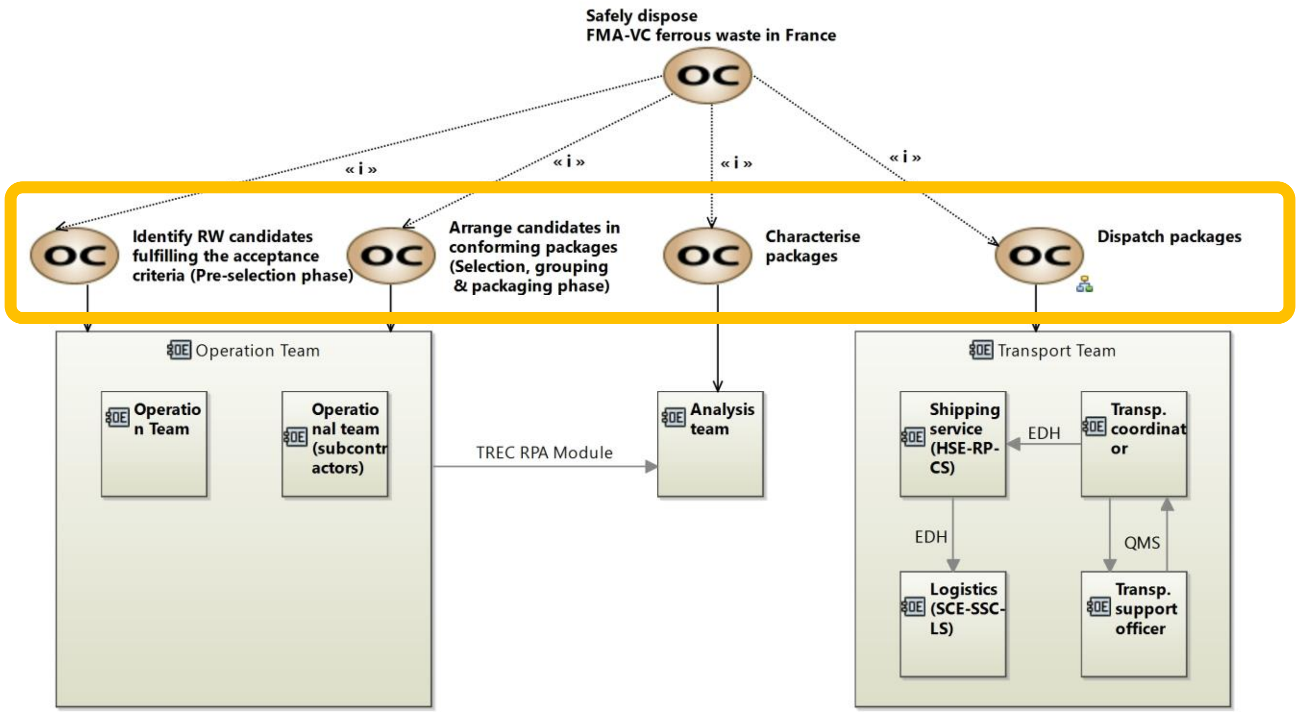
- Barriers: Open-source software ➝ **Capella**
- Personal: Self learning and training/coaching ➝ **ARCADIA**
- Team: Identify a use case ➝ Development of a new
  - ➔ **RW elimination pathway by melting**
  - ➔ **Application to all other pathways**
  - ➔ **Feedback from external stakeholders**

Selected approach
A “tiny bit” of ARCADIA & Capella



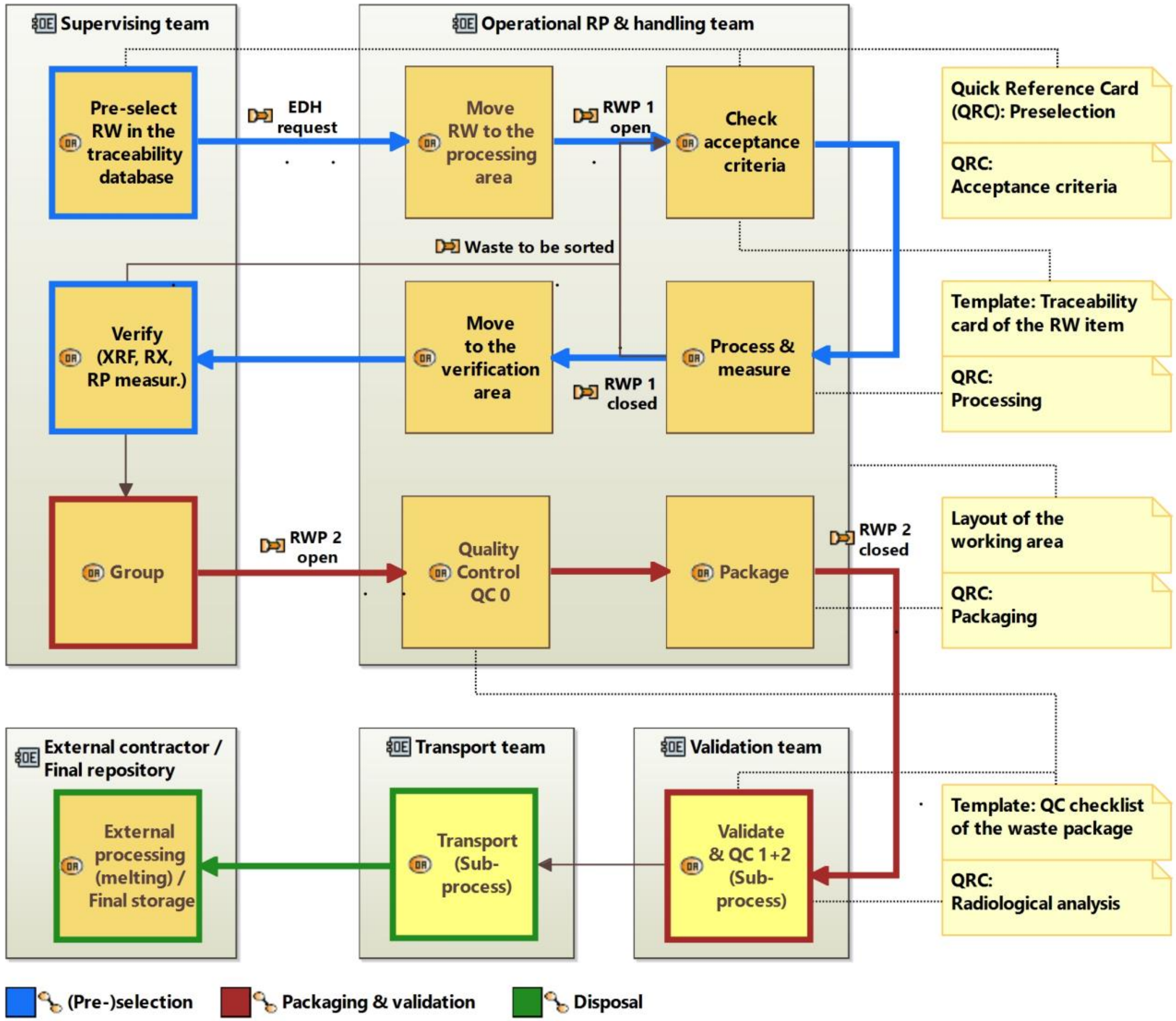
- **“Waste” is not a product**. It is the end-of-life stage of any equipment.
- “**Waste management**” **is not a system**. It is a (complex) operational process.
- **ARCADIA and Capella seemed unsuitable** to develop the melting process, as they seemed to support the step-wise development only of equipment and systems.
- **However, the operational analysis has similarities with YACA**, the business process modeling in use at CERN, with the advantage that it is more rich and, in addition to a syntax, it has a semantics.
- Although only this “tiny bit” seemed applicable, **an attempt was made** to conceive and document the process by ARCADIA and Capella.

A simple model



Capabilties diagram of the waste process.
(EDH: CERN Electronic Document Handling system;
TREC: Traceability system of Radioactive Equipment at CERN)

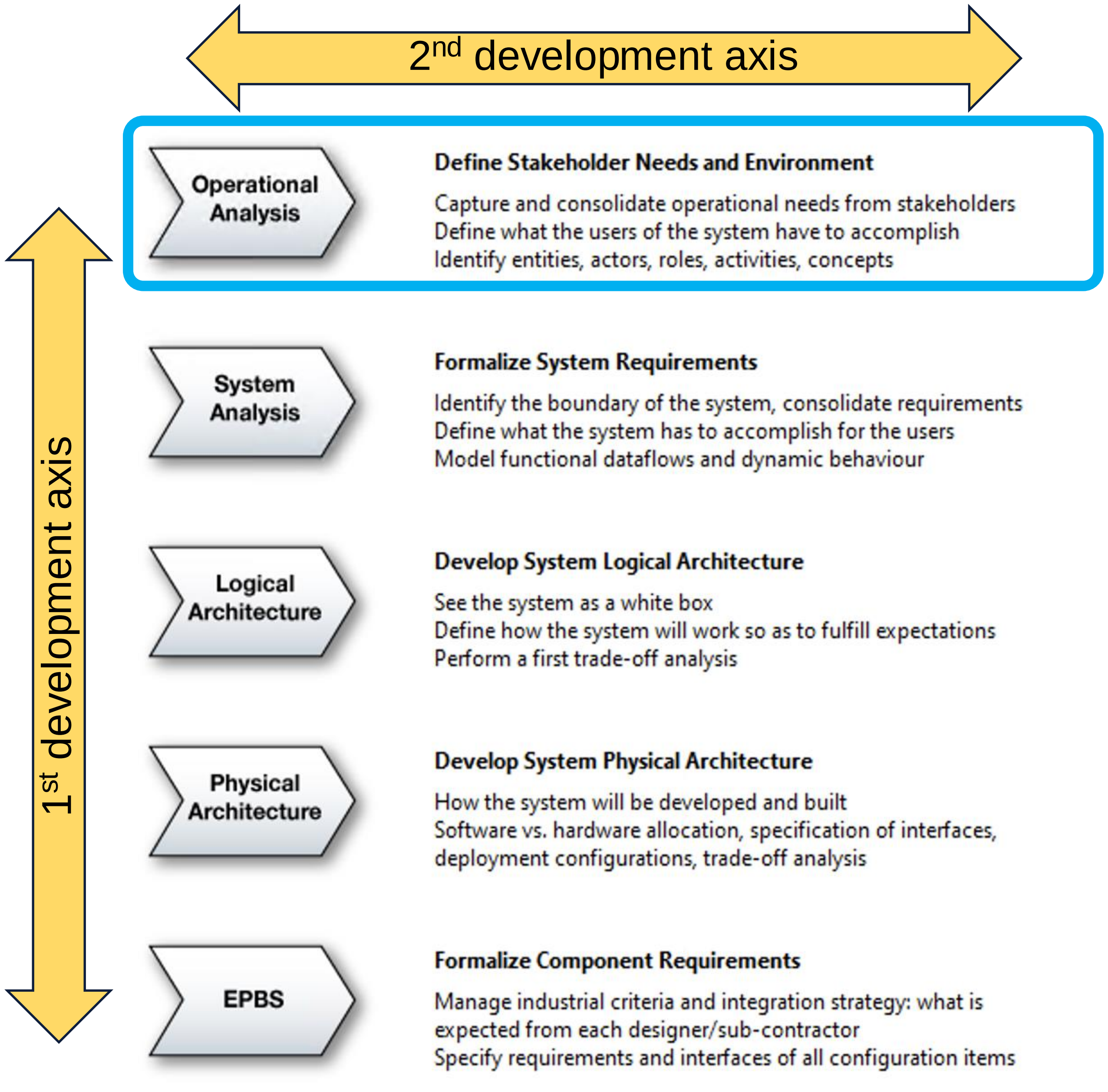
- **The model was developed "by the book"** defining the goal and scope of the process by a capabilities diagram in Capella 5.1 (later upgraded to v.6.1).
- **It encompasses only the operational analysis**, including one main process and two sub-processes, totaling 69 activities.
- **Access to the model is provided by 11 diagrams**: 1+2 (simplified) architecture diagrams, 1+2 capabilities diagrams, 4 entity scenarios, and 1 state machine diagram.
- **Additional diagrams**, such as activity interaction diagrams and detailed operational architectures, were used during the model construction.
- **System analysis** and **logical architecture** steps were conducted to model the CERN quality management system. However, these steps **ultimately proved unnecessary** for demonstrating compliance with the Authorities' requirements.



Operational architecture of the waste process.
(EDH: CERN Electronic Document Handling system; QC: Quality Control; RWP: electronic RW Processing request; QRC: Quick reference Cards)

The result
A gain of six months

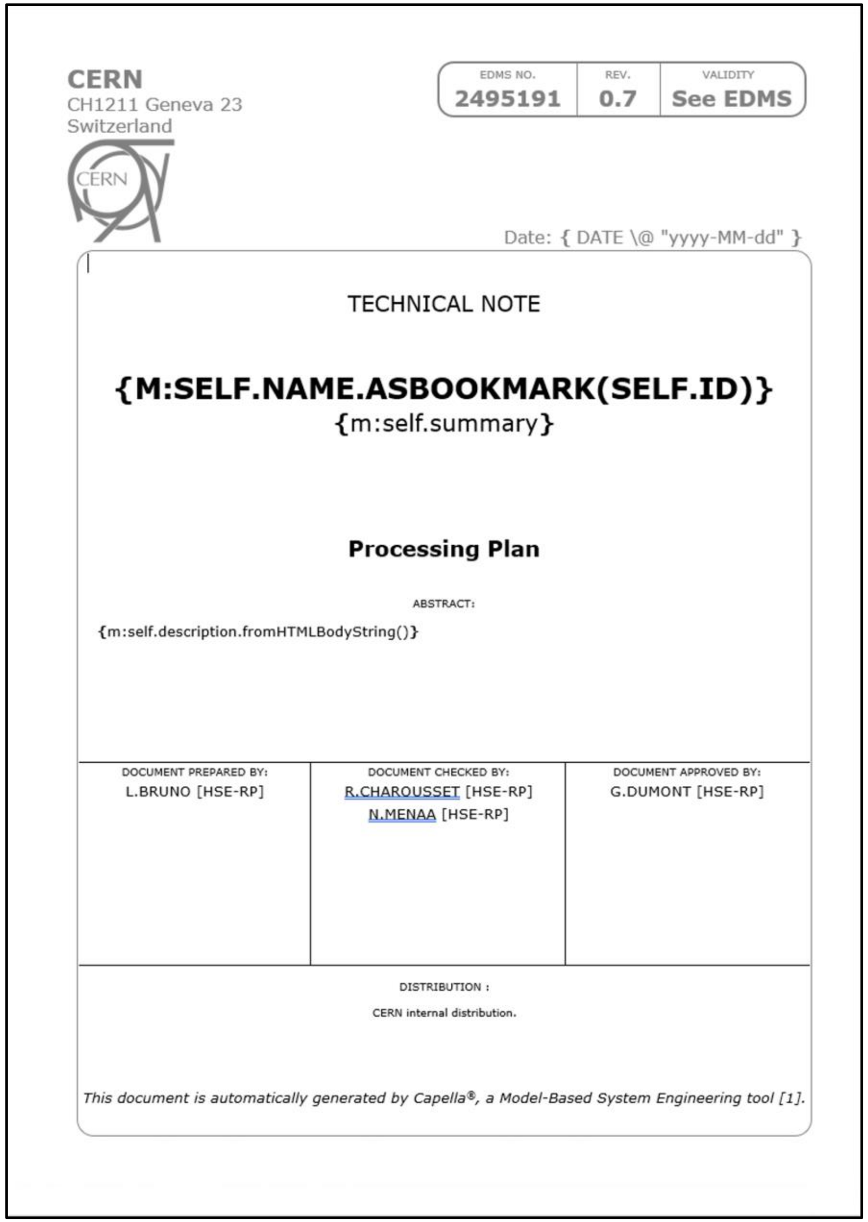
- Capella provided a comprehensive set of diagrams **that addressed all design needs**.
- Beyond the model and the low-level operational documents therein referenced, **no additional documentation was needed** for designing, auditing, and implementing the process.
- The diagrams served as a clear basis for discussion. Differences in the **educational backgrounds** of technicians, engineers or physicists **played little or no role at all**.
- **Communicating with the auditors** was so **effective** that the process was approved the very same day of the audit.
- **The model was re-used** for the elimination of non-meltable radioactive waste. The development took ~12 months instead of 18. **About 6 months of work were saved**…



Interpretation

Why a gain of six months?

- **A picture is worth a thousand words**: the diagrams were extremely effective in conveying the information.
- **A 2nd development axis seems to exist**: the traditional text-based approach progresses “horizontally”, with documents addressed to the different stakeholders (physicists, engineers, technicians…). The model’s information is thus repeated and adapted for the reader.
- **The process was developed in one go** thanks to Capella, which streamlined information sharing and avoided repetition.
- **The semantics facilitated the impact analysis** of the changes requested by the stakeholders.
- **The stakeholders’ attention shifted** from the text documents to the process itself.



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TECHNICAL NOTE

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Processing Plan

ABSTRACT:
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DOCUMENT PREPARED BY:	DOCUMENT CHECKED BY:	DOCUMENT APPROVED BY:
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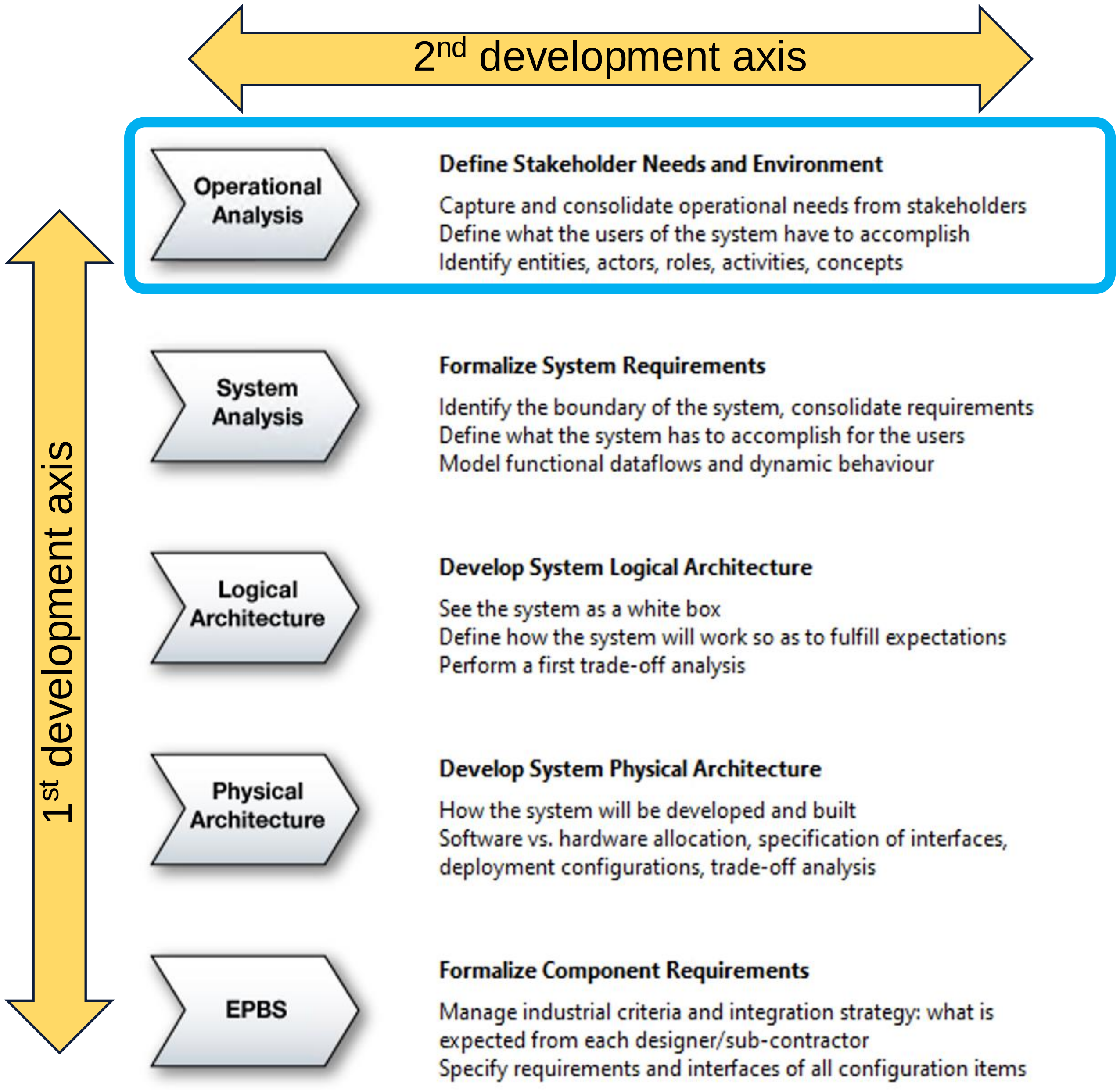
This document is automatically generated by Capella®, a Model-Based System Engineering tool [1].

The text documents
A special "viewpoint": M2Doc

- "**Text documents do not own any of the knowledge specific to the model** and, in fact, should be perceived as just another set of Views that make up the Model, albeit text-based Views" (J.Holt & T.Weilkiens, *Systems Engineering Demystified* 2nd ed.).
- Actually, only a set of contextual information common to all CERN RW elimination pathways is given in the template.
- **Indispensable** to interact with stakeholders that are not familiar with the MBSE approach or the Capella tool.
- The **text documentation boils down ~10 pages** containing diagrams and tables, possibly with the low-level "Quick Reference Cards" (QRC) as annexes.
- The Authorities accept referencing documents in the QRCs without version number. This gives **flexibility to disclose information** and avoids freezing the operational documentation in the context of a formal approval.



Some final remarks…

- **The model was extended to all other elimination processes**, unifying and consolidating roles and operational activities.
- **The extended model was adopted**: its views are now the standard process reference.
- **Capella has not (yet) been adopted** by the team. Despite a user-friendly software and objective results, it is not straightforward for newcomers to "go from start to the finish line".
- **The French auditing authority was surprised** by the fast results obtained, as they were unfamiliar with the approach.
- **Life Cycle Analysis could benefit from** a suitable implementation of **the "2nd axis"**: a "gate-to-gate" approach would then be possible, integrating information otherwise dispersed across the organisation.

Conclusions

- The **ARCADIA method** was used to conceive and specify efficiently a process for the elimination by melting of CERN ferrous low-level/intermediate-level metallic radioactive waste.
- **Capella** was instrumental in the transition from the traditional approach in use at CERN to the new MBSE mindset.
- **M2Doc** was indispensable to interact with stakeholders that are not familiar with the MBSE approach or the Capella tool, producing very concise text documentation.
- The method and tool ensured the **quality** requested by the French auditing authority to meet the acceptance criteria set by the foundry and the final radioactive waste repository.
- The model gave **insight** on all other elimination processes, unifying and consolidating roles and operational activities.
- The approach could have **potential benefits** in other domains, such as streamlining environmental life-cycle assessment.

Thank you
for
your attention