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« ASTRID PROJECT: MAIN PROGRESS ON SAFETY DESIGN PROVISIONS »

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ASTRID is the Advanced Sodium Technological Reactor for Industrial Demonstration which is intended to prepare the Generation IV reactor, with improvements in safety and operability.
In order to comply with the related specifications, the Astrid project integrates innovative options.
In the earlier phase of ASTRID project, a specific safety approach was set and its main guidelines were agreed by the French Nuclear Safety Authority. This safety design guide is currently applied as reference for the choices of the design options.
The paper presents:
- *The main design provisions, to prevent any severe accident, as far as reasonably possible;*
- *The design approach, called "top-down" approach, relating to the radiological "confinement" safety function.*

As concerns prevention of severe accident, the design measures for "neutron reactivity mastery" are presented. These measures are based on efficient, reliable, redundant and diversified means for reactor shutdown. In addition, core features and inherent reactor behavior are enhanced and supported if needed by innovative devices.

In the same frame of prevention of severe accident, loss of the "decay heat removal" safety function must be practically eliminated in order to prevent, with a very high level of confidence, a severe accident that could lead to a cliff edge effect. The method applied to reach this objective is described and the resulting architecture of decay heat removal is presented.
In the frame of ASTRID safety studies, analyses are devoted to well define:
- *A domain of accidental sequences with very low occurrence frequency for which severe accident can reasonably be prevented thanks to appropriate design provisions,*
- *A few hypothetical situations, consequences of which could not reasonably be mastered, requiring robust safety demonstrations, in terms of prevention.*

As concerns the mitigation of potential radiological consequences, the paper presents the design provisions based on a "plant state" approach.
The main objectives, as regards the radiological risk, are to postpone a hypothetical off-site release of radioactive material coming from core degradation and also to decrease its health and environmental possible consequences.
Design provisions are taken, considering the different potential release ways inside the confinement.

As for the sodium risk, main objectives are to limit by design an overpressure of the containment.

I. INTRODUCTION

ASTRID reactor is a technological demonstrator designed by CEA and its industrial partners (Ref. 1). Innovative options have been integrated to contribute to the safety and improve efficiency, reliability and operability.
Complying with WENRA (Western European Nuclear Regulators Association) recommendations, the conceptual design of ASTRID takes into account a severe accident involving whole core degradation.

The safety design approach of ASTRID is based on the defence in depth principle.
The implementation of a defence in depth includes an extension of the design basis domain whatever the low probability of the events sequences. The objective is to prevent further the occurrence of a severe accident (definition of a SP domain). Despite this extension,

mitigation provisions are integrated to cope with the consequences of a severe accident (SM domain).

This SM domain is used to check that the core degradation is acceptable and that the mitigation devices are suitable in order to reduce the off-site consequences.

As regards severe accident situations leading to unreasonably mitigable consequences (high energetic scenario), a robust demonstration of prevention is set for each “practical eliminated” situation.

II. METHODOLOGY FOR SAFETY DEMONSTRATIONS

II.A Method for severe accident prevention

II.A.1. Line of defence method (LoD)

The ASTRID project takes into account the severe accident in accordance with the fourth level of defence in depth and uses, at the stage of the design, LoD method to show that the prevention of the severe accident is sufficient.

The LoD method which implements the first three levels of the principle of defence in depth, allows to check that any accidental evolution of the state of the plant, up to severe accident, is prevented by minimal set (in quantity and quality) of lines of defence. These LoD are conceived in order to minimize the risks of common mode failure and thus by ensuring a diversification, a functional and physical independence between them.

A line of defence is described as strong (or ‘a’) if it corresponds physically either to passive equipment (e.g. structure) carried out and exploited like a radiological barrier, or with a system of safety conceived in particular according to the single failure criterion and qualified by representative tests. The components of the LoD must be designed with adapted margins with respect to the stresses corresponding to the situations in which they have to achieve their functions (application of the codes and standards). The order of magnitude of the probability of failure of a strong line (‘a’), based on the experience feedback of systems respecting such requirements, is of 10^{-3} to 10^{-4} per year or per demand.

A line of defence is described as average (or ` b') when it corresponds to a system that isn’t the object of the highest design requirements. In particular, its design according to the single failure criterion is not necessary. An average line can also take the form of an operator action if is simple allowing to be done within a reasonable delay, if the situation is easy to identify, and if it is described in the operating procedures. The order of magnitude of the probability of failure of an average line (‘b’), starting from the experience feedback, is of 10^{-1} to 10^{-2} per year or per demand.

The favorable natural behavior of the core during the accident, supplemented if needed by dedicated provisions called “additional provisions of safety for the prevention” (DCS-P), constitute an average line of defence.

The link between the LoD and the safety classification of the materials which constitute them is presented in section II.C.

II.A.2. Implementation of an extended prevention domain (SP)

In the safety approach of ASTRID, the definition of the domain of the prevention situations (SP) fits first of all in the application of the principle of defence in depth, it corresponds for example to the under-level “3.b” of defence in depth as prescribed by WENRA.

Moreover, the ASTRID Project has fixed, as design objective (within the limits of reasonably achievable), to prevent the severe accident including accidental sequences (or multiple failures) of extremely low occurrence frequency. Indeed, even if the estimated frequency of the sequence is very low, in particular the sequences with failure of the reactor shutdown, the prevention of the severe accident is required. The goal is to push back as much as reasonably achievable the limits of prevention of the severe accident. The analysis of the consequences allows in particular to seek at the stage of the design the improvement of the natural behavior of the core and if needed to define additional devices of prevention (DCS-P).

II.A.3. Practically Eliminated Situations (SPE)

They are situations whose radiological consequences can’t be reasonably controlled. They must be the object on a case-by-case basis robust demonstration of safety as regards the prevention. For a family or a kind of situations, only the extreme cases the consequences of which would not be controllable have to be practically eliminated. The less severe events of the family are taken into account in the preceding domains (Operating Conditions, SP, SM).

The practically eliminated situations are not subject of a safety analysis to the usual direction; the safety analysis relates on the accidental sequences involving the risk to lead to such an eliminated situation and not to the consequences of the situation itself. The robust demonstration of a satisfactory prevention of SPE, require implementation of concrete provisions of prevention. The rules of analysis (e.g. mode of taking into account of uncertainties) correspond to those used for the treatment of the initiating accidental sequences.

The deterministic demonstration is supplemented, when if it is relevant, by a probabilistic study (e.g. for loss of the DHR function).

II.B Method for severe accident mitigation

The phenomena concerned in the scenarios of severe accident being radically different from those intervening in the domain of prevention, the need to define an approach dedicated to the severe accidents is essential. On previous SFR, the approach was focused on the analysis of a single initiating transient (unprotected primary pumps trip) arbitrarily penalized to cause sodium boiling. The primary phase of the accident was studied thoroughly, in particular with the important experimental programs carried out in the CABRI facility.

On the ASTRID project, although a new R & D program and more powerful computational tools come to improve knowledge and to reduce uncertainties, the orientations of safety aim at attenuating the influence of uncertainties through the definition of a new approach of the studies, in particular:

- the list of the studied initiating events is representative of the families of sequences which can be at the origin of a severe accident;
- the analysis is done with the "best estimate" approach which could be supplemented by the identification of the parameters having a significant influence on the results, and the analysis of their associated uncertainties;
- with respect to the development of the severe accident, the usual mechanistic approach describing a core degradation is preserved and a second approach is applied in parallel. This one consists in uncoupling the description of the successive phases of the severe accident, in order to identify the parameters having a significant influence on each phase and to perform sensitivity studies (physico-statistics approach).

The studies of severe accident will thus provide more complete and detailed results compared to "best estimate single mechanistic calculation.

II.B.1. "Top-Down" approach and "Lines of mitigation" method (LoM)

In the event of severe accident, the general safety objective being to minimize the radiological consequences, the mitigation provisions based on the implementation of barriers beyond the first barrier.

The LoM method defined for ASTRID intended to identify the whole functions necessary to ensure the confinement of radiological products. This allows to structure the mitigation provisions contributing in fine radiological containment.

The fourth level of defence in depth is treated while following a "Top-Down" approach which aims at uncoupling, as much as reasonably possible, the LoM design and the evaluation of the loadings to which they are subjected:

- design mitigation provisions following a plant state approach, by aiming at the best effectiveness and by pushing back the limits of behavior as much as reasonably achievable, until reaching a homogeneous behavior of the LoM;
- minimization by design of the consequences of the severe accident, considering the various families of initiating events.

The plant state approach consists in postulating several states of core degradation, each state representing a certain level of degradation of the safety functions. These levels can be for example associated to the potential mechanical energy release. The safety functions defining these states are mainly: leak tightness of the primary circuit, structural integrity of the primary circuit, operability of the cooling systems, management of the sodium leaks, leak tightness of the confinement system.

The "Top-Down" approach thus consists in controlling, by LoM design, as far as reasonable achievable the degraded states. The minimization by design of the severe accident consequences is not leading to a reduction of the required performances of the mitigation means.

The functions associated to the main LoM are:

- LoM-1: To identify and reinforce the weak points of the primary circuit in terms of containment and resistance to a hypothetical mechanical energy release. To set up provisions dedicated to management of the severe accident in the primary circuit, also called "additional provisions of safety for the mitigation" (DCS-M), in particular for the containment of whole the corium (option in vessel retention). To reinforce the weak points of the cooling circuits.
- LoM-2: To limit a pressurization of the confinement system which would be due to a possible sodium fire;
- To prevent the contact of sodium and concrete. To delay the possible radioactive release, starting from the various possible ways of release (cover-gas circuit, roof leakages…), by implementing intermediate volumes inside the confinement system.
- LoM-3: To implement a leak tight confinement system; to isolate ventilations in an optimal way with respect to the; to minimize the risks of by-pass of the confinement system.

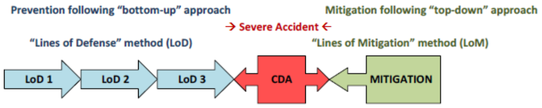

Fig.1: Lines of defence and top-down approach

II.C Safety classification of the equipment

The safety classification of the equipment (SSC) is an important stage of the design process.
Usually the classification of the SSC is based on the significance of the related safety functions.

For ASTRID, the method used for classification is firstly based on the role of each SCC in the safety demonstration in particular in terms of LoD and LoM.

The role of the SSC in the safety demonstrations is thus used as reference for classification as follows:

- Importance of the SSC contribution to the demonstration (e.g. effectiveness, reliability);
- Importance of the impact in case of a SSC failure (e.g. level of consequences, prevention of SPE).

For ASTRID, the main safety classes are defined as follows:

- Safety classes of prevention:
  - CSP-1: SSC whose failure in the safety demonstration must be equivalent to the failure more than one strong LoD.
  - CSP-2: SSC involved in a strong LoD, including confinement barrier needed to meet the objectives of category 4.
  - CSP-3:
    - SSC whose failure impacts SSC classified in CSP-1 or CSP-2;
    - barrier devoted to meet the objectives of category 2;
    - SSC monitoring SSC classified in CSP-1 or CSP-2 in order to check the availability of these materials.
- Safety class of severe accident mitigation:
  CSM: SSC involved in a LoM.

III.PREVENTION OF SEVERE ACCIDENT

III.A Reactivity control

The prevention of the severe accident is ensured by:

- Preventive measures of the initiating events likely to damage the core.
- Control of the fundamental safety functions:
  - the reactivity control,
  - the decay heat removal.
- The preventive measures necessary to justify "practical elimination" of particular severe accident situations whose radiological consequences cannot reasonably be limited.

The reactivity control measures are first based on efficient, reliable, redundant and diversified systems for reactor shutdown.
In addition, inherent core behavior is enhanced and supported if needed by innovative devices.
These systems are deterministically designed with stringent criteria.

An important need required for ASTRID core design is to insert sufficient negative reactivity in case of unprotected loss of cooling accident to avoid severe accident. The CFV core concept (Ref. 2) provides a large part of negative reactivity insertion thanks to its favorable natural behavior (neutron feedback). At this design stage, to ensure larger margins, the natural behavior of the core is completed by additional safety devices able to insert sufficient negative reactivity (DCS-P).

III.A.1. Features of the main shutdown systems

An innovative reactivity control (Ref. 3) which is studied in the frame of the ASTRID project is presented. All the rods participate to power management and shutdown. Comparatively to traditional systems, the gains of this architecture in terms of safety, in particular in case of control rods withdrawal, are noticeable and allow reducing the overall number of control rods.

The reactivity control is pressed on a set of mobile neutron absorbents positioned in the core. The control rods are divided into two distinct and diversified families. Two redundant and diversified automatic shutdown systems are envisaged (each system includes a mix of the two families of rods).
Both families of control rods, RBC and RBD, provide at the same time the functions of control (start up, adjustment of the neutronic power, compensation of the burn-up, neutronic flux adjustment) and the function of reactor shutdown. This kind of architecture, called RID (for "pilotage en RIDeau"), presents compared to a conventional system of SPX type, the following advantages:

- the reactivity core potential at the beginning of cycle being only compensated by the insertion of the control rods in the core, so plus the number of inserted rods is important, less the abnormal control rod withdrawal (CRW) will be severe. With the same number of rods, the behavior in case of CRW is thus improved with architecture RID;

- the possibility to improve the distribution of both rod families (RBC and RBD). At this design stage (9 RBD + 9 RBC) are implemented in ASTRID.

The control rods are composed of absorbents in B_4C enriched in ^{10}B.

RBC is a control rod element dedicated to reactor operation and shutdown. In case of gravity drop, the RBC rods drop with their driving line after decoupling the electromagnets located in gas, above the sodium level.

RBD is a diversified control element used for reactor operation and shutdown too, contrarily to past where it was only dedicated to safety function. As a major design option, disconnection in case of shutdown between the RBD rod and its drive mechanism would occur via an electromagnet located in sodium.

RBC and RBD are gathered in two independent groups connected to the shutdown systems.
The safety analysis required the detection of each initiating event by two different parameters monitored by each shutdown system.

III.A.2. Additional design provisions *(DCS-P)*

Within the framework of the development of additional Safety provisions aiming to severe accident Prevention (DCS-P), it is envisaged to supplement the natural behavior of the core in case of total failure of both shutdown systems by the passive intervention of two types of (DCS-P) initiated by a physical phenomenon:

- one in case of loss of flow, noted (DCS-P) – H rod (Ref. 4);
- the other, under development, in case of temperature increase (Curie point), noted (DCS-P) – T rod.

The insertion of negative reactivity by one of these systems (DCS-P) allows to stop the chain reaction and to ensure a long term safe state, compatible with the behavior of the structures.

(DCS-P)-H would constitute a provision independent of both shutdown systems. It has only a safety function.

(DCS-P)-T is carried by one family of control rods. The (DCS-P)-T includes an electromagnet in sodium.

III.B Decay heat removal safety systems

After reactor shutdown, the core decay heat must be adequately removed in order to avoid large damage of core and primary circuit structures. This is achieved by maintaining a sufficient sodium level in the primary circuit and with capability to remove the decay heat by forced convection and by natural circulation if the normal electrical supply of the primary pumps fails as well as implementation of dedicated circuits.
The main challenge concerning the decay heat removal function is to implement very reliable systems capable to maintain the reactor in safe conditions during long time, until the decay heat decreases sufficiently to allow the decay heat removal through natural thermal losses or by a diverse heat removal system.
In case of severe accident, the long term management of molten fuel (corium) is mandatory. This leads to implement devices for both maintaining the corium in a sub-critical state, and removing its decay heat. The devices implemented for achieving these functions should not be unacceptably damaged by the accident.

The architecture and the reliability of the systems involved in the decay heat removal have to allow the practical elimination of the complete loss of the DHR function.

This objective is translated in particular by:
- the search for one or several systems with important passive capacity and the less dependent possible to support systems,
- a design allowing to facilitate reparability in case of failure.

To obtain the practical elimination of the total loss of the function, the architecture is based on the implementation of three safety systems:
- Two DHR systems insuring a direct cooling of the primary sodium, by heat exchangers in the vessel diving into the primary sodium (called RRA and RRB). Each system should implement multiple trains;
- A system implemented outside of the safeity vessel. It is absorbing the heat emitted by radiation and convection from the vessels. This system introduces a level of additional diversification with regard to RRA and RRB. It presents in particular the advantage not to transit by the reactor roof and not to be submitted directly to the hypothetical mechanical energy release in case of severe accident.
The RRA is an active system located in the cold plenum.
The RRB is a passive system located in the hot plenum.

IV. MITIGATION OF SEVERE ACCIDENT CONSEQUENCES

IV.A Core concept and additional safety devices (DCS-M)

The ASTRID core includes devices dedicated to the mitigation of the whole core accident. These devices must reduce the effects of a severe accident through the following actions:

- CFV core concept which allow to avoid large reactivity insertion during the primary phase of the accident (Sodium void effect);
- Fuel and structural materials re-localization on the core catcher;
- Limitation of radial corium propagation, in order to avoid the in-vessel fuel storage degradation.

This additional mitigation device is characterized by transfer tubes (DCS-M-TT), in the core and within the first line of reflector sub-assemblies.

IV.B Enhanced confinement provisions

The function of containment is provided by the implementation of design provisions and measures to maintain the radiological substances in the plant in order to respect the associated safety objectives (environment and people protection)

This section presents the design approach for the reactor confinement provisions related to severe accident.

This hypothetical accident is retained according the fourth level of defence in depth. It corresponds to the most significantly severe conditions considered because of the importance of the radiological inventory released following the loss of the first barrier integrity. The provisions are also beneficial for events with lower radiological risk.

The design approach consists to limit and delay the potential releases towards the environment by the implementation of adequate provisions in the objective to prevent and limit the measures protection of the populations. This objective includes measures of sheltering limited in space, absence of emergency evacuation beyond the immediate vicinity of the plant, absence of long-term restrictions of food consumption and absence of permanent rehousing.

During such an accident, the fission products contained in fuel are released. A part is trapped in sodium, in particular a more or less large fraction of iodine and cesium which have strong chemical affinities with it. The remainder is found in gas (cover-gas volume). The transfer of the mobile radiological inventory in the plant and potentially towards the environment is consecutive:

- to the pressurization of the cover-gas volume due to:
    - the release of fission gases and volatile isotopes not trapped by sodium;
    - heat produces by the fission products which are in the cover-gas volume;
    - dilation of sodium.
- to the possible primary sodium circuit leaks in case of an hypothetical important mechanical energy release, in particular on the level of the main vessel and the roof. These sodium leaks can growth the pressure of the buildings where they take place, especially in case of sodium fire.

The analysis which guides the choice of the confinement provisions is based on the identification of the release ways, by taking account of the risk of degradation of the requested barriers. It takes account of the risks of confinement by-pass. The experience feedback of the former reactors is also integrated into this analysis.

It is noted that, as the objective is to avoid by design high energetic accidents, the most realistic way of release is the cover-gas circuit, via its valves. Nevertheless, the other potential ways, resulting from the failure of barriers, are considered in accordance with the application of the “Top-Down” approach presented in section II.

IV.B.1. Safety provisions of each potential release way

IV.B.1. Argon circuit

This argon circuit has in particular as function to limit the variations of cover-gas pressure under normal operations. It is thus a circuit made up of several volumes of great capacity and provided with safety valves.

The confinement measures implemented on this circuit are the following ones:

- to isolate the circuit at its ends in order to profit from its great volume which limits the pressure, dilutes contaminated gas, condenses the volatile ones and delay the transfers;
- to recover in a retention room the contaminated gas possibly released by the safety valves;
- to locate the whole circuit and the retention room inside the confinement system.

This design of the cover-gas circuit allows the limitation of the circuit leaks, allows to enhance the delays and to contain the eventual leaks inside the confinement system without risk of by-pass.

IV.B.1.2 Roof

Under normal operation, the roof ensures the leak tightness of the cover-gas circuit in particular at the level of its penetrations which are provided with specific devices.

The severe accident could lead to a mechanical energy release likely to damage the sealing of the roof.

The design takes into account the possibility of a leak between the cover-gas volume and the above roof area.

This leak can lead to a release of gas towards the above roof area and to a primary sodium ejection which can burn in contact with air.
The selected confinement provisions have two objectives:

- to prevent that the pressure, increase due to the sodium fire does not damage the confinement system;
- to create a zone confining the leakages through the roof.

To this end, the above roof area is contained in a as low as possible small volume, distinct from the confinement system.
This volume is voluntarily not perfectly sealed in order to limit the possible duration of fire by air release out of the volume, and thus to limit the effects of fire (pressure, temperature) in the volume and the reactor building. Moreover, the design of the systems located in this zone and needed, in post-accidental situation, takes account of these effects. The risk of vapor production by heating of the concrete is also considered.

The leak-tightness of this zone is defined in order that the loadings in terms of pressure and temperature of the confinement system are limited. This leak-tightness is in particular ensured by the above roof area ventilation isolation.

IV.B.1.3 Primary Vessel

The primary vessel contains a core catcher whose object is to avoid the damage of confinement system.

Because of the possible mechanical energy release during the accident, the leakage of the main vessel could occur. Thereby, it is surrounded by a safety vessel which is conceived not to be damaged by the accident.

In the vessels gap, the nitrogen circuit has in particular as a function to maintain the pressure between the primary vessel and the safety vessel in an acceptable value, in particular thanks to a safety valve connected to the cover-gas circuit. The other safety valves are connected to the retention room.

The main confinement measure is to isolate the nitrogen circuit to limit the contamination coming from the vessel or the cover-gas volume (gas or sodium leaks).
As for the cover-gas circuit, the whole nitrogen circuit is located inside the confinement system what allows to contain the possible leaks without risk of confinement by-pass.

IV.B.1.4 Circuits connected to the primary circuit

The fluid circuits (except sodium circuit) connected to the primary circuit are isolated. It concerns in particular:

- Gas circuits ensuring the leak tightness of the roof penetrations;
- Roof cooling system.

The secondary sodium circuits are designed to remain leak-tight in case of a hypothetical mechanical energy release.
Nevertheless, leaks of the heat exchangers between primary sodium circuit and secondary sodium are considered because they are equipment impacted by the accident. In this case, the confinement is ensured by the part of the secondary circuit which is not affected.
However, provisions to manage these possible leaks are under investigation (e.g. isolating valves).

IV.B.2 Confinement system

In order to avoid the risks of by-pass, the confinement system this includes the whole ways of releases up to the isolation devices, as well as the primary circuit.
Concerning the sodium circuits (circuit of extraction of the normal power and of decay heat removal), the approach consists in being ensured by design which they are not damaged by the severe accident and to study provisions to manage the possible leaks through the most impacted zones.

The containment system is carried by the reactor building. The risks of by-pass are limited by:

- the isolation of reactor building ventilation;
- Implementations of leak tight devices at the singular points of the building in particular secondary sodium loop penetrations and openings. These singular points are located at lower part of the building, in front of adjacent buildings.

The selected design provisions ensure that the severe accident does not lead to a significant pressure and temperature increase inside the building. This one is designed to resist to loadings more important than those induced by the severe accident (earthquake, aircraft crash…).
The option of reactor building as a confinement system, including a large volume, allows the limitation of the pressure during the accident.

V. CONCLUSIONS

In the earlier phase of ASTRID project, a specific safety approach was set and its main orientations were agreed by the French Nuclear Safety Authority. This safety design guideline is currently applied upon the new phase of basic design for the choices of the design options.

Reactivity mastery function is warranted by two diverse shutdown systems with related design criteria giving sufficient safety margins for different plant states. Beyond the high reliability of these shutdown systems, inherent behavior of reactor is improved to cope with hypothetical transients without scram. This second approach by "event family" (ULOF, ULOHS…) is completed in parallel by a third "plant state" approach involving special devices acting in case of loss of flow or core heating whatever the initiating event of the accident.

Decay heat removal function is assured by several systems with diversified hydraulic zone of implementation in order to deal each possible DHR fault situation. DHR means are composed by a system devoted to heat removal at normal shutdown states, two different safety systems connected to primary circuit, an ultimate system inside the reactor vault to manage hypothetical situations with degraded reactor, at long term. All these systems have a potential for repair at short time.

Finally, the design of the ASTRID confinement provisions includes the set-up of a confinement system which contains all the release ways of radioactive materials and which recovers their possible leaks.

A special attention is given to the singular points in order to avoid any risk of by-pass through the confinement system.

REFERENCES

1. 1. J. ROUAULT, ASTRID, The SFR GENIV Technology Demonstrator Project: Where are we Where Do We *Stand For?*, *Proc. of ICAPP 2015*, Nice, France (2015)
2. C. VENARD et al., "The ASTRID core at the midterm of the conceptual design phase (AVP2)", *Proc. of ICAPP 2015*, paper 11527, Nice, France (2015)
3. B. FONTAINE et al. "ASTRID: an innovative control rods system to manage reactivity", Proc. of ICAPP 2016, San Francisco CA, USA, April 17-20, 2016
4. GUÉNOT-DELAHAIE et al., "The innovative RBH additional safety device for ASTRID to address unprotected loss of flow transients: from design to qualification", Proc. of ICAPP 2016, paper 16116, San Francisco, USA (2016)
5. P. Lo Pinto et al., "Safety orientations during ASTRID conceptual design phase", Proc. of FR13, Paper CN-199-267, Paris, France (2013)
6. B. Carluec et al., "Post-Fukushima lessons and safety orientations for ASTRID", Paper CN-199-321, Paris, France, (2013)