SOFIA, an engineering simulator to improve the nuclear safety for pressurized water reactors

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

SOFIA: an engineering simulator to think ahead and improve PWRs safety

One of the available means used by IRSN to assess French PWRs safety, is SOFIA - Simulator for Observation of Functioning during Incident and Accident- allowing the Institute to carry out studies related to the expertise in PWRs. With SOFIA, IRSN owns a representative platform of 900 MWe, 1,300 MWe, 1,450 MWe reactor types, as well as the EPR. SOFIA allows simulating a wide range of situations from cold shutdown states to full power state. Thanks to the modern and modular data-processing architecture of SOFIA, the configurations in conformity with the actual state of the nuclear power plants are easily kept up-to-date, by introducing the latest modifications carried out on French NPPs.

An engineering simulator is a computer system able to calculate and display in real time the physical parameters of a nuclear power plant.

It simulates equipment failures and actions carried out by operators, with the ability to freeze the simulation at any given time, in order to assess the actual plant state or to start the simulation again but at a previous time step with a modified scenario.

All actions are initiated from a user-friendly multi-screen human-machine interface.

SOFIA: an efficient use for safety evaluations, training and emergency response exercises

SOFIA makes it possible to improve the quality of safety evaluations, to train IRSN or external personnel, and to prepare emergency response exercises.

Studies in support of safety evaluation

The studies carried out are in support to the safety evaluation in particular for the analysis from systems, from incidents, but also from reactor operation in accidental situation. In addition some of these studies provide improved data for probabilistic safety assessments.

Training

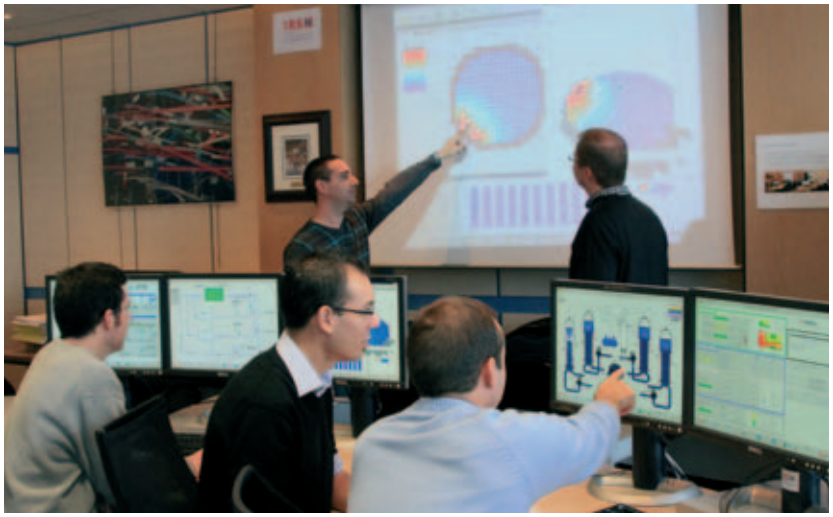
SOFIA is the privileged tool for IRSN personnel trainings as well as trainings for other French and foreign organizations to improve the know-how on the functioning of systems and circuits during reactor operation in normal, incidental and accidental states, as well as for safety analyses of accidents. SOFIA is an educational tool, which helps teaching circuits and systems functioning as well as basic knowledge on safety physical analyses and operating actions related with accidents. More than 800 trainees (from beginners to experts) were trained since 2000 (at the rate of 3 to 4 three-week sessions per year, in 3 different modules).

National emergency response exercises

The scenarios prepared by IRSN are worked out on the simulator, and the output data are used during these exercises.

A modern tool for study and training:

- to study the functioning of a nuclear reactor under normal conditions or in case of accidents;
- to train IRSN or Nuclear Safety Authority staff as well as engineers of other French or international organizations;
- to prepare emergency response exercises.



Expert team

The operation and development of the simulator SOFIA is carried out by a team of IRSN experts skilled in operations, physics and safety of reactors, simulation and training.

SOFIA: an extensive simulation scope

SOFIA performs the functioning of a PWR from cold shutdown states to full power state. Accidental transients can be performed up to the beginning of fuel cladding oxidation, corresponding to a cladding temperature around 2,000°F.

SOFIA uses the CATHARE French thermalhydraulics code, which is a reference for foreign and French nuclear institutions. It guarantees the best available physical modeling.

The simulator includes the following descriptions in full compliance with the nuclear power plant:

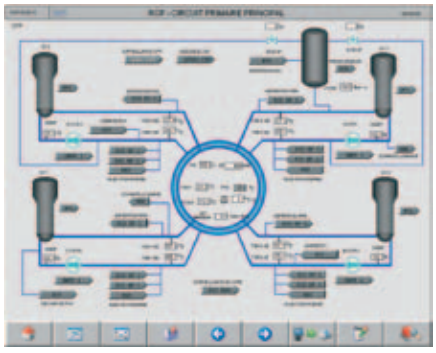
- hydraulic circuits connected with primary or secondary circuits;
- instrumentation and control systems, protection and safety systems including a part of the electric power distribution;
- containment;
- neutronics behavior of the core.

The modularity of SOFIA allows IRSN to keep its simulator up-to-date with the current state of the French nuclear plants, and to improve the simulation scope to reach a better modeling level. Thereby, IRSN is always able to offer an adapted reply to any specific study request.

SOFIA engineering simulator benefits from top level multi-physical modeling, and is **representative for any French operated NPP type**, including EPR Flamanville 3.

A user-friendly interface

Through a user-friendly multi-screen interface, the user can directly simulate a malfunction or a manual operated action. It is also possible to access in real time any physical value measured by sensors, and look at the system state.

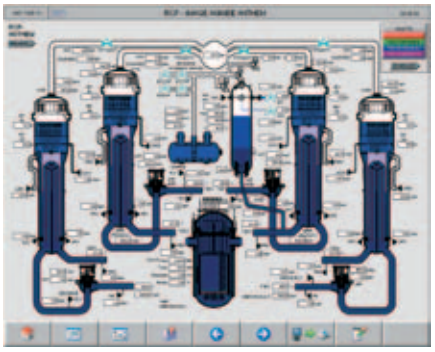


The hydraulics circuits of a nuclear reactor are schematized on the interfaces with their different components: pipes, steam generators, vessel, pumps, valves...

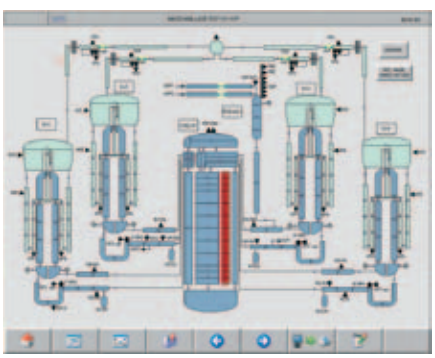
A very realistic representation of phenomena

On the SOFIA simulator, the different parts of a circuit are represented in a realistic way. The thermalhydraulics behavior and physical phenomena are displayed in real time using animated schemes. There pictures represent real-time liquid and steam flows, the proportion of liquid and steam being depicted with various shades of blue.

SOFIA offers a representation of the meshing used for the modeling of primary and secondary circuits. The thermalhydraulics parameters calculated during the simulation are accessible for the user by simply clicking on the meshes. It will give the exact thermalhydraulics state of the circuits.



EPR reactor under normal operation. Liquid water appears dark blue, whereas steam appears in white.



Meshing used by CATHARE for the main circuits of a PWR, where physical equations are solved during the simulation.

SOFIA: a fruitful collaboration between IRSN and Areva NP

The new version of the simulator

Since the beginning of the 90s, both IRSN and Areva NP possessed their own simulators. In 2004 the two institutions jointly decided to replace them because of hardware and software obsolescence, and prohibitive maintenance costs.

IRSN and Areva NP therefore signed in 2005 a collaboration agreement for the joint development of an engineering simulator, so as to share both costs and skills.

IRSN got thereby, with controlled manpower and financial costs, a user-friendly and long-lasting engineering simulator, including the latest state-of-the-art physical modeling.

The realization of this renovation was entrusted to the Canadian company L-3 COMMUNICATIONS MAPPS Inc., after an international invitation to tender putting the best experts in competition.

Since 2006, SOFIA was gradually put in use at IRSN and Areva NP for the various French PWRs plants. It is progressively replacing the previous IRSN engineering simulator – SIPA - and thereby improving not only the simulation possibilities and performances but also the user-friendliness.

Within the framework of this project, IRSN and Areva NP signed in October 2009 a contract amendment with L-3 COMMUNICATIONS MAPPS Inc., for the co-development of a configuration corresponding to the EPR Flamanville 3.

A flexible tool adaptable to any other PWR types, able to run and study any past accident (as Three Mile Island).

A mastered schedule

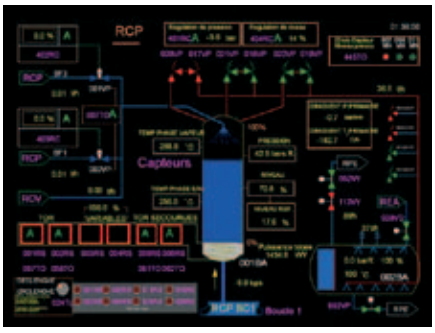
2006 - 2008: the first part of the project, related to the renovation of the simulator for three reactor types operated in France - 900 MWe, 1,300 MWe and 1,450 MWe - was carried out at the rate of one reactor type per year.

2009 - 2010: the second part of the project, related to the improvement of the physical modeling with the integration of CATHARE, the French thermalhydraulics reference code, was carried out in three steps: in June, 2009 with the supply of the 1,450 MWe simulator; in April, 2010 for the 900 MWe; and finally in October, 2010 for the 1,300 MWe.

2009 - 2012: the third part of the project, related to the realization of a configuration for EPR Flamanville 3, began at the end of 2009 and was validated in September, 2011. The version including the CATHARE code is to be delivered to IRSN at the latest in spring, 2012.

SOFIA: Simulator for Observation of Functioning during Incident and Accident

- **Representative for 900 MWe, 1,300 MWe, 1,450 MWe and EPR plants in their current state.**
- **Thermalhydraulics CATHARE 2 Code.**
- **3D neutronics modeling of the core for EPR.**
- **A flexible tool adaptable to any other PWR types.**
- **1,000 to 1,200 meshes used for the modeling with CATHARE code.**
- **Real time simulation except for very damaged situations.**
- **Physical behavior of reactor modeled up to beginning of fuel degradation.**
- **Simulation available from full power to cold shutdown states, with associated accidental transients.**



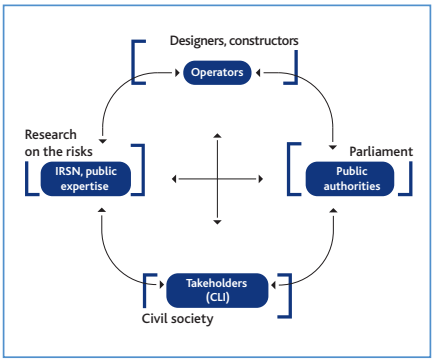
IRSN: national public expert for nuclear and radiological risks

The French Institute for Radiological Protection and Nuclear Safety, set up by law 2001-398 of 9th May 2001 under the statute of public authority of industrial and commercial nature (EPIC), is the national public expert in nuclear and radiological risks. IRSN contributes to public policy-making concerning nuclear safety, health and environmental protection against ionizing radiation. As a research and expert appraisal organization, IRSN works together with all the participants concerned by these policies.

IRSN groups together over 1,700 specialists: engineers, researchers, doctors, agronomists, vets and technicians.

In France, the prevention against nuclear and radiological risks rests on four complementary pillars:

- **Operators** are responsible for the safety of their installations. They must demonstrate the relevance of the technical and organisational solutions retained for that purpose (safety analyses reports and rejection impact study).
- **Public authorities** determine policy-making in the field of nuclear and radioprotection safety. They organize and apply controls in agreement with the law 2006-86 of 13th June 2006 related to the transparency and safety for nuclear matters.



- **IRSN, French organization for nuclear safety, security and radioprotection,** produces assessments of the reports produced by operators. It analyses permanently the feedbacks from installations exploitation. It evaluates human and environmental exposition to radiations and proposes measures to protect the population in case of accident. IRSN expertise is sustained by research activities, mostly conducted in an international frame, allowing the use of the most performing investigation means.
- **Local Commissions for Information (CLI) and High Committee for transparency and information on nuclear safety (HCTISN)** form together society take holders concerned with nuclear installations. They are singled-out organisms for the access to information in term of safety, security, public health and environment protection.

IRSN certified quality management system

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

Head office
31, avenue de la Division Leclerc
92260 Fontenay-aux-Roses
RCS Nanterre B 440 546 018

Phone
+33 (0) 1 58 35 88 88

Mailing adress
BP 17 - 92262 Fontenay-aux-Roses Cedex

Website
www.irsn.fr

Photo credits : Noak/Le Bar floréal/IRSN