ASTRID, The SFR GENIV Technology Demonstrator Project Where Are We, Where Do We Stand For?

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ASTRID, The SFR GENIV Technology Demonstrator Project: Where Are We, Where Do We Stand For?

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Abstract –*The Preconceptual Design phase (AVP1) of the ASTRID Project ended late 2012, the main goal was to evaluate innovative options. It is now followed by the AVP2 phase planned until the end of 2015 whose objectives are both to focus the design in order to finalize a coherent reactor outline and to finalize by December 2015 the Safety Option Report.*

The CEA acts as the industrial architect of the project. In 2014, twelve industrial partners were involved in the project. Japan which participates now in the design studies and also in R&D in support of the ASTRID Project and VELAN of the French "Pôle Nucléaire de Bourgogne", are the latest partners to join the Project.

The Option Selection Process (RCO) is continuing during the AVP2 phase although structuring decisions remain to be made (the choice of the Energy Conversion System between Rankine cycle and Gas Brayton cycle). Other important option selections, which could nevertheless be reconsidered before starting the core of the Basic Design phase are: the choice of an internal fuel storage and a gas fuel handling chain, a rectangular reactor building with a single wall containment, the steam generator size the vertical handling of components. In addition, BOP studies considering the MARCOULE site as a possible one are going on.

The next important milestone is at the end of 2015 with the release by the Project team of a convincing and coherent Conceptual Design file.

I. INTRODUCTION

Near the end of the ASTRID Conceptual Design (AVP2), 12 industrial partners have now joined the Project which organization is now fully operational. The objectives are shared and the collaborative work aims at convincing French government to launch the Basic Design.

One of the main objectives of the 3 years (2013-2015) ASTRID Conceptual Design phase (AVP2) is to propose a coherent and innovative design of a GENIV sodium cooled fast reactor technology demonstrator which design, licensing process and operation has to be valuable for a commercial size reactor. In particular ASTRID Safety Option Report should be finalized by the end of 2015. ASTRID is a 1500 thMW self-sustainable pool-type SFR equipped with its energy conversion system. In addition of its prototype character, ASTRID should authorize some experimental capabilities such as offering irradiation services for:

- Demonstrating Fast Reactors flexibility to breed or burn Plutonium, and transmute Minor Actinides
- Advanced fuels and materials.

The AVP2 was preceded by:

- 3 years of R&D (2007-2009) reconsidering all the design options in the light of past SFR reactors feedback but also current projects (ASTRID Project was not launched at that time)
- Followed by 3 years (2010-2012) of ASTRID pre-conceptual design phase (AVP1) in which

the search for mastered innovations was an important incentive.

ASTRID Project current driver schedule is shown in Fig. 1. It considers at the end of the AVP2 a 4 year duration Basic Design phase (2016-2019).

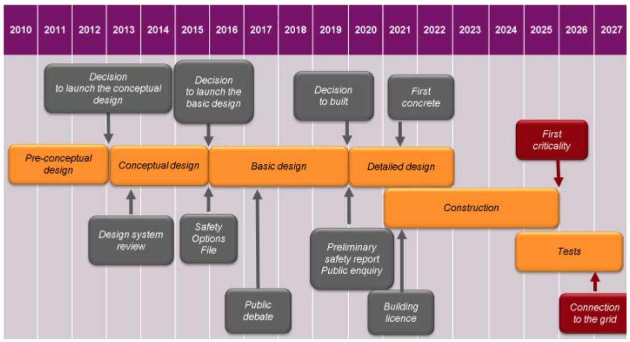

Fig. 1. ASTRID Project driver schedule

The objective of this paper is to show the current status of the ASTRID Project (partnerships, organization, reactor configuration, highlights concerning exchanges with French safety authority) before concluding with some prospects for the next phase.

II. STATUS OF THE PARTNERSHIPS AND THE ASSOCIATED ORGANIZATION

II.A. ASTRID Project Partnerships

Since the last status on the ASTRID Project[1], 2 new partners have joined the Project in 2014: Japan[2] and VELAN French company. As shown in Fig. 2, there are now 12 bi-lateral partnerships contracted with CEA.

Fig. 2. ASTRID Project Partnerships

Early 2013, after the accident of Fukushima, the Japanese have wished to re-discuss with France for an entry in the ASTRID Project. Exchanges became very intense, with 8 face to face meetings in Tokyo or Paris in 2013 and 2014, supplemented by audio conferences which frequency has reached a weekly rhythm at certain times. These discussions, which were attended by AREVA, have been successful as a partnership agreement was signed, covering both ASTRID design and the R & D in support.

This partnership is a 2 levels arrangement:

- the general agreement which establishes the main principles of the collaboration; the signatories are for Japan the Japanese Ministry of economy, trade and industry (METI) and that of the education, culture, sports, science and technology (MEXT), and on French side the CEA by delegation of the French government; it was signed on May 2014, 5 during the visit of the Japanese Prime Minister to Paris. This arrangement covers a period up to the end of the Basic Design phase (2019),
- the "implementing arrangement", signed by the Japan Atomic Energy Agency (JAEA), Mitsubishi Heavy Industry (MHI), its subsidiary Mitsubishi Fast Breeder Reactors (MFBR), AREVA and CEA; It lays down the principles and the governance of the R & D and design activities around the ASTRID project, as for example intellectual property, the rights of use, the transfer of information to third parties, rights after 2019 … it was signed August 2014, 7.

29 task-sheets have been approved and are annexed to the implementing agreement, 26 for R & D and 3 for the ASTRID design activity. They cover the development by JAEA, MHI and MFBR of:

- one of the systems of evacuation of the residual power,
- a complementary control system, based on a Curie point electromagnet
- and Seismic Isolation System and related R & D needs.

These task sheets are directly contributing to the AVP2 deliverables.

Another partnership agreement was signed in 2014: in the frame of discussions with companies affiliated with the nuclear pole of Burgundy , the VELAN company joined the ASTRID project with a contribution on the design of large diameter sodium valves to isolate the intermediate sodium circuit.

It is also important to underline the signature in September 2014 of the extension of the cooperation agreement which binds now EDF to CEA until the end of 2019.

The organizational structure of the project is schematized in Fig. 3. It now involves about 600 people.

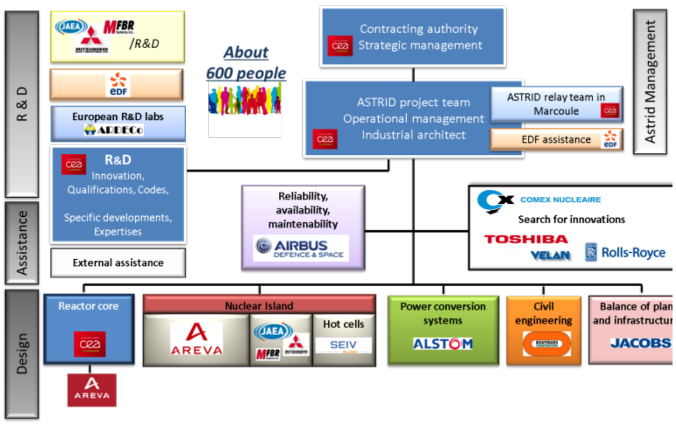

Fig. 3. ASTRID project Organization

CEA still acts as the industrial architect of the Project, supervising the consistency of the design and managing the 3D reactor mock-up's. The project is organized in Engineering batches and also transverse activities (reliability, availability) and search for innovation (main and security vessels inspection carrier, electromagnetic pump for the secondary circuit[3], compact Na/N_2 heat exchanger for the gas energy conversion system which remains the preferred option for ASTRID during the AVP2).

2014 has also been the year of the intensification of the European R&D cooperation in support of ASTRID (ARDECO project):

- Swedish universities contribute to the project (post-doc and PhDs funding).
- An agreement was signed with the Paul Scherrer Institute concerning core thermalhydraulics in accidental situations.
- Other contacts are in good progress with several other European R&D labs

II.B. Project organization improvements and highlights

Improvement of the efficiency to make simultaneously working the industrial companies involved in the Project was an objective of the AVP2: at the beginning of AVP2, it has been made the observation that on subjects with a strong interface between 2 partners (core of CEA responsibility and Nuclear Island of AREVA responsibility for example), the AVP1 mode of operation based on an exchange of data at regular intervals was not sufficient. It had been therefore decided to implement integrated working groups to improve the efficiency and better anticipate the data exchanges between partners. These working groups are now effective. The concerned topics are:

- the reactivity control mastering,
- the integration of core instrumentation and experimental channels in the nuclear Island,
- control rods mechanisms,
- sub-assembly handling and error of handling,
- core and assembly mechanics,
- core volume reduction,
- devices for corium evacuation from the core to the core catcher,
- secondary sodium radioactivity,
- thermo hydraulic studies at the core/Nuclear Island interfaces,
- fuel internal storage,
- civil engineering codes and norms,
- constructibility and workshop phasing optimization,
- hot cells.

Methodology of Design Option Selection process has been reinforced. The Design Option Selection (DOS) reviews are very important steps of the Project, since they allow to gradually freeze the technical options chosen in the design to get a coherent reactor configuration at the end of the Conceptual Design in late 2015. They continued throughout the year 2014 on the following topics (non-exhaustive list):

- intermediate heat exchangers,
- fuel sub-assembly axial neutronic protection,
- operation of control rods system,
- fuel handling and internal storage,
- ISIR, instrumentation,
- sacrificial material choice for the core catcher,
- severe accident mitigation strategy,
- containment options,
- sodium/water/air reaction and associated design approach of the Steam Generator building,
- components qualification strategy[4],
- sodium retention device.

A document that synthesizes the decisions of these reviews is regularly updated. The DOS process involves a technical analysis by the CEA ASTRID Project Team and all the partners concerned by the subject; to do this, one or more preparatory meetings may be necessary as well as an internal meeting to the Project team to share information and discuss design choices orientation; the program leader is associated or informed of the guidelines; industrial partners have in general also an internal meeting. Proposals are presented and discussed in a plenary session, open to all interested persons, so that all views can be expressed, such as the technical performance, industrial, safety, security, operation costs; the consensus is generally reached; if not the chosen orientations and decisions are given by the ASTRID program and/or project managers.

Technical reviews, intended to give an update on the progress of a technical field, are not as formalized as DOS meetings because they do not lead to major decisions. A lot of technical reviews took also place in 2014:

- nuclear island
- primary circuit auxiliaries,
- I&C,
- treatment of cold traps,
- site management,
- electrical systems,
- scientific calculation tools roadmaps,
- roof of building reactor,
- special handling equipment in the reactor building,
- review of design on electromagnetic pump,
- review of the fuel and Steam Generator buildings,
- primary mechanical pumps,
- hot cells,
- confirmation of the decay heat removal means,
- options for the CFV V4 core and associated complementary safety devices,
- control rod mechanisms
- …

Finally, to ensure the completion of the options selection and/or confirmation processes, a systematic approach based on the ASTRID Product Breakdown Structure developed at level 5 is used (see Fig. 4). It helps recording taken decisions and programming Design Option Selection and Technical Reviews to meet the extensity and coherency of the design.

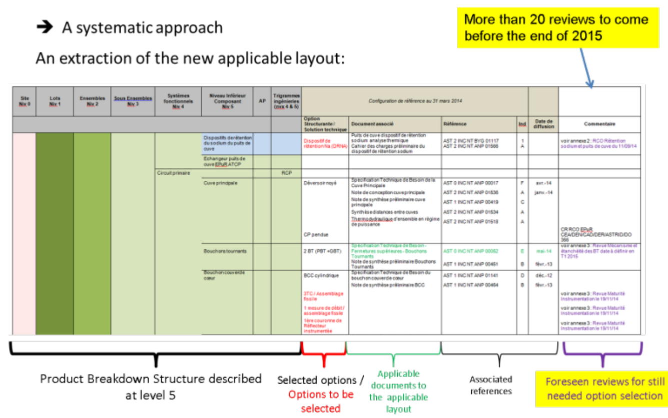

Fig. 4. ASTRID Product Breakdown Structure

II.C. Communication

Like every year now, the ASTRID project held on October 17, 2014 its annual information seminar at the intention of CEA and its industrial partners. Held at Cadarache, it was broadcast on video at Saclay and Marcoule. Like last year, the High Commissioner, the Deputy Director of the CEA Nuclear Energy Division and CEA nuclear research center Directors attended the seminar. For the first time this year, representatives of the Directorate General of energy and the climate (DGEC) of the French Ministry of ecology, sustainable development and the energy (MEDDE) participated.

III. RECENT EVENTS IN THE FIELD OF SAFETY

III.A. French Safety Advisory expert Committee on the GEN IV systems

On demand of the French Safety Authority, the French Safety Advisory expert Committee (FSAC) for nuclear reactors met on April 10, 2014 to give an opinion on the characteristics in terms of safety and radiation protection of the 6 GENIV nuclear energy systems selected by the Generation IV International Forum (GIF). The GIF coordinates worldwide research and development activities relating to these systems:

In this frame the 6 following systems has been analysed by the FSAO:

- the Sodium cooled Fast Reactors, SFR,
- the Very High Temperature Reactor , VHTR,
- the Gas cooled Fast Reactor, GFR,
- the Lead cooled Fast reactors, LFR,
- the Molten Salt Reactors, MSR,

- and finally the SuperCritical Water Reactors, SCWR.

The main findings of the FSAC are as follows: they consider that important research and development programs are still necessary to reach the 4th generation standards even if the amount of required development work is different depending on the particular system. They stress the interest to focus on systems insensitive to events that may occur in the plant or outside it.

Among these systems, the SFR system is considered are the only one with a sufficient level of maturity for the realization of a prototype in the first half of the 21st century with a safety level at least equivalent to that of the 3rd generation systems like the EPR pressurized water.

III.B. French Safety Authority follow-up letter after the Advisory Committee on ASTRID Safety Orientation Report

French Safety Authority letter after the June 27, 2013 FSAC on ASTRID Safety Orientation report issued in June 2012 has been communicated on April 10, 2014, at the occasion of the FSAO on 4th generation systems. It is usefull to recall that the FSAO considered that the guidelines presented in the Safety Orientation Report were globally satisfactory and that past-experience on SFRs was correctly taken into account; however, the FSAO made the following 3 recommendations:

- the project should demonstrate the safety of its installation taking into account the risks of chemical release according to a deterministic approach complemented by probabilistic analyses. The project should clarify the approach that it intends to implement to this end,
- project should address, in the Safety Option Report, the list of structures, systems and components necessary for the management of situations relative to the "Complementary domain of natural origins external aggression" to avoid early releases or important (this new notion of complementary domain arises from the application to new plants of the lessons learned from the Fukushima Daiichi accident)
- attacks used to design the reactor should be considered for all the states of operation of the facility.

The Safety Authority letter immediately makes echo of the FSAO recommendations as well as some recommendations of the IRSN analysis of the ASTRID Safety Orientation Report. The 20 requests contained in this letter are relative to the 7 following themes:

- ASTRID reactor objectives,
- regulatory rules,
- design approach: classification of situations and analysis methods,
- safety criteria related to the fuel and to the first barrier,
- safety functions and risks related to sodium,
- R & D in support of security,
- experience feedback from past SFRs.

These requetst can present significant challenges for the project such as the role of ASTRID as safety demonstrator): the 4th generation of reactors must bring a significant gain in safety when compared to the 3rd generation. ASTRID must therefore allow testing enhanced safety options.

III.C. Preparation of ASTRID Safety Option Report

Elements of these requests should be identified and answered in dedicated sections of the ASTRID Safety Option Report to be finalized for the water/steam energy conversion system by the end of 2015

The ASTRID Safety Option Report will be organized in 3 volumes: volume I on the safety guidelines and the general principles, a volume II which presents the site, describes the design and the selected options, and a 3rd volume III developing safety functions, analysis of the operating conditions, taking into account external and internal hazards analysis of hypothetical situations, and safety analysis associated with the experimental use of ASTRID.

Planning and organization in support of the milestones to monitor the progress of the preparation of volumes I, II, III of Safety Option Report have been defined. A specific organization is set up to accompany the process of drafting and review. The reassembly and verification of the consistency of the whole report must be completed by the end June 2015 in order to keep the time required for the process of validation before the end of 2015.

IV. SOME SKETCH OF ASTRID CONFIGURATION STATUS

The choice of an heterogeneous core with a negative or null sodium void effect (CFV core) is confirmed. Its version 3 with AIM1 as cladding material (see Fig. 3) has been finalized in 2014 and is the basis for the Safety Option Report. The design of the core and the sub-assemblies ensures a level of secondary sodium level activation lower than 10 Bq/cm3 thanks to a non-sealed and removable upper neutronic shielding enriched in B10, while fulfilling the others core performance objectives. It is equipped with additional complementary safety devices acting for the protection of the reactor (passive shutdon systems acting in case of loss of flow for a first system and Na temperature increase for the second system) and the mitigation of hypothetical severe core degradation (discharge tubes to evacuate the corium towards the recuperator). The core design includes now 144 internal storage positions and 22 other ones for the management of clad failures.

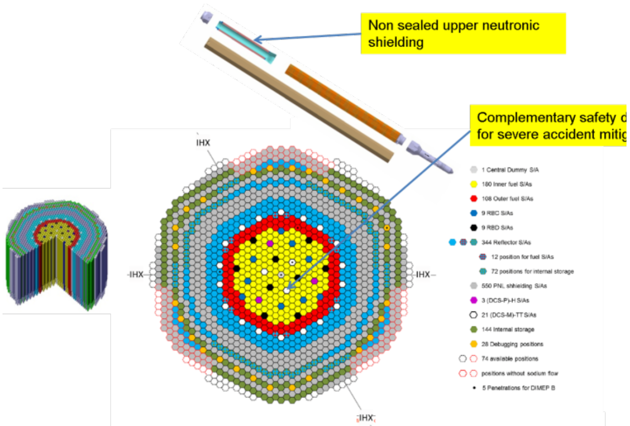

Fig. 5. ASTRID core main features

c Choise of 3 primary pumps and 4 secondary loops. The use of electromagnetic pumps for the secondary loops has been confirmed (see Fig. 6).

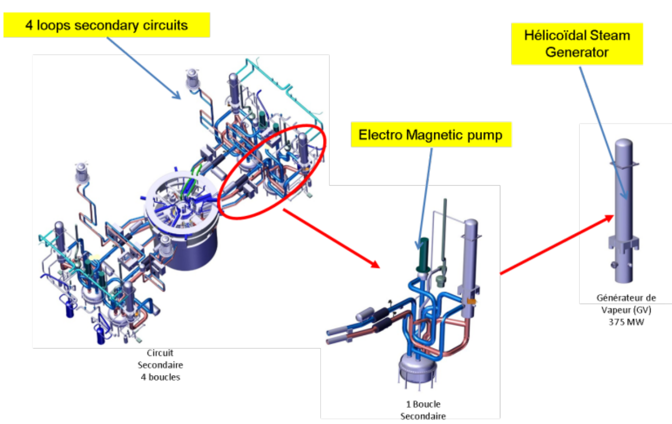

Fig. 6. ASTRID secondary loops (steam/water ECS option)

The year 2014 helped refine the design of the 375 thMW helicoidal steam generator with sodium inlet and outlet at the bottom of the component for a better segregation of steam/water and sodium regions[5]. Today the feasibility of the component looks achievable but it remains to necessary to carry out thermomechanical optimization studies of the lower part of the steam generator.

In order to prevent from hypothetical scenarios of Sodium Water Air Reaction (SWAR), the principle of a bunker around each steam generator has also been confirmed (Fig. 7). This cylindrical bunker is part of the civil engineering structure of the steam generator building. It is designed as a mixed structure made of two concentric steel tubes with concrete inside the annular space between them. The bunker diameter is 9 meters and its thickness of about 1.5 meters. There is no reinforcement of the concrete (in mixed structures, tensile strength is ensured by the steel plates). Studies are now focusing on the constructability of such mixed structures for which the experience feedback remains limited.

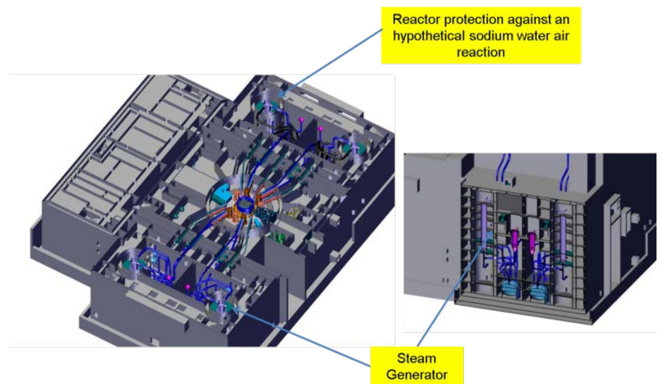

Fig. 7. ASTRID secondary loops (steam/water ECS option). View of the bunker protection around the steam generators

The evaluation of the performances of the decay heat removal through the vessels (RRC according the ASTRID nomenclature) led the project to redefine the Decay Heat Removal (DHR) strategy, strengthening the role of the systems located in the main vessel (RRA and RRB) until situations of mitigation. The RRC system is then seen as an emergency mean (associated with the filling with sodium of the space between main vessel and the security vessel). Fig. 8 illustrates de 3 diversified DHR systems of ASTRID.

Therefore the two main DHR systems are those implemented in the main vessel: the active one (or RRA) and the passive one (RRB). These systems now have a role in all situations of operation: from normal operation (function of the power residual during the stops when the secondary loops are no longer available) until situation of prevention, and now also in a situation of severe accident mitigation.

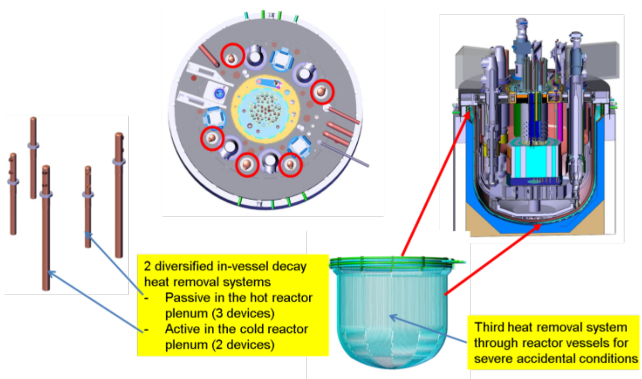

Fig. 8. ASTRID decay heat removal systems

The design of the active system is now a Japanese contribution to the project. The RRA has two independent trains having each a capability of 100% DHR. Retained fluids are sodium for the RRA loop itself, and air as cold source. Each train consists of: a sodium/sodium heat exchanger immersed in cold pool (therefore crossing the internal vessel), an electromagnetic pump ensuring the flow of sodium retained as a heat transfer fluid, a sodium/air exchanger, protected against the risk of aircraft crash exchanger, and the pumps supplying air to the sodium/air exchanger.

The design of the passive system remains the responsibility of AREVA. The main differences with the active system are: architecture in three trains, with a requirement that the function can be fully ensured by two trains on three (response to the so-called requirement of the single failure criterion), sodium/sodium exchangers are immersed into the hot collector, the location of these heat exchangers allows them to put the primary sodium in natural convection in the event of loss of the pumps.

The third DHR system consists of two trains, each with a tubular exchanger placed around the safety vessel, and with oil as fluid. Choice of oil is today the reference configuration, other fluids considered having been excluded, but it remains to be finalized. Oil circulates in forced convection, the choice of the natural convection was rejected because too impacting on the overall architecture of the nuclear island. Finally, each train has an oil/water exchanger, with water cooling via a common to both trains cooler. Design of the cold source allows operation for 7 days without water make-up or need from the water circuit power supply.

In 2014, parametric analysis of the development of the platform to receive the ASTRID plant (Fig. 9) on the model site of Marcoule near the Phenix prototype reactor now under decommissioning have been performed. This was a multi-criteria analysis considering the volumes of excavated materials, the cost and the duration of the development of the platform ... The constraints are the implementation of all the nuclear and the conventional islands on the rocky area of the site, the easiness of site civil engineering, optimization of the operation of the plant and the physical protection against external aggressions.

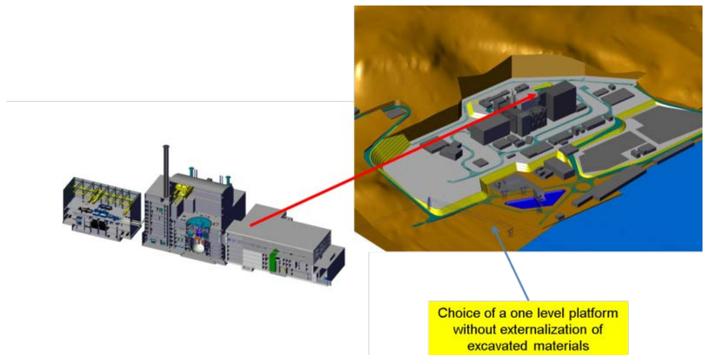

Fig. 9. ASTRID decay heat removal systems

The analysis presented in October 2014 led to the choice of a single level platform with the total reuse of excavated materials. This option requires a partial burying of the nuclear island of about 9 m which is beneficial on architectures of galleries.

V. TOWARDS THE END OF THE AVP2

Main objectives towards the end of the AVP2 are to finalize:

- ASTRID design by fulfilling the Design Option Selection process (many reviews are still to come in 2015),
- The safety option file on the water/steam option. It is to be recalled here that if this energy conversion system was chosen during the AVP2 for the complete plant configuration assessment, design studies are focusing on the gas energy conversion system (preferred option during the AVP2 in order to increase its maturity level) and that a choice between the 2 options is foreseen in December 2015,
- And the security option file. Security and protection against malevolence option definition follow a parallel process to safety. ASTRID will be one of the first plants to integrate early in the design process security considerations.

Mid of 2015 will be also issued an up-date of the 2012 ASTRID report to the government delivered in the frame of 2006 French act on waste management.

Finally, the major issue will be to provide to the government with a convincing and coherent conceptual design file. The main content of this file is given in Table I.

TABLE I

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Content of ASTRID conceptual design file

- Synthesis reports: ✓ ASTRID description, performances, content of the conceptual design file ✓ Systems technical specifications (STB)
- 3D mock-up for the water model (AST-V)
- Preliminary evaluation of ASTRID cost - Provisional planning of realization - Project risks analysis
- Safety Option Report (DOS) - Security Option Report - Codes and norms basis for ASTRID - Qualification roadmap for scientific calculation tools (OCS)
- Preliminary plan for ASTRID definition: ✓ Design choices justification ✓ Performances justification (including safety, operability and inspection capabilities) ✓ Needs for R&D and components qualification
- One synthesis file per partner
➔ Indicative number of issued documents (pre and conceptual design) : 2350

Some possible issues for the start of the basic design phase are as follows:

- if gas Energy Conversion System was to be selected, the corresponding Safety Option Report should be finalized in 2016
- a basic design preparatory phase could be necessary and include :
  - a strategic brainstorming on the prototype cost/power ratio,
  - the possible reconsideration of some design choices in case of unresolved difficulties,
  - discussions on the organization and logic of the next project phase.

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