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## Safety approach for a new French research reactor

D. Rive  
L. Bertrand  
J. Couturier

*Nuclear Safety and Radioprotection Institute, France*

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**ABSTRACT:** After a general overview of the technological irradiation reactors existing in Europe, this document details the safety approach adopted for a new research reactor to be constructed in France and the main recommendations resulting from IRSN assessment.

### 1 INTRODUCTION

As shown in the table below, the existing technological irradiation reactors in Europe are now ageing.

Norway	HBWR	25 MW	1959
Sweden	R-2	50 MW	1960
Belgium	BR-2	80 MW	1961
Netherlands	HFR	45 MW	1961
France	OSIRIS	70 MW	1966

The French Atomic Energy Commission (CEA) implemented a new project of pool type reactor called “Jules HOROWITZ reactor” (RJH). Its construction is planned on the Cadarache site with an operational start by 2013. In 2002, the CEA transmitted an application to the General Directorate for Nuclear Safety and Radiation Protection with regard to the safety options selected for this project. The CEA, designer of new nuclear plants, stated its intention to obtain an increased safety level. Search for improvements should be an ongoing concern with regard to safety. For existing plants, improvements are implemented in accordance with a pragmatic method, considering the design limitations, during scheduled safety reviews. For new plants, a significant safety improvement is required at design stage.

This significant step, at design stage, is possible in an “evolutionary” roadmap if the necessary attention is paid to the lessons learnt from the operating experience, the in-depth studies conducted for existing plants, and the results of safety researches. However, the introduction of innovating provisions should also be considered, in particular for preventing and controlling major accidents.

The purpose of this paper is to highlight the strong points, as safety improvements, resulting either from options deliberately selected by the CEA, or from recommendations resulting from IRSN assessment, presented to expert groups, then notified by the relevant Safety Authorities. This paper will especially deal with the case of the “Jules HOROWITZ reactor”, the only planned research reactor in France in the past 20 years.

## **2 ASSESSMENT OF THE SAFETY OPTIONS FOR THE “JULES HOROWITZ REACTOR”**

### **2.1 Description and basic design options**

The construction of the RJH is planned on the CEA Cadarache site. The RJH will be a pool type research reactor, cooled and moderated with light water; its maximum thermal power will be approximately 100 MW.

The general layout of this installation is illustrated in Figure 1. The RJH is composed of a reactor building (BR) and a nuclear auxiliary building (BAN), as well as a control building and other installation support buildings.

The reactor building, with a cylindrical shape (approximately 36 m in height and diameter), will be partitioned in two geographically distinct zones, one compartment for reactor operation and one for the operation of experimental devices.

The nuclear auxiliary building (parallelepiped) will more specially house:

- a “hot zone”, designed for experiment preparation and operation; it will include hot cells, pools and laboratories for analysis, on-line or post-irradiation measurements,
- a “cold zone”, housing the components providing nuclear auxiliary systems required for the installation operation.

The nuclear unit (BR and BAN) will include only one civil engineering infrastructure. The containment between BR and BAN will be differentiated in the superstructures. The common base ~~mat with mat~~ will support the “water-block”, a single-block assembly made of reinforced concrete, which will in particular gather the pools (reactor, intermediate storage and work), the primary system bunkers and a transfer channel between the various pools and hot cells. It will rest on an aseismic support system.

A great variety of experiments are considered. In particular, it is planned to conduct, in the RJH installation, experiments intended for irradiating:

- actinides, or products including a high content of  $\alpha$  emitters,
- samples, located in core or in reflector zone, under environmental conditions (pressure, temperature and coolant fluid), significantly different from the reactor core conditions (via core experimental loops),
- fuel samples, under degraded thermohydraulic conditions (experiments on broken fuel elements with experimental sequences conducting to sample melting).

The design options selected for this pool type reactor are deeply derived from the existing research reactors (especially OSIRIS and ORPHEE), although they involve significant evolutions. In addition to the reactor building and nuclear auxiliary building aseismic insulation, using elastomer support devices, these evolutions also concern:

- the composition of the driving core, consisting of low enriched uranium 235 (less than 20%) fuel plates; this will be a UMo-AL alloy, selected for non-proliferation and reprocessing possibility,
- the use of closed cooling systems, not only for power removal, but also for residual power removal (primary system and safety system).

The following options should also be noted:

- the “water-block” concept aimed at preventing core uncovering,
- the leak recovery zone (“buffer” space between BR and BAN containments); the reactor building will thus include no direct outlet to the environment.

## **2.2 Topics reviewed and resulting conclusions**

The review requested from the permanent Group especially concerned:

- the justification for the selected location of the future reactor,
- the safety options,
- the reactor design and sizing basis.

The technical assessment conducted by IRSN was presented to the expert Group for reactors during three meetings, on March 20, April 3 and 24, 2003.

During this assessment, difficulties were reported in connection with inaccuracies in the safety options file, as well as inconsistent or non consolidated positions from the operator with regard to certain topics.

### *2.2.1 General methodology of the safety analysis*

The safety analysis approach for the RJH will be aimed at demonstrating that the provisions taken with regard to the various in-depth defense levels are sufficient versus general safety objectives defined for this plant, both in normal operation and after incident and accident situations. Normal operation will include maintenance operations.

Despite all measures taken with regard to design and development quality, the failure possibilities and associated risks will be investigated. This identification of risks impacting the plant condition, or even the environment, will result in a classification of these risks in accordance with the frequency–consequence couple, resulting in a list of operating situations according to the classification specified in the table below.

Definition	Occurrence probability value (/year)
1 – Normal operating conditions as defined in the operation technical specifications	$p = 1$
2 – Incidents whose consequences should remain limited	$1 > p \geq 10^{-2}$
3 – Accidents & 3a – Complex sequences with multiple failures whose consequences should remain acceptable	$10^{-2} > p \geq 10^{-6}$
4 – Controlled severe accidents	

The safety approach proposed by the operator is based on such design choices as:

- definition of a system safety classification, in accordance with six criteria,
- gradation of requirements applied to safety classified systems,
- the taking into account, as from the design stage, of:
  - the risks of common failures and human errors,
  - internal and external hazards, earthquakes (MHPE and SSE) being combined with operating situations in compliance with Fundamental Safety Rule IV.2.a,
  - severe accidents,
  - risks, for the plant, associated with reactor experimental device failures,

and an overall safety analysis, based on:

- general safety objectives, expressed in terms of radiological consequences,
- analysis of operating situations, not yet defined, which will be classified according to their estimated occurrence probability after inventory and grouping, in a limited number of families, of initiator events,
- the adding of a single failure for this analysis (second and third category situations),
- analysis of internal (fire, internal floodings, internal explosion, etc.) and external (earthquake, airplane crash, etc.) hazards, with the purpose that a hazard should not result in an accident situation.

With regard to controlled severe accidents, the operator assumes:

- a BORAX type reactivity accident, in the reactor building, leading to destruction and partial melting of the core,
- a generalized fire in hot cell, in the nuclear auxiliary building, with failure of associated filtration systems.

Severe accidents, as from the design stage, both through preventive provisions and provisions for managing and attenuating their consequences, are taken into account and should allow for strengthening the plant in-depth defense.

Furthermore, the operator provided a list of so-called excluded situations, such as, for instance, air melting of fuel and pool dewatering, for which he will demonstrate that he can run a sufficient number of robust preventive provisions.

Finally, the experimental aspect more specially results in the following objectives:

- physical separation between reactor operating systems, experimental device operating systems and safety systems,
- design of the installation, in order to allow implementation of new components,
- the taking into account of the failing of experimental devices and associated operations.

The approach, basically similar to the approaches applied in France for pressurized water reactors in the Electricité de France plants and the Superphenix fast neutrons reactor, is a noticeable progress for research reactors.

### *2.2.1 Positions and recommendations resulting from the assessment conducted by IRSN*

As a result of the assessment conducted by IRSN, a number of positions and recommendations were issued, and most of them are examined below; it should be noted that some recommendations (especially the wide application of the “hazard-event” approach, effects of aircraft fuel fire) represent progresses with regard to reactor safety, and not only for research reactors.

#### Selection of the installation site

The selected site for installation of the RJH results from an approach involving three steps:

1. selection: after collection and study of the available documents, three potential sites were preselected. After field studies, which improved the existing mapping, two of the three preselected sites were selected for installing cored and destructive borings;
  2. qualification: this step was associated with more detailed characterization of both selected sites (hydrogeological monitoring, tectonic, seismotectonic and seismological surveys). On completion of this step, the site with the most appropriate characteristics for the RJH installation was selected;
  3. confirmation: the purpose of this step was to conduct detailed investigation of the selected site, in particular geotechnical studies in order to define the structure calculation parameters.
- The selected site (Bargette East sector on the Cadarache site) raised no objections; however, the operator was asked to pay particular attention to the risk of water table rise, considering the high water level reported in the past.

#### Selection of an aseismic insulation

It appeared that selection of an aseismic insulation for the reactor building and the nuclear auxiliary building, through elastomer support devices, required the operator to perform an in-depth analysis of the technological control of such design, especially in terms of ageing, vulnerability to malicious actions and compatibility with the control of major accident consequences.

#### “Clean reactor” option

The fact that the operator did not state a clear position with regard to the application of the usual “clean reactor” option (unloading of a fuel assembly showing a clad failure, as soon as detected), selected for research reactors, was strongly discussed. Consistent with the rules stated by IAEA for

research reactors, it was requested, during operation, to limit the operating time with a degraded fuel element in the feeding core. In this respect, the operator should describe, in the preliminary safety analysis report (PSAR), the provisions planned in case a broken clad is detected, more specially specifying the selected approach to define the warning and automatic core shutdown thresholds, the surveillance systems used, and the modes of identification and unloading of degraded elements.

#### Safety analysis approach: Operating situations

The safety analysis approach described in the safety options file for the design of the RJH, based on the definition of reference situations studied with deterministic rules, was considered as satisfactory in principle. However, the operator was requested to:

- apply the usual classification of accident situations, corresponding to a single initiator event, in two categories,
- prepare, as a support to the lists of operating situations to be presented in the RPrS for the various parts of the RJH (reactor, cells, experimental devices, etc.), a file describing the identification of initiator events, how they were grouped in envelope operating situations, and how the situations were classified in the various categories; the interest of using a probabilistic risk assessment (PSA), in particular to confirm the list of operating situations, will be reviewed at a later stage,
- specify the list of so-called complex situations (multiple failures situations), the associated frequency, and the study rules selected for assessing their consequences,
- specify the elements that allow considering a situation or a scenario as “excluded”,
- demonstrate, in the PSAR, that controlled major accidents selected for the reactor part and the nuclear auxiliary parts are highly improbable, through the availability of preventive provisions equivalent to two strong lines of defense,
- finally, transmit a first list of operating situations.

#### Safety analysis approach: Consideration of aggressions

The operator was requested to:

- implement an “hazard-event” approach, not only for earthquake, but also for such hazards as, for instance, extreme meteorological conditions; this approach involves the following steps:
  - identification of equipment essential to maintain or restore the safe condition of the installation during the hazard considered and direct consequences,
  - design of this equipment to withstand the initial hazard,
  - check that the failure of installation equipment not sized for the initial hazard, would not affect the above-mentioned safety related equipment or, as a minimum, would not prevent conducting the required safety actions,
  - otherwise, design of the equipment in question to also withstand the hazard and/or implementation of protective provisions for safety-related equipment.
- specify the approach for incorporating extreme meteorological conditions, especially combinations with operating situations and other hazards,
- classify “safety” those systems whose failure in case of internal or external hazards would result in an accident situation,

- incorporate the fuel fire effects added to the direct effects of the impact of selected aircraft, as well as the airborne resources used in case of external firebreak for studying the risks of aircraft crash,
- propose an argued position with regard to the interest of fitting the reactor with an automatic emergency shutdown in case of earthquake, consistent with the rules states by IAEA for research reactors,
- assume a firebreak in any rooms and not systematically exclude from the analysis the fire hazards in rooms where ignition sources were not evidenced.

### Single failure criterion

With regard to the application of the single failure criterion, it was requested that the operator should pay a particular attention to the presence of check-valves in the design of the various systems, when these components are considered as passive components.

### BORAX type reactivity accident

In the options considered for design of the reactor containment system, the operator selected, for the controlled severe accident category (AGM), a BORAX type explosive reactivity accident. The selected accident is characterized by a 50% melting of the core fuel, a thermal energy of 135 MJ deposited in the fuel during the accident, added to the energy initially contained in the fuel, and a mechanical energy release corresponding to 5% of the thermal energy released during the accident, i.e. 6.75 MJ; these values may be increased by the values of the thermal and mechanical energies that may be released by the experimental devices installed in the reactor and that may be damaged during the accident.

The operator also planned studying the radiological consequences of the accident, assuming the whole core melting, as well the post-accident cooling of the damaged core, with reasonable envelope hypotheses and considering the various possible effects, particularly on the containment, of mechanical energy release. Although consistent with those selected in the past for certain research reactors (OSIRIS, ORPHEE, etc.), the above-mentioned hypotheses are arbitrary.

For a new research reactor, such as the RJH, it appeared necessary that the operator provides the elements to confirm the envelope character of the values of released thermal and mechanical energy and selected hypotheses for assessing the accident consequences. In this respect, the operator should in particular:

- identify the accident sequences that may result in core melting and correspond to the notion of controlled severe accident, in terms of probability,
- assess for these sequences the energy deposited in the fuel, using the currently available tools,
- also assess, using the available tools, the mechanical energy developed by the release of the steam bulb generated during the thermodynamic interaction between the melt fuel and water,
- also assess the transfers of radioactive products into the hall, the risks of solid material or existing pool systems projections, etc.

### Fuel

The UMo-Al alloy is selected as the reference solution for the core fuel (and U<sub>3</sub>Si<sub>2</sub>-Al as the fallback solution). This new type of fuel requires a qualification, which should especially demonstrate its compliance with the fuel response requirements selected in the various operating situations (“service limits”), including accident situations. In this respect, the operator was requested to select as a

target, for the feeding core, the absence of clad breaks, not only for first category situations, but also for second category situations. Furthermore, it appeared necessary that the radionuclide release rates selected in case of fuel degradation be confirmed by a sufficient experimental data basis.

### Experimental devices

With regard to the safety options relating to experimental devices, the operator's overall target to match the requirements applied to these devices depending on the safety stakes, was considered as satisfactory. However, the operator was requested to define the device failure cases representing situations to be considered when sizing the installation.

The operator was also requested to specify:

- first, the notion of full failure of a device, specifying how the various events that may generate stress on the device barrier(s) are considered,
- second, the approach planned for designing and sizing the device barriers and the systems associated with these barriers.

### Human and organizational factors

The operator was requested to detail, in the PSAR, the action plan implemented to incorporate the human and organizational factors throughout the design process, as well as the initial results of implementation for this action plan.

## **3 CONCLUSION**

As a general conclusion, the safety-related provisions taken by the Atomic Energy Commission (CEA) for the RJH will allow to obtain a safety level consistent with the future power generating reactors safety level, with, as the most significant progress, the consideration, from the design stage, of the severe core meltdown accidents from all points of view (control of the removal risk in containments, post-accidental cooling of relocated materials, etc.). Generally, it was considered that these provisions constitute a satisfactory "evolutionary" basis for the continuation of the project.

However, the assessment conducted by IRSN led to issue a certain number of recommendations, particularly relating to some relatively arbitrary assumptions and approaches (for example: energies considered for BORAX accident).

The projects of new facilities implemented by CEA seem to be on the right way: an "evolutionary" way and not a "revolutionary" way.

Figure 1: General installation of the RJH

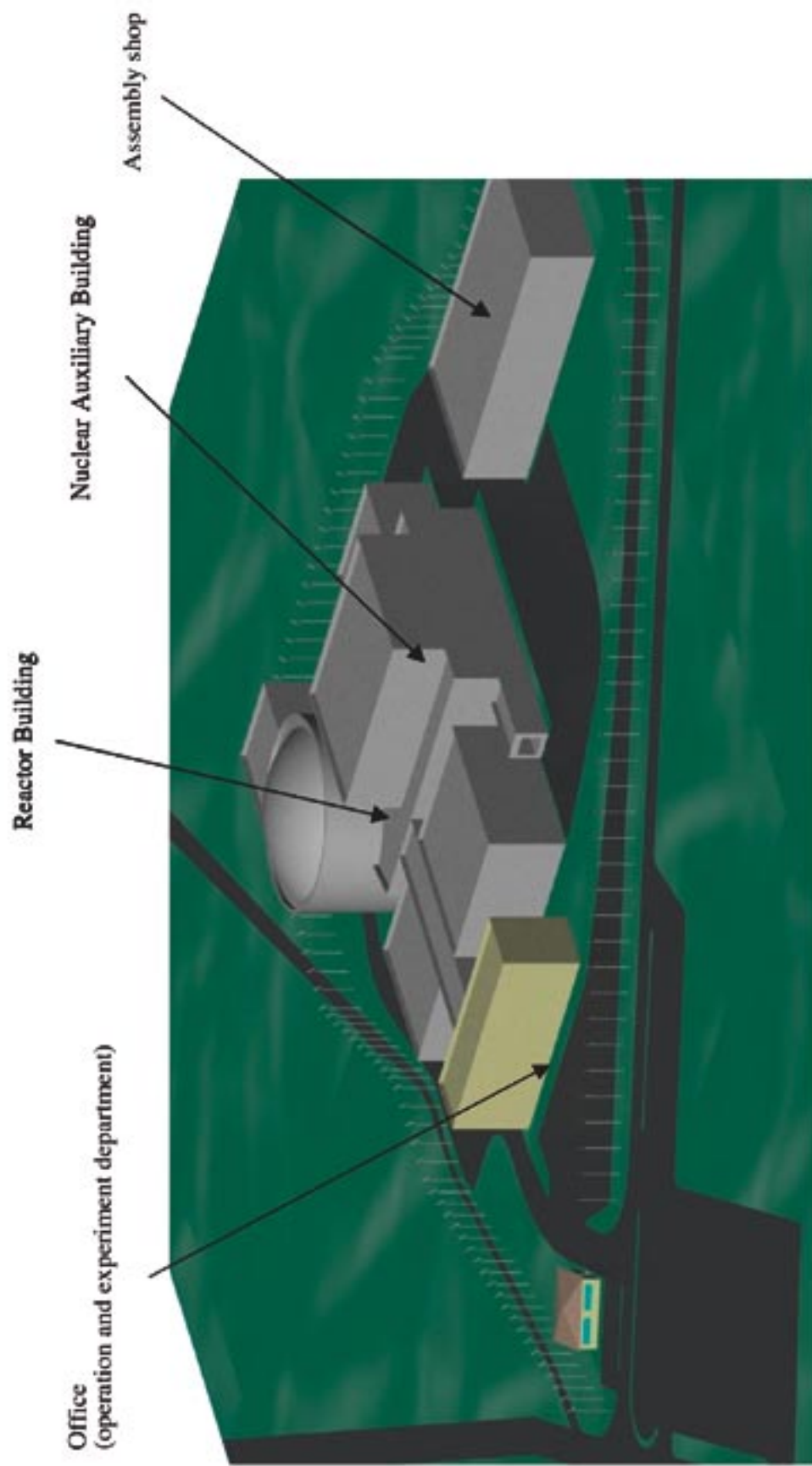


Figure 2: Core and fuel elements of the R

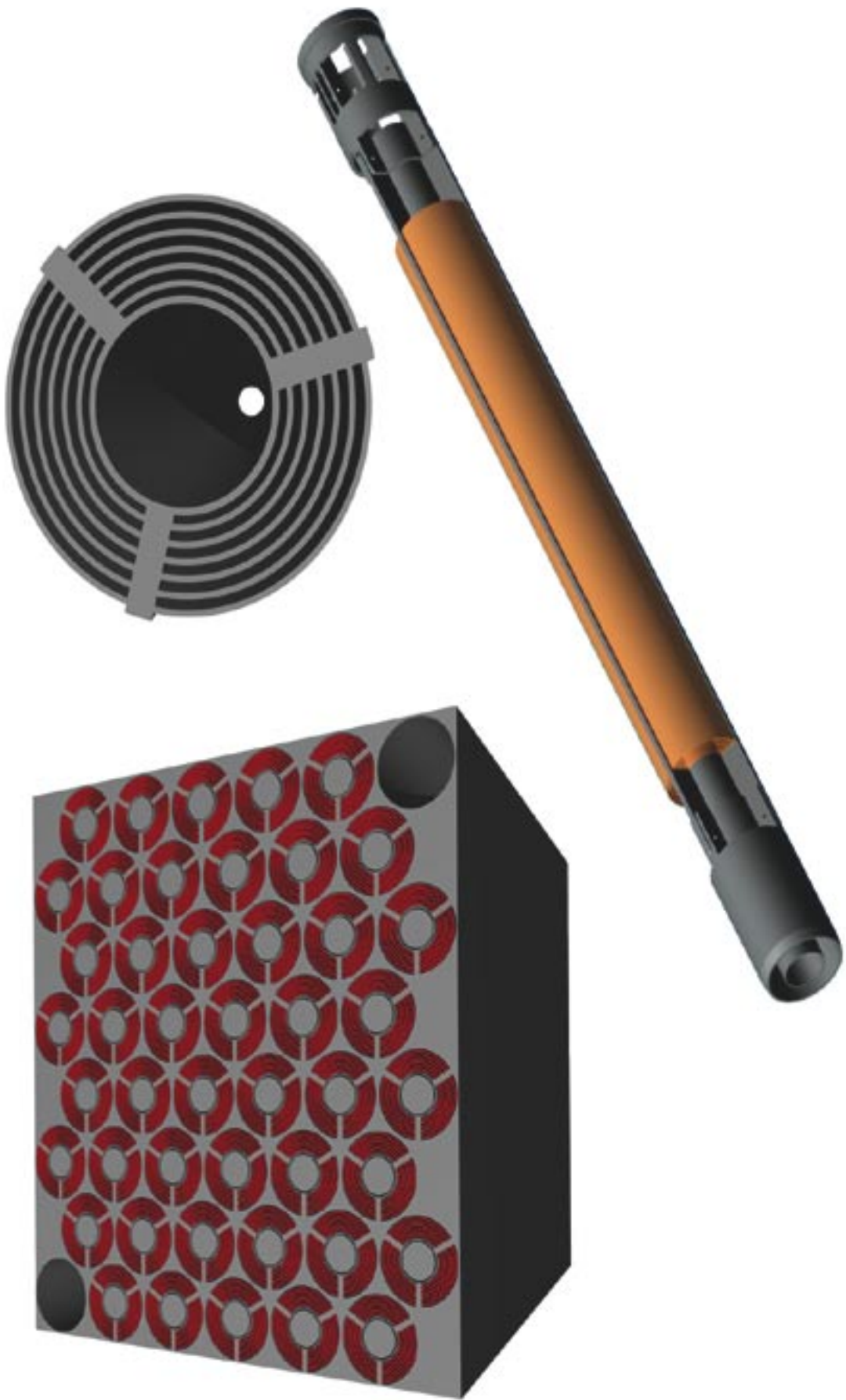


Figure 3: Functional diagram of the RJH cooling

