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## THE COLLABORATION OF JAPAN AND FRANCE ON THE DESIGN OF ASTRID SODIUM FAST REACTOR

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**Abstract** - Since the beginning (2010), the management of ASTRID project was organized around a strong involvement of industrial partners in the reactor design. The ASTRID project has now entered into its Basic Design phase (duration from year 2016 to 2019) with fourteen industrial partners. Since 2014, a partnership with Japanese nuclear institutes and industries is effective on two main items: ASTRID reactor design studies and R&D in support of Sodium Fast Reactors (SFR). This French-Japanese collaboration on ASTRID Program and Sodium Fast Reactor has been set up in two steps: the signature of a General Arrangement between CEA and the representatives of MEXT and METI on May 5<sup>th</sup>, 2014; and in a second step, an Implementing Arrangement signed the same year on August 7<sup>th</sup> by CEA, AREVA NP, JAEA, MHI and MFBR.

This collaboration of a significant level is foreseen to run at least up to the end of 2019. At the beginning, the collaborative work (input data, planning and deliverables) was divided in 29 Task Sheets covering ASTRID design (3 Task Sheets) and R&D (26 Tasks Sheets). Since 2016, the contribution of JAEA/MHI – MFBR to the ASTRID reactor engineering studies has significantly raised, passing from 3 to 9 Design Task Sheets. Thus, even if the cooperation is recent, the cooperation between CEA, AREVA NP, JAEA, MHI-MFBR is fruitful and it has been planned by all parties to enlarge Japanese contribution to a process called “Joint Evaluation” to prepare future Joint Design.

This paper aims at the overview of the significant involvement of JAEA/MHI – MFBR in the ASTRID design studies through these 9 Task Sheets, covering in particular the design of an active decay heat removal system, and of a passive reactor shutdown system based on a Curie point electromagnet system. MHI / MFBR teams are also implies in fabricability studies of complex component such as the Above Core Structure or the Polar Table. In addition the new Task Sheets are now focusing on thermal-hydraulic and thermomechanical studies related to the primary vessel.

Japan contribution to ASTRID program is significant and important. Except CEA (which act as the industrial architect of the project), JAEA-MHI-MFBR became in 2015 the 2<sup>nd</sup> largest contributor to ASTRID program - behind AREVA NP - in terms of involved staff and financial contribution. It means that ASTRID project has to adapt its project management to cope with this important partnership. The related innovative project organization will be presented too.

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### I. INTRODUCTION

After 6 years of Conceptual Design phase (called AVP Phase), the ASTRID Project is involved since January 2016 in its Basic Design Phase. Since the beginning (2010), the management of ASTRID project was organized around a strong involvement of industrial partners in the reactor design. The ASTRID project has now entered into its Basic Design phase with fourteen industrial partners [1].

Since 2014, a partnership with Japanese nuclear institutes and industries is effective on two main items: ASTRID reactor design studies and R&D in support of Sodium Fast Reactors (SFR) [2]. This French-Japanese collaboration on the ASTRID Program and Sodium Fast Reactor has been set up in two steps: the signature of a General Arrangement between CEA and the representatives of MEXT and METI on May the 5<sup>th</sup>, 2014;

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Since 2016, the contribution of JAEA / MHI – MFBR to the ASTRID reactor engineering studies has significantly raised, passing from 3 to 9 Design Task Sheets. Thus, even if the cooperation is recent, the cooperation between CEA, AREVA NP, JAEA, MHI-MFBR is fruitful and it has been planned by all parties to enlarge Japanese contribution to a process called “Joint Evaluation” to prepare future Joint Design.

After a brief recall of the ASTRID context and the genesis of this collaboration, this paper aims at the overview of the significant involvement of JAEA / MHI – MFBR in the ASTRID design studies through these today nine Design Task Sheets.

## II. THE ASTRID PROJECT MANAGEMENT

### II.A. ASTRID Project partnership

As defined in the 2006 Law of 28 June 2006 on the sustainable management of radioactive materials and waste CEA/Nuclear Energy Division is responsible for the ASTRID project [1].

For the Basic Design phase, CEA has renewed the bilateral partnership for this new step, traducing the acceptance of the different partners to be involved in the ASTRID project. As shown in Fig. 1, there are now 14 bi-lateral partnerships connected to CEA for the next four years. The organizational Project structure has not changed since 2014 and the synoptic structure is presented in Fig. 2.



Fig. 1: Set of ASTRID Partnership

Since beginning of the project, CEA acts as the Project manager from the definition of the main functional requirements to the assembly of the 3D mock up including performance control, configuration management and interfaces between elementary products. The project management is totally organized since AVP on a cutting based on a Product Breakdown Structure (PBS) which is in constant evolution.

### II.B. Japan and France cooperation in the nuclear SFR field before ASTRID Project

Japan and France are involved for a long time in the peaceful use of nuclear energy and have many nuclear power plants to produce electricity. Each of the two countries is developing the technology of the Sodium Fast

Reactors for several decades. Japan operates JOYO and MONJU and France have operated RAPSODIE, PHENIX and SUPERPHENIX. Collaborative R&D arrangements exist for a long time. This was concluded by mutual interests in the respective design and related safety approach. Indeed, even if Japan chose the concept of a loop type reactor when France considers a pool type, cross-analyses showed that there are many similarities in design, technology, materials, fuel, safety approach... It has been the subject of exchange of company employees between SFR reactor and the detachment of CEA sodium specialists on MONJU site. Several common publications can illustrate these fruitful exchanges [3], [4], [5], [6].

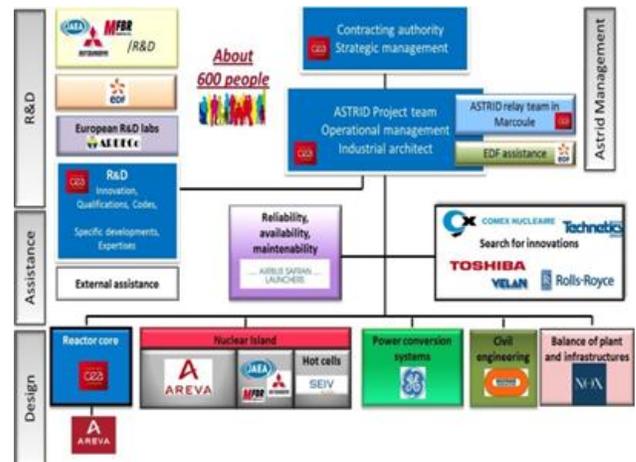


Fig. 2: ASTRID Project organization

### II.C. The ASTRID Project partnership with Japan

The history and the ruling of the ASTRID Project partnership with Japan have been extensively explained in [2]. This chapter will just recall the main milestones. First exchanges on a possible involvement of Japan in the ASTRID project took place in 2010, but no further action had been given because the priority for France was to structure the ASTRID project which was just launched.

In 2013, Japan and France initiated the discussion for an entry in the ASTRID project. Negotiations became very intense carried out mainly by audio or video conferences which frequency had reached a weekly rhythm at certain times. They all conclude to Face to Face meetings (see Fig. 3 and 4). Five working groups have been created:

- Definition of the terms of the agreement and of its principles of governance,
- ASTRID design activity,
- R&D on severe accidents,
- R&D on fuel,
- Other R&D subjects (Na technology, ISI&R, Instrumentation ...).



*Fig. 3: Preparatory meeting of the design activity at Tokyo, June 2014*

These discussions came to a 2 levels partnership:

- The "General arrangement", which establishes the main principles of collaboration; the signatories are the Japanese Ministry of economy, trade and industry (METI) and Ministry of education, culture, sports, science and technology (MEXT) on the Japan side, and the CEA by delegation of the French government. It was signed on May 5<sup>th</sup>, during the visit of the Japanese Prime Minister in Paris.
- The "implementing arrangement", signed by the Japan Atomic Energy Agency (JAEA), Mitsubishi Heavy Industries (MHI), its subsidiary Mitsubishi FBR Systems (MFBR), AREVA and CEA. It explains in detail the principles and the governance of the R&D and design activities, as intellectual property, rights of use, the transfer of information to third parties, rights after 2019 ... It was signed on August 7<sup>th</sup> 2014. The "Task Sheets" that describe the technical program, the deliverables, deadlines and input data are annexed to the implementing arrangement. At the starting point 29 Task Sheets have been approved, 3 for ASTRID design and 26 for R&D.



*Fig. 4: First face to face meeting at Lyon, September 2014*

The practical organization is the following. The executive committee is responsible for proposing the creation of new implementing arrangements, follow their progress and solve the related difficulties. The joint team is in charge of the day to day control of design and R&D work and of the definition and the follow-up of "joint evaluation" on important subjects for GEN IV SFR. This organization is fully imbedded and coherent with the organization set-up with the other partners of the ASTRID project.

Work began quickly, immediately after the signing of the general arrangements, and without even waiting for the signing of the implementing arrangement.

#### **II.D. Collaborative studies on design studies**

In the design field, Japanese team first contributed directly to the ASTRID AVP phase on three topics coherently with ASTRID driver planning. In particular, Japanese design work are submitted to the Design Option Selection process of the ASTRID project organization which aimed at defining a complete coherent reactor outline by 2015 for the Conceptual design, then by 2019 for the Basic Design phase.

At the beginning three Japanese design topics were initiated. They concerned the design of:

- active decay heat removal system,
- control rod system with Curie point electro magnets,
- and seismic isolation systems for the Reactor Building.

Design activities increased sharply during the year 2016 from three Task Sheets to nine. In particular, through evaluation activities by the Japanese part of the technological solutions selected by the project which could lead, in a second time to proposals for improvement. The current list is as follows:

- Task Sheet D1: Active Decay Heat Removal System (DHRS),
- Task sheet D2: Curie Point Electro Magnet (CPEM) for diversified control rods,
- Task Sheet D3: Seismic Isolation System (SIS),
- Task Sheet D4: Fabricability and thermo-mechanical calculations of the Above Core Structure (ACS),
- Task Sheet D5: Fabricability of the Polar Table,
- Task Sheet D6: Contribution to design the Core Catcher,
- Task Sheet D7: Transient evaluation of Astrid plant,
- Task Sheet D8: Thermomechanical analyses of main and inner vessel,

- Task Sheet D12: General discussions on the Astrid reactor system, in the scope of the Joint Team, to have discussions for preparation of future Design Task Sheet or Joint Evaluation.

The gap between D8 and D12 Task Sheets are numbers booked for subjects still under discussion. Next chapter is devoted to a short overview of technical progress in these nine Task Sheets.

### III. OVERVIEW OF TECHNICAL PROGRESS OF THE DESIGN TASK SHEETS

#### III.A. TS D1; Active DHRS

The objective of this task is to design the whole circuit of Active Decay Heat Removal System (in the vessel) – called RRA on the ASTRID nomenclature. After a first proposal of design presented in 2015, JAEA – MHI/MFBR participated to the ASTRID Confirmation Configuration Phase (from Jan. to Sept. 2016) which has redefined the Active DHRS functions now called RRA'. The functions of this RRA' is to conceive a heat exchanger with a window in hot pool that can connect hot and cold pools in case of loss of power. This DHRS configuration is considered as a strong line of defense. The technical feasibility of the shutter connected the two pools is now demonstrated but the detailed design plus qualification needs are to be pursued in the Basic Design phase.

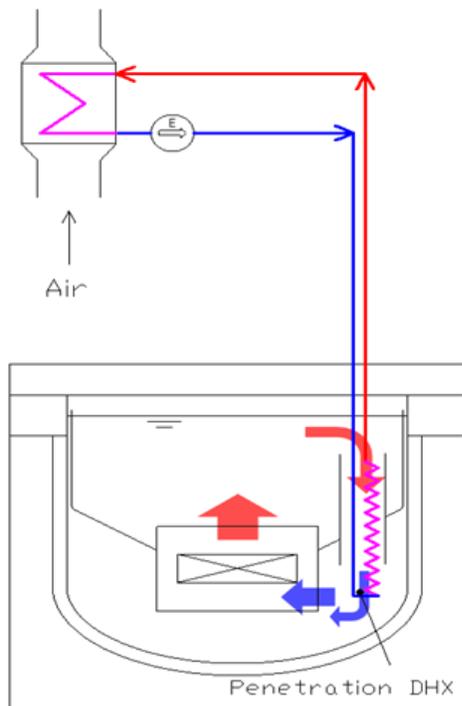


Fig. 6: Schematic view of the RRA' principle

#### III.B. TS D2; Curie Point Electro Magnet (CPEM) for diversified control rods

ASTRID's in-core reactivity control system consists of two distinct absorber assembly types, named RBC and RBD. The latter uses an electromagnet to connect the absorber-rod sub-assembly to the rod drive-mechanism. This electromagnet has to be of a particular design as it is situated within the absorber assembly, ie. in sodium.

The rod sub-assembly has furthermore a function of complementary safety device by inserting negative reactivity in case of an over-temperature transient of the core sodium (ULOHS transient). To this end, the electromagnet holding the rod sub-assembly is equipped with a Curie-point magnetic material, prompting the loss of magnetic properties and thereby the drop of the absorber rods when a certain temperature threshold is exceeded.

The responsibility of a principle of a Curie point Electro Magnet system and its implementation in the whole Diversified Control Rod plus its qualification program are the main tasks of this work. It is based upon the Japanese SASS (Self Actuated Shutdown System) concept [7].

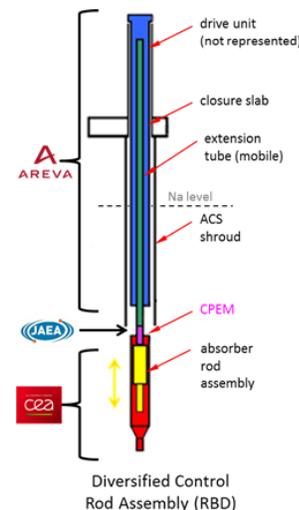


Fig. 7: Schematic view of the Diversified Control Rod system with the connection of the CPEM

#### III.C. TS D3; Seismic Isolation System (SIS)

As SFRs have thin walled components which are strongly affected by severe earthquakes, advanced seismic isolation systems were developed for JSFR which could be relevant for ASTRID too. The vertical response to seismic solicitation is of concern for JSFR as it is for ASTRID, that is to say the peak of the floor vertical

response appears at a frequency which is close to the vertical mode of the primary components.

As a result, the floor response spectrum with a seismic isolation system in the range of the natural frequency of the primary component decreases when compared with no isolation system.

The Japanese partners JAEA / MHI - MFBR has contributed in designing seismic isolation system with the correct characteristics regarding the overall ASTRID building and components behavior under seismic solicitation. They provided in 2016 a coherent solution that reply in all points to the ASTRID initial technical specifications. The continuation of the subject was under discussion at the end of 2016.

#### **III.D. TS D4; Fabricability and thermo-mechanical calculations of the Above Core Structure (ACS)**

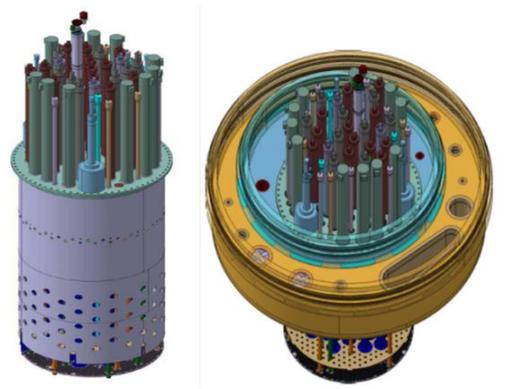
The ACS (Above Core Structure) is a very specific components gathering three major challenges:

- It is playing an essential role in core surveillance and core monitoring.
- It is the subject of significant level of temperature (core outlet mean temperature 550°C with some extrema at 575°C) and thermomechanical solicitations. As a consequence the justification of its lifetime by thermomechanical calculations is a critical technical point that remains today challenging. At the same time even if this components is designed to be replaceable it has to be designed for the whole reactor lifetime (60 years) and its replacement must be envisaged only in exceptional situation to avoid losing the whole reactor investment.
- Inspection of this equipment is therefore of prime importance because this structure is operating in hot region with thermal gradients in normal operation (due to heterogeneity in the core outlet temperature) and during fast transients such as fast reactor trips or scrams. In addition its ruin could lead to major consequences for the reactor safety; some scenarios of its ruin could even be initiators of severe accidents.

Therefore, three items have been focused on that component:

- A benchmark on thermochemical dimensioning of this component regarding creep fatigue,
- A fabricability study of this component according to AREVA's ACS drawings as input data,
- A feasibility study of the Failed Fuel Detection Localization (FFDL) according to CEA technical

specification plus design and performances constraints.

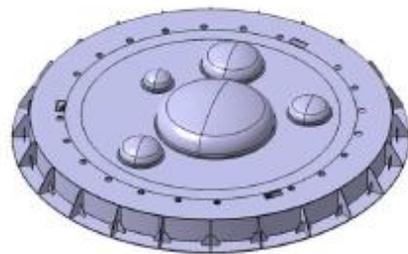


*Fig. 8: 3D view of the ASTRID ACS*

This Task Sheet was signed in Dec. 2015 and the set of deliverables is planned for first semester of 2017.

#### **III.E. TS D5; Fabricability of the Polar Table**

The general arrangement of Astrid reactor building has determined a closed space between the Astrid upper closure and the reactor building: it is called the above roof area. This area is delimited on its lower part by the upper reactor closure (also called the reactor roof) and on its upper part by the Polar table. This polar table is conceived to limit the pressure loading in the reactor building in case of sodium fire in the above roof area. In addition, it prevents from the risk of heavy charge fall on the reactor roof.



*Fig. 9: Design of the polar table at the end of AVP2 phase*

The main functional requirements of this polar table are:

- To limit the consequences of a sodium leak on the upper enclosure (i.e. limit the constraints of the reactor building by limiting the pressure release and the temperature).
- To limit the consequence of a component falling on the roof (i.e. protection and impossibility to damage some main safety components such as the control rod mechanism by this polar table).

- To allow a simple and quick access to the components to handle under the polar table.
- To allow a simple and quick access inside above roof area to allow components maintenance.

The main objectives of the study are:

- Study the fabricability of the polar table, including:
  - o Analyze the design and general drawings,
  - o Study the manufacturing of the polar table and evaluation of required manufacturing tools
  - o Estimate achievable tolerances,
  - o Some specific component should be analyzed in further details such as various seals and in particular the dynamic seal
  - o Feasibility of control
  - o Recommendations for optimizing the general design to facilitate the fabrication
- Realize a failure mode effect and critically analysis of the overall component and define a preliminary program of maintenance and inspection.

This Task Sheet was signed in Dec. 2015 and the set of deliverables is planned first semester of 2017.

### III.F. TS D6; Contribution to design the Core Catcher

Discussions around the D6 Task Sheet are related to the design of the core catcher. It is in close link with some R&D tasks Sheets related to Severe Accident scenarios and Corium phenomenology. This Task Sheet is proposing to focus on design measures for short term corium criticality management on core catcher surface. It could lead to propose new solution for the ASTRID core catcher. This TS started in April 2016 and the first months were devoted to data transmission from CEA/AREVA towards JAEA – MHI/MFBR and technical exchanges. First results are foreseen in the first semester of 2017.

### III.G. TS D7; Transient evaluation of Astrid plant

This TS is gathering all the thermo hydraulics calculations (CATHARE code, CFD and coupling codes) to supply input data in support of related design other task sheets. It is split in several subtasks:

- Subtask 1: CATHARE and CFD shell description for CFD calculation performed in the frame of the D1 TS. For the reactor vessel components, the D7 will supply the shell needed for the calculation of the global performance of the DHR systems that will be performed in D1.
- Subtask 2: CATHARE calculations needed by D2 TS as input data. It consists in numerical calculations with

CATHARE on unprotected transient ULOHS in order to supply data for CPEM design.

- Subtask 3: STAR-CCM+ or STAR-CD codes calculation needed by D8 TS as input data. It determines transient analysis on reactor internal structures to supply boundary conditions for D8 TS.
- Subtask 4: CATHARE code calculation on transients leading to hot and cold shocks on primary circuit.
- Subtask 5: Evaluation of argon suction from the free surface. It provides 3Dimensional analysis on the whole plenum (360-deg) with STAR-CCM+ or STAR-CD codes.

This Task sheet starting in Sept. 2016 with a big effort from CEA/AREVA Companies to provide inlet data in order to compute the ASTRID primary vessel and allow to thermohydraulic calculations. These data were officially provided to JAEA / MHI-MFBR colleagues during a face to face meeting in Tokyo in Oct. 2016 (see Fig. 10). First thermohydraulic calculations are planned in 2017.



*Fig. 10: Picture of the CD-Rom containing the ASTRID main vessel CATHARE inlet data for TH Calculations*

### III.H. TS D8; Thermomechanical analyses of main and inner vessel

The D8 TS is devoted to design analyses of the main vessel and inner vessel. It is split in three subtasks:

- Subtask 1: thermal insulations on the upper part of the primary vessel.
- Subtask 2: thermosiphon phenomena. The evaluation of the thermosiphon phenomena will be performed according to three intermediate steps, with Go / No Go decision at each step.
- Subtask 3: in vessel mechanical stress calculation and design proposal.

It was jointly agreed to carry out the prior step of Subtask 3 with thermal hydraulic analyses on steady state (full power operation) condition and scram conditions (performed in D7). This task Sheet started in parallel with D7 TS.

### III.I. TS D12; General discussions on the Astrid reactor system

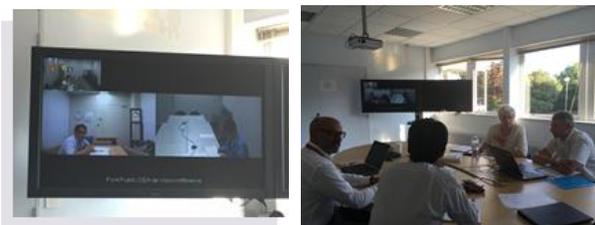
This Task Sheet is a way to be able to discuss on various ASTRID items before - if it comes to a common agreement - the creation of a new Task Sheet. The discussion scope is the following:

- Shielding design
- Thermal Hydraulic behavior
- Reactor cover structure
- Reactor shutdown system
- Decay Heat removal system
- Core design and fuels
- Reactor structure and system
- Primary sodium system
- Fuel handling system

### IV. CONCLUSIONS

Japan contribution to ASTRID program is significant and important. Except CEA (which acts as the industrial architect of the project), JAEA-MHI-MFBR became in 2015 the 2<sup>nd</sup> largest contributor to ASTRID program - behind AREVA NP - in terms of involved staff and financial contribution. It means that ASTRID project has to adapt its project management to cope with this important partnership.

Thus, since 2014 ASTRID Project Team is including a JAEA detachee in its Project organization which acts as a precious link between French and Japanese organizations for the daily progress and management of this collaboration. Some regular video conferences are now carried out to follow the work in progress and punctuated by Face to Face meetings. The Steering Committee is programmed every semester, and it allows an overview of the progress of work and current status of this fruitful collaboration.



*Fig. 11: The efficient use of the video conference system to exchange at 10 000 km distance*

### ACKNOWLEDGMENTS

Many people are involved in this collaboration and it was impossible to put all of them as co-authors. Neither the less authors would like to thank all persons involved in the different Task Sheets, coming from ASTRID project team, Project and Engineering teams from Japan (JAEA / MHI - MFBR) and France (AREVA NP), and

R&D teams for their important involvement in the progress of these studies.

### NOMENCLATURE

ACS:	Above Core Structure
ASTRID:	Advanced Sodium Technological Reactor for Industrial Demonstration
AVP1/2:	Conceptual design studies, phase 1/2 of ASTRID project
BD:	Basic Design
CEA:	French Atomic Energy Commission
CFD:	Computational Fluid Dynamic
CPEM:	Curie Point ElectroMagnetic system
DHR:	Decay Heat Removal
DHRS:	Decay Heat Removal System
FBR:	Fast Breeder Reactor
FFDL:	Failed Fuel Detection Localization
GEN IV:	Fourth Generation Reactor
ISI&R:	In-Service Inspection & Repair
JAEA:	Japan Atomic Energy Agency
JSFR:	Japan Sodium Fast Reactor
METI:	Japanese Ministry of economy, trade and industry
MEXT:	Japanese Ministry of education, culture, sports, science and technology
MHI:	MITSUBISHI Heavy Industry
MFBR:	Mitsubishi FBR Systems
PBS:	Product Breakdown Structure
R&D:	Research and Development
RRA:	French Acronym to Define the ASTRID Active DHRS
SASS:	Self Actuated Shutdown System
SFR:	Sodium Fast Reactor
SG:	Steam Generator
SIS:	Seismic Isolation System
SPX:	Superphenix ( <i>French SFR</i> )
TH:	Thermal Hydraulic
TS:	Task Sheet
ULOHS:	Unprotected Loss Of Heat Sink
3D:	Three-Dimensional

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