Title of the Paper: Status of ASTRID Nuclear Island Design and Future Trends

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Abstract. In the frame of the French ASTRID project led by CEA, AREVA NP is in charge of the design studies of the whole Nuclear Island. The conceptual design was completed end of December 2015 with the issuance of a large amount of engineering files (few thousands). The design of ASTRID intends to cope with GEN IV objectives regarding the new reactor concepts and includes ambitious performances to deal with concerning safety and availability for instance. Thus, numerous technical challenges were faced and successfully managed by AREVA NP during the conceptual design phase dealing with:

- Deployment of design process based on System Engineering standards,
- Selection of adequate architectures and design justification (at the conceptual level stage) for the various main systems and components: primary circuit, secondary loops, decay heat removal systems, fuel handling and component handling systems, I&C platforms, electrical systems, general layout of nuclear island building etc.

Throughout the design progress, AREVA NP experimented new approaches in terms of management of innovations, advanced numerical simulations, management of large CAD models and the related interfaces with the other industrial partners, introduction of Virtual Reality tools to enhance the complexity mastering of the layout.

In addition, this paper describes the main technical achievements regarding the NI and main systems or component definition at the end of the conceptual design phase.

Future trends for the design of the NI are presented in terms of evolution of the technical configuration and enhancement of the engineering tools.

Key Words: ASTRID, Nuclear Island, design tools, virtual reality.

1. Introduction

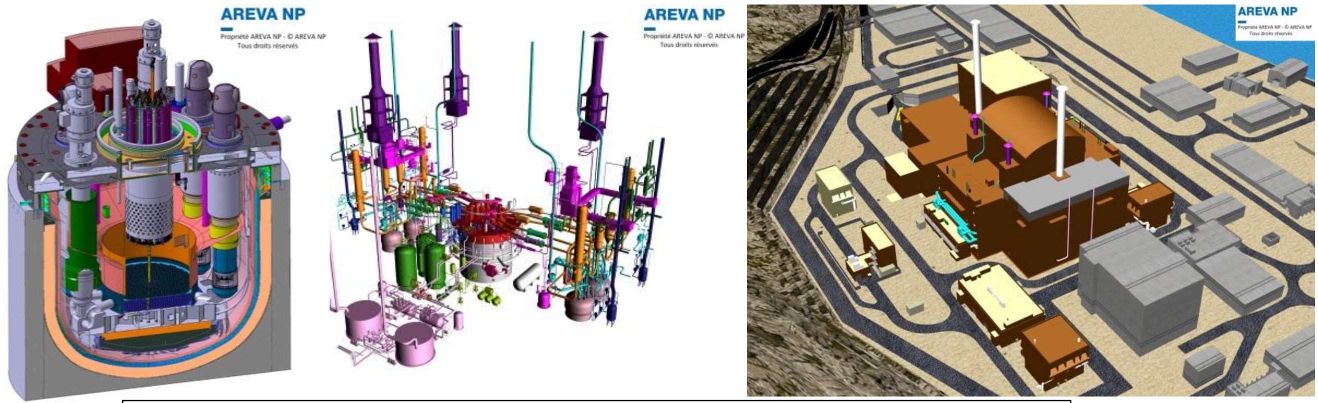
This paper presents the main achievements of the ASTRID conceptual design phase as performed by AREVA NP and dedicated to the Nuclear Island definition. The completion of this conceptual design phase end of 2015 was a key milestone on the ASTRID development route. Started end of 2010, the conceptual design lead to intensive engineering studies, involving all the engineering disciplines and required to master of large amount of technical data, interface parameters between disciplines and other parties involved on the project (CEA and the other 13 industrial partners), with the final issuance of several thousands of engineering documents at the end of 2015.

A focus is made in this paper on the advanced and innovative design process, engineering methods, numerical simulation tools and 3D digitalization approaches successfully deployed to master the high level of complexity inherent to the design of the whole Nuclear Island (NI) of an Advanced Sodium Fast Reactor prototype like ASTRID.

2. Conceptual Design of ASTRID: A Key Milestone

The completion of the conceptual design phase end of 2015 implied the management and the selection of adequate architectures throughout numerous technical options investigated. Preliminary design justifications were issued (at a suitable level of definition) for the various main systems and components: primary circuit, secondary loops, decay heat removal systems, fuel handling and component handling systems, I&C platforms, electrical systems, general layout of nuclear island building etc.

This lead to a coherent conceptual design file for a 600 MWe SFR Nuclear Island included a power conversion system based on the classical water-steam cycle. In addition, a first version of the Safety Option Report was formalized and fixed the safety referential basis for the design.



ASTRID NSSS + Nuclear Island Conceptual Design Reference Configuration

3. New engineering Practices for Complexity Mastering

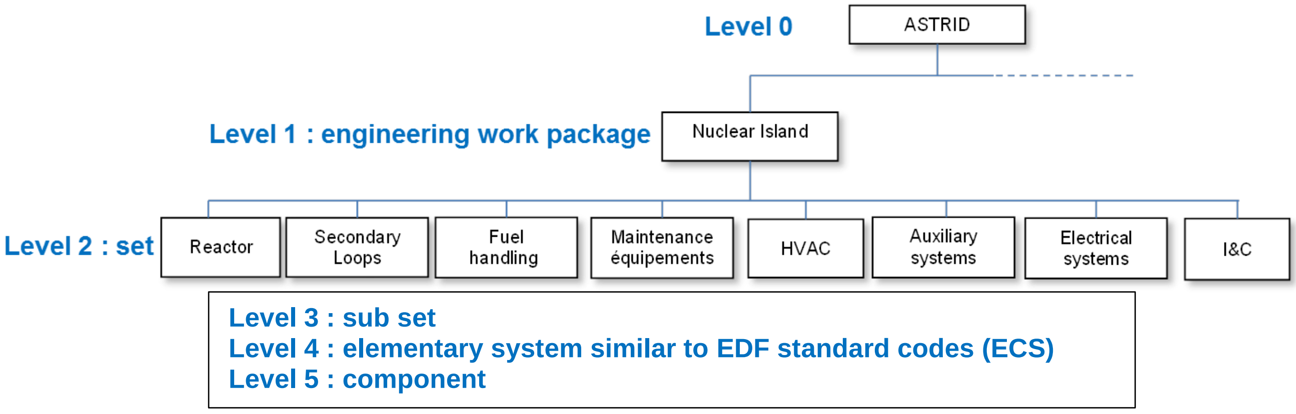
3.1. Design Process & System Engineering

Design Process deployed for the engineering studies are based on the RG Aero standards as required by CEA on ASTRID Project. System engineering methods are part of RG Aero Standards (through RG AERO 00077). For the Conceptual design phase of ASTRID it has been decided to apply a simplified approach of RG AERO Standard including some elements of System Engineering referential.

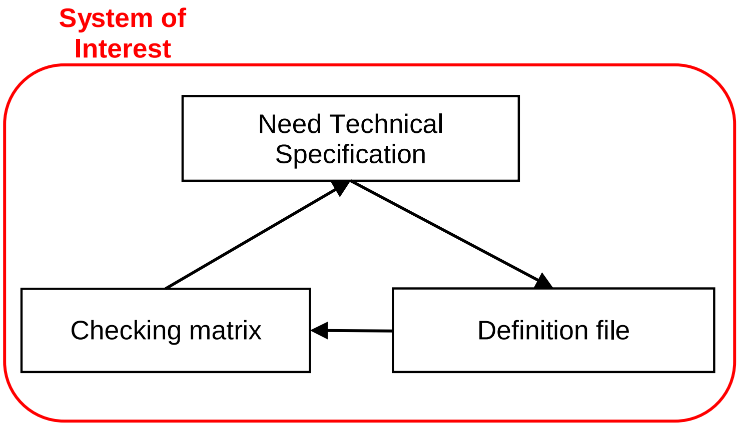
Thus, the ASTRID document organization is based on:

- Product Breakdown Structure (PBS),
- Functional Breakdown Structure (FBS),
- Need Technical Specifications (NTS),
- Definition files,
- Checking matrix.

PBS is a hierarchical representation of the different systems of the product to design, structured with 5 levels (as converged with CEA & EDF).

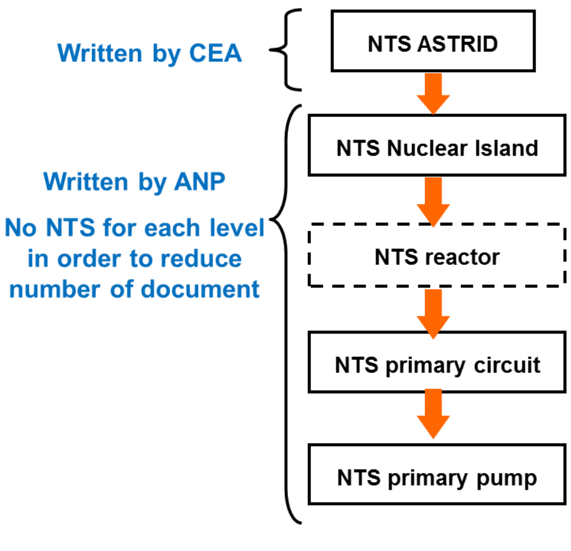


For the Conceptual Design Phase, systems of interest of the PBS are selected to be the purpose of the design studies. For each system, the technical documentation is structured and managed as follows all along the design process:



NTS: lists all the requirements needed to design a system. The NTS are written relatively to several nodes of the PBS (the main ones as regards the conceptual design stakes). NTS contains: a functional analysis (which functions are performed by the system ?), requirement tables with 5 parameters: Function/Requirement/Criteria/Level/Flexibility, with in addition the traceability with customer needs (NTS ASTRID = highest level).

NTS structure and organization:



Fifteen NTS have been issued during the Conceptual Design Phase.

FBS is a hierarchical list of the different functions performed by the product to design. High level functions are defined in NTS ASTRID. FBS compiles the list, in one document, of the results of the different functional analysis performed in the various NTS.
Example of FBS cascade:

- **1. Transfer thermal power from core to ECS**
  - **1.1 Transfer thermal power from core to secondary loop**
    - **1.1.1. Provide forced circulation of primary sodium**
      - **1.1.1.1 Support the primary pumps**

Design files formalize the answer to NTS. They contain design reports, drawings, mechanical diagrams, etc. and the need for support studies (thermal-hydraulic, thermomechanical analysis, etc.).

Checking Matrix: dedicated to check if the design fulfills (or not) the requirement of the NTS. The structure of the checking matrix is the following:

Requirement	Criteria	Level	Flexibility	Is the requirement fulfilled ?				Corrective actions	
				Yes	No	Need for details on requirement	Not checked yet	Description	Milestone

From NTS (Requirement, Criteria, Level, Flexibility) — Design consistency (Is the requirement fulfilled ?, Corrective actions)

Checking Matrix have been partially completed at the end the Conceptual Design Phase in connection with the progress of the design studies. Not compliant or missing will motivated complementary analyses in the next design phase and/or addition design iterations and/or mitigation action plans in the case of the occurrence of critical risks.

In addition transverse requirements, mainly related to safety and/or regulatory topics, are expressed in dedicated documents. Those transverse requirements are taken into account at different level of the PBS as needed. NTS of the corresponding PBS nodes refer to these transverse requirements to ensure the suitable traceability.

System Engineering process are key to structure the design route, the design documentation cascading and issuance and the suitable propagation of the requirements to fulfill at the different levels of the Product Breakdown Structure. This will help at the end the validation of the adequacy of the design solutions through the compliance matrix. System Engineering is a proven route to master a high level of engineering complexity as it is facing when managing a whole Nuclear Island conceptual design phase.

System Engineering deployment motivates in addition the implementation a suitable Design Team Organization. For AREVA NP and the management of the whole Nuclear Island scope a dedicated team of Architects Engineers are been settled acting as the Design Authority for the technical mastering of the project execution. Those Architects are in charge of the major PBS nodes (level 2) in terms of work program definition and survey, technical arbitrations related to architectures definition and sub-systems design options, management of technical risks. In addition they manage transverse topics (safety, radiation protection, ISI, codes and standards, product performances, transverse requirements etc.).

The design of the sub-systems to consider at the Conceptual Design stage is managed by Technical Responsible Engineers acting in close connection with engineering disciplines team with respect to the Work Breakdown Structure (WBS) implemented.

The System Engineering processes defined for the Conceptual Phase will be continuously broadened during the following steps of the project to enhance the compliance of the SE standards as required.

3.2. Advanced numerical simulation

The design of a new and innovative GEN IV reactor model like ASTRID is a challenge especially regarding Engineering tools and methods. The design of the whole NI implies to deal with numerous sub-systems and master the complexity of the systems arrangement and interactions. In that frame CAE (Computer Aided Engineering) and numerical tools are key aspects dealing with a strong coupling between a large variety of disciplines:

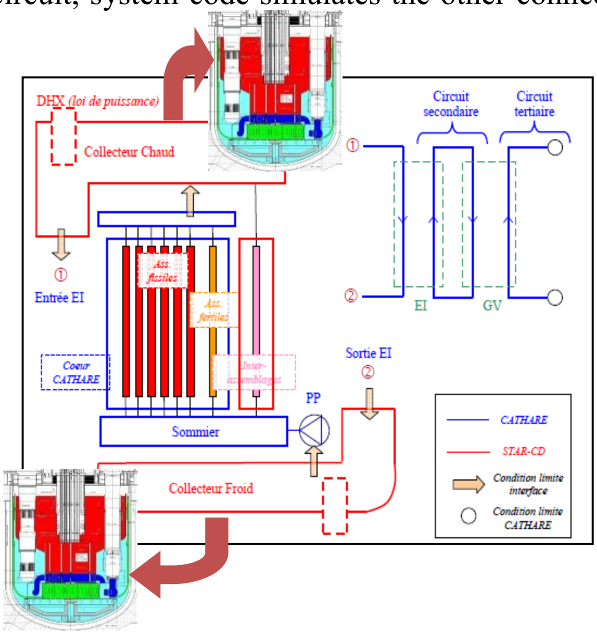
- Physics and Core Design,
- Materials behavior (standards & codes criteria),
- Structures and Components design,
- Thermal-hydraulics,
- Environment,
- Plan Layout and civil work (dynamic seismic response),
- I&C systems.

In addition, safety demonstration need to manage plant dynamic simulations encompassing the complexity of the whole coupled contribution of the various disciplines. This will be addressed through Systems Design Simulation tools. Design and Licensing imply then the simulation of an exhaustive range of the 'plant state situations': normal operation including transient regimes, incidental and accidental transient situations, for sub-systems and the whole plant.

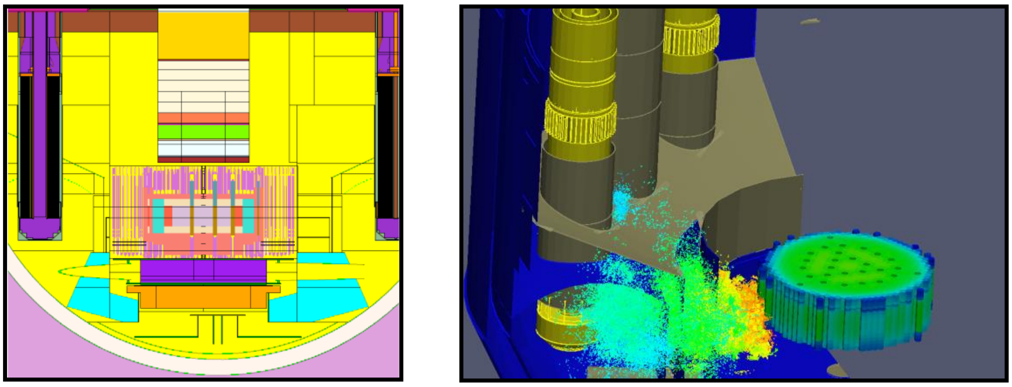
In that frame key topics deal with:

- Multi-physics,
- Multi-scales: in terms of geometry and characteristic time of the phenomena (duration of the transients situations : from 1s to several weeks)

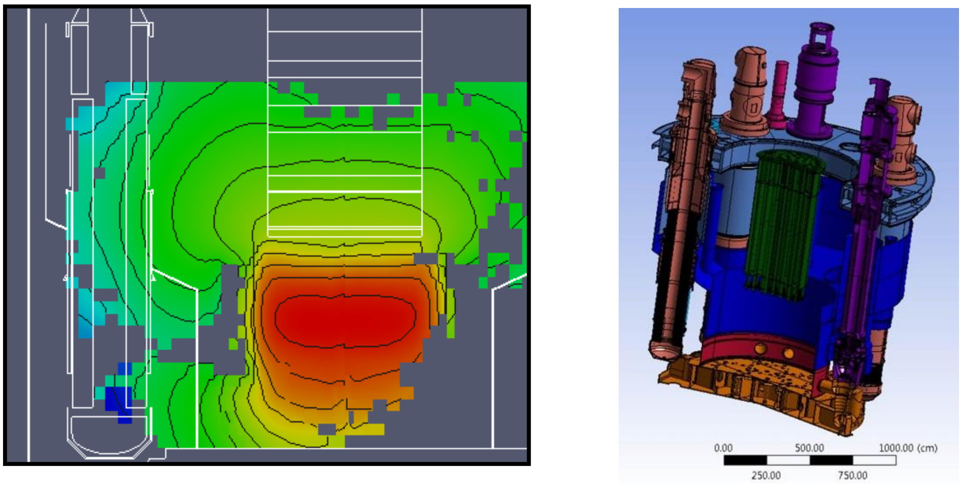
For ASTRID design coupled simulation of the whole plant has been performed by an innovative coupling between a CFD code and a system code: CDF is focused on the detail simulation of the primary circuit, system code simulates the other connected circuits and systems. See below:



Radiation propagation evaluation is other major topic to master: to specify suitable lateral neutron protection devices all around the core, to validate adequate low irradiation level in the secondary sodium loops for instance. In that radiation propagation through the complex geometry of the primary circuit (core, internals, primary component) in taken into account using large Monte Carlo models (with MCNP code) base on an advanced simulation environment. The CAD surfaces defining the geometry to consider are directly converted in boundary surfaces suitable for MCNP computations. In addition all the required data (materials, lattices etc.) are implemented through the same pre-processing tool. A validation step has been managed with the deployment of the same simulation route defined for ASTRID to the Superphenix configuration, that allowed a very good comparison with onsite measurements.



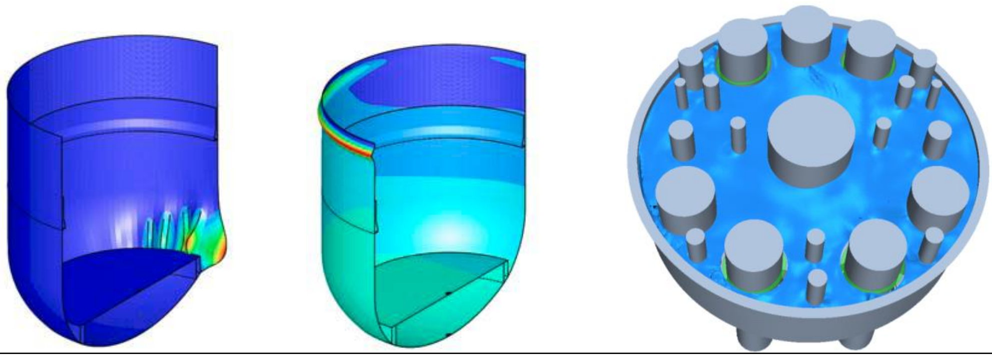
MCNP model – Primary circuit of Superhenix



MCNP model – Primary circuit of ASTRID (neutron flux distribution,

Advanced numerical simulations have been also managed in other domains: thermomechanical justification for components design, dynamic studies (main vessel seismic response and sloshing effects at the primary sodium free surface – see bellow), sodium fire accidents, accidental radioactive or chemical releases evaluations, component justification in case of sever accident scenarios etc.

The design of the Next Generation of nuclear systems is a favorable framework to deploy new methodologies and tools.



Dynamic studies of the ASTRID main vessel + sloshing simulation in seismic conditions

3.3.Mastering of large 3D CAD models for the whole NI

The design of the ASTRID NI needed the production and the management of numerous CAD models of the various mechanical parts through CATIA. The global ‘remontage’ of the NSSS systems is performed using CATIA leading to a big numerical model requiring adequate computing resources. In some cases limitations are encountered in the CATIA environment due to the size of the digital model obtained. Configuration management process has been deployed for the management of CATIA CAD models. Improvements are still need to reach a satisfactory efficiency in the engineering process. In the future, the envisaged connection with a PLM tool could offer a proper solution to improve the present situation.

The nuclear buildings definition and arrangement are managed using the PDMS tool. The integration of the various systems in order to deliver the whole ‘remontage’ of the Nuclear Island implies the import of CATIA data in the PDMS environment leading to a very large 3D CAD mock-up. Like for CATIA, configuration management of PDMS models has not been considered fully satisfactory at the end of the Conceptual Design phase.

Globally, throughout the conceptual design phase, the mastering of the CAD tools has increased continuously with the capitalization of the best practices generated, taking benefit in parallel from the other ongoing new build projects (EPR, ATMEA1) within AREVA NP.

3.4. Virtual Reality deployment

Since September 2015, a Virtual Reality (VR) tool has been deployed and integrated with the design process of ASTRID for the NI scope performed by AREVA NP.

The selected tool is the IC.IDO software package distributed by ESI-Group. This selection has been validated after a 6 month trying period managed during the first half of 2015. The tests have been performed in the frame of nuclear reactor engineering activities dealing with immersive virtual sessions based on EPRs, ATEMA1 and ASTRID 3D CAD mock-up.

Key Drivers related to the selection of IC.IDO have been the followings:

- Fully open to visualized CAD models coming from various sources, especially CATIA, PDMS, SolidWorks and ability to mix easily the different models,
- Reduced effort to prepare a VR session,
- Ability to manage very big CAD models like Nuclear Reactors ones with realistic animations and immersions (limited hardware resources required)
- Dedicated and efficient VR functionalities of IC.IDO (especially in the frae of Hua Factor analyses).

A CAVE (Cave Automated Virtual Environment) has been implemented at the Lyon (France) site of AREVA NP. It included a single power wall (large screen), a 3D projector and 3D glasses for the participants to the virtual reality immersive sessions.

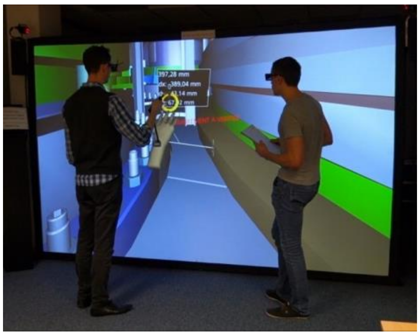
The main uses of the VR tool are the followings:

- Virtual engineering (design stage, validation process, multidisciplinary reviews),
- Virtual build (anticipation of the mounting and erection phase)
- Virtual services (maintenance aspects to be taken into account at an early stage in the design process),
- Virtual product presentation (efficient way to present the progress of the design with stakeholders and the customer in particular).

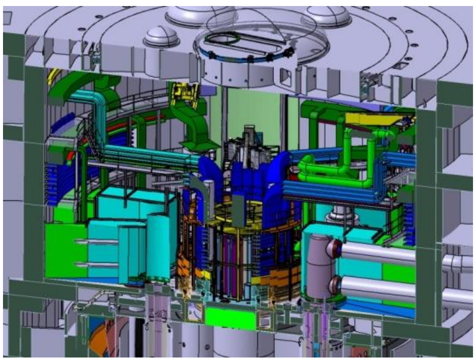
All those aspects have been deployed within the design process of ASTRID and scheduled in the work program. For instance, VR design reviews are connected to the main milestones of the project execution to help de design validation.

VR is a powerful tool to manage complex layout definition, like for the area located just above the roof slab of the primary circuit (the ‘grenier’). It allows efficient communication and is especially deployed for training sessions dedicated to new comers within the design teams.

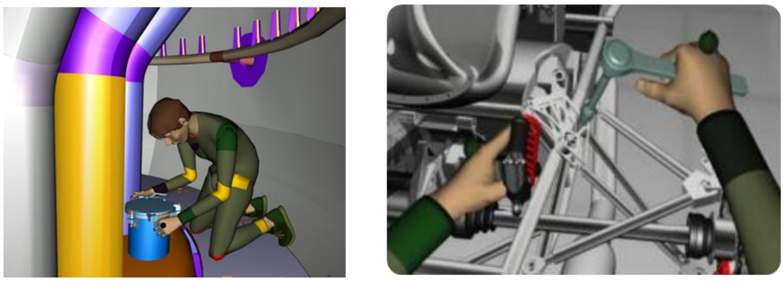
VR design processes are progressively formalized in the whole design route deployed for ASTRID. The main benefits are: better quality control, efficient multidisciplinary communication and understanding, fully compatible with design review with stakeholders, better anticipation of Human Factor aspects and future phases (erection and construction, operation, maintenance).



CAVE at AREVA NP Lyon (France)



Complex layout management



Virtual Reality tool for maintenance studies

4. Future Trends

Reference [1] details the future trends of the ASTRID design route: start of the Basic Design phase with a preliminary phase consisting of options studies to reconsider the Power Conversion System (PCS) (water-steam to be replaced by a Brayton Cycle: the Gas PCS) ith in addition some optimizations leading to cost reduction and/or plant availability improvement.

Regarding the design process, the deployment of the System Engineering approach will be reinforced: completion of the various SI steps, digitalization of the Project SI process by the implementation of the PLM tool. In addition the progress and use of advanced numerical tools will continue following a project roadmap including the required step of validation and qualification of those tools.

5. Acknowledgement

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