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ALLEGRO

Design and Safety Roadmap

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Abstract

This document presents the updated ALLEGRO Design and Safety Roadmap with a detailed task description and distribution among the V4G4 partners.
On each task, needed manpower and investments are estimated.
Even if it presents all phases of the project, it is mainly focused on the two first: the pre-conceptual and the conceptual design.
This Design and Safety Roadmap will be completed by a R&D Roadmap.

Content

1 INTRODUCTION

This document presents the updated Roadmap for the Design and Safety of the European gas cooled demonstration reactor ALLEGRO project following the recommendation of the V4G4 Steering Committee (Ref.1), namely:

- Start up core with reduced thermal power to face the safety limits of the stainless steel cladding of the initial oxide fuel.
- The potential use of an enriched Uranium fuel instead of MOX fuel to facilitate the procurement.

In addition, developments to increase the use of passive safety related systems are planned.
The Roadmap includes a detailed technical work plan and the related R&D of the V4G4 organizations, VUJE (Slovakia), UJV (Czech Republic), MTA EK (Hungary) and NCBJ (Poland).
At the very beginning of the project, the Design Specifications of the reactor and the Safety Specifications shall be defined.
This Roadmap shall be completed by a R&D Roadmap in support of the Design and Safety.

2 TERMS AND DEFINITIONS

The terminology used in the ALLEGRO Design and Safety Roadmap is based on the IAEA, WENRA and industrial terminology.

DESIGN-RELATED TERMS

Design requirements & Objectives
Documentation of the primary decision-making process & assumptions behind design decisions made to meet the owner's project requirements. It describes how the systems, assemblies, conditions, and methods will be chosen to meet the owner' requirements to the project. It is a set of conditions, needs, and requirements taken into account in designing a facility or product, i.e. summarization in words & a few key numbers: What the unit has been designed to do, and under what assumptions (Ref. 2).
The four main phases of the Project: Pre-conceptual Design, Conceptual Design, Basic Design and Detailed Design are defined in §3

ETDR 2008
Concept by CEA issued from the FP6 GCFR STREP project (50 MWt, one primary loop, water on secondary side).

ALLEGRO CEA 2009 (Reference design of ALLEGRO)
Concept ALLEGRO by CEA (75 MWt, two primary loops, water on secondary side) (Ref. 3)

ALLEGRO CEA 2011
Concept ALLEGRO (75 MWt, two primary loops, helium on secondary side with turbomachinery) (Ref. 4)

ALLEGRO V4G4 20XX
Concept under development by V4G4.

SAFETY-RELATED TERMS

The meaning of safety-related terms such as inherent safety characteristics, passive/active components/systems, fail-safe, grace period, foolproof, fault-/error-tolerant, simplified safety system and transparent safety (Ref. 5).

Other terms are defined below:

Safety requirements & Objectives
For designing, constructing and operating any nuclear installation safety objectives are set. The main source of these objectives is the fundamental set of safety objectives as it was defined by the IAEA (Ref. 6) for all nuclear plants as follows:

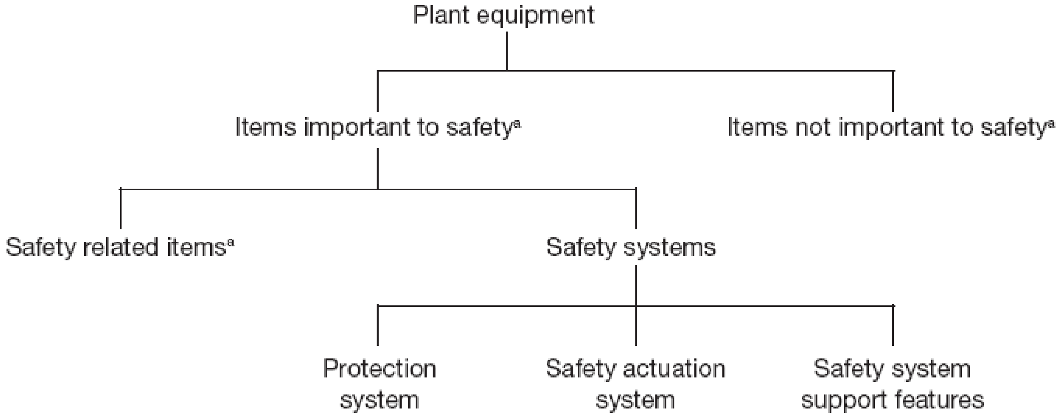
- To protect individuals, society and the environment from harm by establishing and maintaining in nuclear installations effective defences against radiological hazards.
- To ensure that, in all operational states, radiation exposure within the installation or due to any planned release of radioactive material from the installation is kept below prescribed limits and as low as reasonably achievable (ALARA), and to ensure mitigation of the radiological consequences of any accidents.
- To take all reasonably practicable measures to prevent accidents in nuclear installations and to mitigate their consequences should they occur; to ensure with a high level of confidence that, for all possible accidents taken into account in the design of the installation, including those of very low probability, any radiological consequences would be minor and below prescribed limits; and to ensure that the likelihood of accidents with serious radiological consequences is extremely low.

Recently a set of additional objectives for future reactors have been proposed, to increase public confidence in their safety (Ref. 7):

- Minimisation of toxic, radioactive waste production and release at normal and incidental operation (ALARA principle) and following abnormal occurrences, thereby improving protection for the public health and the environment.
- Need of minimal emergency protection action of the population around the site, and further the elimination of any technical justification for offsite emergency response.
- An enhanced resistance to proliferation risks, through unattractive route for diversion and theft of weapons-usable materials.

The safety requirements are more explicit requirements which are derived from these objectives, considering also the European Utility Requirements (Ref. 8) and the requirements of the WENRA group (Ref. 9). The safety requirements are fixed in the national nuclear safety regulation. As the current national safety regulations do not contain specific requirements for Generation IV reactors, the corresponding safety requirements have to be elaborated parallel with the development of the new reactor types.

Plant equipment according to IAEA Safety Glossary, Terminology Used in Nuclear Safety and Radiation Protection, 2007 Edition



[a] In this context, an 'item' is a *structure*, *system* or *component*.

Safety system

A system important to safety, provided to ensure the safe shutdown of the reactor or the residual heat removal from the core, or to limit the consequences of anticipated operational occurrences and design basis accidents. Safety systems consist of the protection system, the safety actuation systems and the safety system support features.

Protection system
System that monitors the operation of a reactor and which, on sensing an abnormal condition, automatically initiates actions to prevent an unsafe or potentially unsafe condition. The system in this case encompasses all electrical and mechanical devices and circuitry, from sensors to actuation device input terminals.

Safety actuation system
The collection of equipment required to accomplish the necessary safety actions when initiated by the protection system.

Note: After a postulated initiating event, some required safety system support features may be initiated by the protection system and others may be initiated by the safety actuation systems they serve; other required safety system support features may not need to be initiated if they are in operation at the time of the postulated initiating event.

Safety system support features
The collection of equipment that provides services such as cooling, lubrication and energy supply required by the protection system and the safety actuation systems.

Safety feature for design extension conditions
Item designed to perform a safety function or which has a safety function in design extension conditions.

Safety related system
A system important to safety that is not part of a safety system.

Design Basis Conditions (DBC)
Normal Operation, Incident and Accident Conditions of internal origin for which the plant is designed according to established design criteria and conservative methodology**.**

Design Basis Category 1 Conditions (Normal Operation)
Conditions which are expected frequently in the course of power operation, refuelling, maintenance or manoeuvring of the plant. As such, Design Basis Category 1 Conditions are accommodated with margin between any plant parameter and the value of that parameter which would require either automatic or manual protective action

Design Basis Category 2 Conditions (Incident Conditions)
Conditions which may occur once or more in the life of the plant ($f>10^{-2}$). These conditions, at worst, result in a reactor trip with the plant being capable of returning to operation. These conditions do not propagate to cause a more serious fault, i.e. Design Basis Category 3 or 4 Conditions.

Design Basis Category 3 Conditions (Accident Conditions)
Conditions which may occur very infrequently ($10^{-2}>f>10^{-4}$). These conditions may result in the failure of only a small fraction of the fuel rods. A Design Basis Category 3 Condition does not, by itself, generate a Design Basis Category 4 Condition or result in a consequential loss of function of the Reactor Coolant System or Containment System.

Design Basis Category 4 Conditions (Accident Conditions)
Conditions which are not expected to take place ($10^{-4}>f>10^{-6}$), but are postulated because their

consequences would include the potential release of significant amounts of radioactive material. They are
the most extreme Design Basis Conditions which must be designed against and represent limiting cases.

Design Extension Conditions (DEC)
A specific set of accident sequences that go beyond DBA, to be selected on deterministic and probabilistic
basis and including :
• Complex Sequences,
• Severe Accidents.
Appropriate design rules and criteria are set for DEC, in general different from those for DBA

Source: EUR (Ref. 8).

Level 1 PSA
Probabilistic safety assessment Level 1 comprises the assessment of plant failures leading to determination of the frequency of core damage.

Level 2 PSA
Probabilistic safety assessment Level 2 includes the assessment of containment response, leading, together with Level 1 results, to the determination of frequencies of failure of the containment and release to the environment of a given percentage of the reactor core's inventory of radionuclides.

<u>LICENSING-RELATED TERMS</u>

Safety Analysis Report (SAR)
The SAR represents an important communication between the operating organization and the regulatory body, and it forms an important part of the basis for licensing a nuclear power plant and an important part of the basis for the safe operation of a plant. The SAR should therefore contain accurate and sufficiently precise information on the plant and its operating conditions.

Introductory safety analysis report
Introductory Safety Analysis Report is a standard document required (in Atomic Acts) for siting licensing in the Slovak Republic developed based on Conceptual Design. Basic information on the design of nuclear installation, on management of safety and on site evaluation is included in this document. Extend of the information submitted to the state authority shall enable for regulatory review and assessment of the possibility to construct nuclear installation in the site and operate it safely.
Introductory safety analysis report includes:

a) Terms of reference for the nuclear facility project stemming from nuclear safety requirements,
b) Assessment of the building site from the viewpoint of nuclear safety,
c) Safety principles adopted for design of the nuclear facility, safety objectives and the method of their harmonization with basic safety principles,
d) The method of achievement of the safety objectives,
e) Detailed information on the nuclear facility and its operating conditions, supporting calculations enabling assessment as to whether a nuclear facility can be built and operated safely.

Preliminary Safety Analysis Report
This report is developed based on Basic Design and supports the application for operational permit.
The preliminary safety report includes:

a) Analytical and experimental evidence that the nuclear safety requirements determined by the reference safety report have been complied with in the design documentation,

b) Requirements for the quality of the nuclear facility being designed, including proposed quantification of nuclear safety parameters2), reliability and useful life,
c) A preliminary schedule of inspections of selected facilities,
d) Adjustment of information given in the reference safety report and justification of deviations from the original design of the nuclear facility,
e) For nuclear facilities with nuclear reactors, draft methodology for probability assessment of safety and its justification, including preliminary assessment results,
f) A general preliminary assessment of nuclear facility design safety verified by an independent organization.

Pre-operational safety report
Incorporates any necessary revisions to the Preliminary Safety Analysis Report following the commissioning and licensing process for the first entry into routine operation.

3 PHASES OF THE PROJECT

The main phases of the whole Project are:

1. Definition of the basic safety and performance goals
2. Pre-conceptual design
3. Conceptual design
4. Basic Design
5. Detailed Design
6. Siting and Licensing
7. Construction
8. Operation

The description of work detailed here concerns the specifications, the business plan, the siting and licensing and the first two phases of the project, pre-conceptual design and conceptual design.
The ALLEGRO Roadmap must be based on a clear terminology accepted by all partners.
For each item of the Roadmap the level of development to be reached by the end of the Pre-conceptual, Conceptual and Basic Design phases have to be clearly defined.
The works have to be organized in a way which ensures that the development of the items is carried out according to a common time schedule which makes it possible to organize the feedback steps between design and safety analysis items.

3.1 Definition of the design specifications and safety requirements and objectives

At the very beginning of the project, the design specifications fixing the performance goals of the reactor as well as the safety requirements and objectives shall be defined.

3.2 Pre-conceptual design

The Pre-conceptual design is the first step of the technical work.
This is a feasibility phase where different design options are assessed.
The Safety Concept has to envisage how it is intended to implement the already accepted Basic Safety Principles. The development of the Safety Concept has to be closely related to the development of the Pre-Conceptual Design that is the first phase of the design with the basic concept of systems. In this phase the non-mandatory Introductory SAR (ISAR) can be prepared (as it is specified in ALLIANCE report D2.1). ISAR shall contain the basic description of the reactor technology and the safety

requirements. The most important items to be prepared in the pre-conceptual design phase are as follows:

- the core design
- definition of Design Basis and Design Extension Conditions
- definition of safety and barrier functions and the rules of safety classification
- classification of each system and preparation of the respective Basic Design Goals
- ISAR

3.3 Conceptual design

The conceptual design phase is devoted to the choice of design options studied in the previous phase and their justification.
The goal of this phase is to reach a level when the site license application can be submitted.
In this phase the Conceptual Design and the Design Safety Concept have to be developed describing a frozen design satisfying all safety requirements. Site data have to be completed. The Conceptual Design shall contain all the necessary design arrangements needed to receive a Site Licence, both by covering the entire plant and also in the depth of the design of systems and components. It has to contain the concept of responding to seismic events, station blackout and other external events. The Conceptual Design is summarized in a Conceptual Design Document that is finalized when the Basic and Detailed Design Documents are completed. The Design Safety Concept has to show how the Safety Concept is implemented in the design. At this stage the formal licensing is started based on the Simplified Preliminary SAR (SPSAR). The SPSAR is preliminary in that sense that the requirements concerning SAR at site licensing are significantly simpler than at obtaining the Construction Licence. E.g. the design requirements emerging from site specific data shall be provided but the design arrangements related to these site specific data are not necessarily given here.

3.4 Basic design, detailed design

The report D5.2 does not make a distinction between Basic Design and Detailed Design. As a matter of fact the Basic Design is prepared by the main designer as a continuation and refinement of the Conceptual Design. Parallel to this the Safety Analysis Report is also refined taking into consideration all aspects of the Basic Design. In the preparation of the Detailed Design designers of the systems and components play the main role and all details shall be determined and fixed both in the Detailed Design Document and in the Preliminary Safety Analysis Report. These documents serve the basis of receiving the construction licence.

Figure 1 presents the phases of the project and the corresponding main activities.

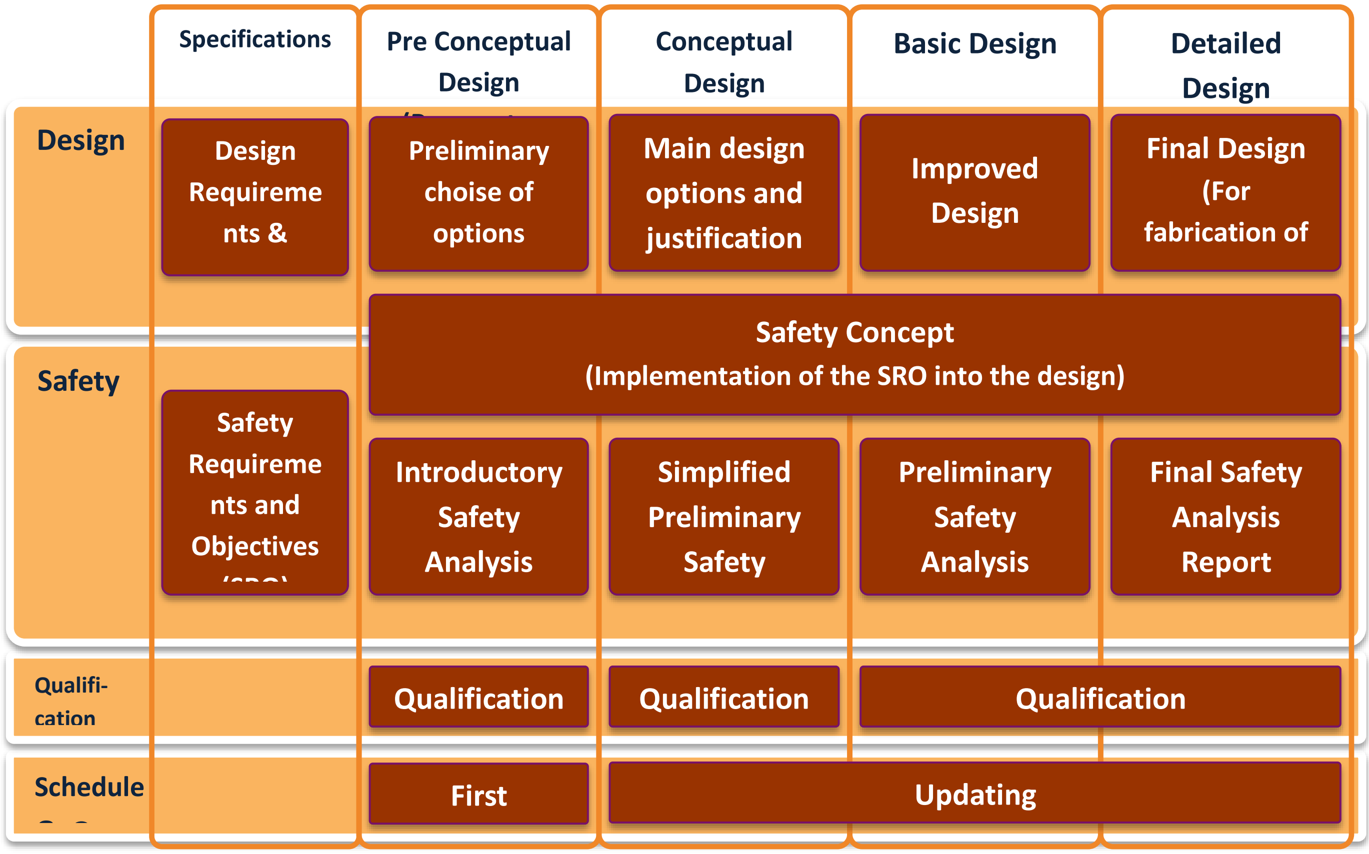


Fig. 1 – Phases of the project

4 DESCRIPTION OF WORK

The work is divided in the following areas (Fig.1):

1. Whole Project activities including Specifications (Design and Safety), Business Plan and legal issues, System integration and assessment, and Siting and Licensing
2. Reactor system
3. Core
4. Systems, Structures and Components
5. Gas management
6. Instrumentation and Control
7. Safety

On each area, the tasks are described in the work program by identifying the:

- Title
- Leader of the task and other contributors
- Objectives of the task depending on the phase of the project
- Technical description
- Level to be reached at the end of various phases
- Tools to be used to perform the task
- Input data
- Time schedule
- Manpower
- Investments

The whole time schedule of the tasks is represented on Fig. 2.

Specifications | **Safety requirements and objectives** | **Business Plan** | **Legal matters** | **Siting and licensing**

System Integration and Assessment

Reactor System
- Heat transport system
- Transition from oxide to ceramic fuel
- Vibrations
- Loads under normal condiions

Core
- Neutronics
- Thermal-hydraulics
- Fuel design
- Control and shutdown
- Fuel qualification
- Fuel fabrication

Systems, Structures & Components
- Reactor Pressure vessel
- Guard vessel
- Heat exchangers
- Blowers
- Valves
- CR drive mechanisms
- DHRS
- Fuel handling
- Fuel management
- Containment
- Core catcher
- Power supply
- Gas turbomachinery coupling
- Reactor protection

Gas Management
- Primary
- Secondary
- Gard vessel
- Transport and deposition of activity
- Gas storage and make-up

Waste Management
- Filters and waste management
- Other waste

I&C
- Temperature, pressure and flowrates measurements
- Neutron flux
- Monitoring of structures
- Cladding failure detection and localization
- Reactor control system

Safety
- Transients analysis
- Severe accidents
- Loads on fuel and components
- Releases to the environment
- PSA

4.1 WHOLE PROJECT ACTIVITIES

4.1.1 Design Specifications AND OBJECTIVES

Leader and other contributors

UJV, VUJE, MTA EK, NCBJ

Objective

Formulate goals, requirements and target values for the ALLEGRO demonstrator and its sub-systems.

Description

The specifications document the primary decision-making process including the assumptions behind design decisions made to meet the project requirements. In the industry it is often called also Basis of design. It represents the basic input for designers of the whole system as well as of the subsystems. It is a living document that is formed iteratively step by step. For example the type and amount of impurities in the primary helium cannot be known before the materials and conditions within the primary circuit are specified.
The specifications are structured in the following way:

1. Reactor as a whole – Goals, main parameters & requirements (T, P, burn-up, lifetime, …).
2. Sub-systems - Goals, main parameters, functions & requirements, including applicable rules, codes and other regulations:
   a. Cores (start-up core, intermediate core, ceramic core),
   b. Circuits (primary, secondary, tertiary, …)
   c. Other subsystems (e.g. He purification system,…)

In service inspection and repair requirements.
The level of development to be reached at the end of each important phase of the project (Pre-conceptual design, Conceptual design, Basic design,…) will be defined here.

Level to be reached at the end of various phases

The Specifications have to be elaborated together with the definition of the basic safety and performance goals. The Specifications have to be fixed in a separate document which will be further refined during the pre-conceptual design and conceptual design phases.

Tools

1. Negotiations between the partners of the project resulting in a consensus about the goals, main parameters & requirements for the reactor as a whole.
2. Assessment of the individual subsystems by dedicated experts.

Input Data

- Reference 10

Time schedule

See Fig. 2

Manpower

12 PM (Persons x Months)

Investment

None

4.1.2 Safety requirements and objectives

Leader and other contributors

UJV, VUJE, MTA EK, NCBJ

Objective

To have a reference framework for the safety studies.

Description

Requirements must be defined in the following areas:

1. Normal operation, abnormal events and prevention of accidents
2. Accidents without core melt
3. Accidents with core melt
4. Independence between all levels of Defense-in-Depth
5. Safety and security interfaces
6. Radiation protection and waste management
7. Leadership and management for safety

Level to be reached at the end of various phases

The SRO has to be defined before the pre-conceptual design phase.

Tools

N/A

Input Data

WENRA (Ref. 11)

Time schedule

The SRO has to be defined before the pre-conceptual design phase.
See Fig. 2

Manpower

12 PM

Investment

None

4.1.3 Business Plan

Leader and other contributors

VUJE, MTA EK, UJV, NCBJ

Objective

A condensed informative document for governmental policy & decision makers and potential public & private investors.

Description

The business plan describes in a very condensed and well-structured way the main characteristics of the project:

1. Goals of the project.
2. Technical solution.
3. Project management.
4. Legal matters.
5. Time schedule.
6. Financial matters.
7. Assessment of risks in the project.

Level to be reached at the end of various phases

Although the Business plan is a living document, it must be elaborated in its complete form at the beginning of the Pre-conceptual phase. Corrections are expected to be made, when necessary.

Tools

N/A

Input Data

Information from the corresponding working groups (Coordination, Design, Safety, Fuel, Licensing, Governance, Financing).

Time schedule

See Fig. 2

Manpower

6 PM

Investment

None

4.1.4 Legal matters (IPR & general NDA)

Leader and other contributors

VUJE, MTA EK, UJV, NCBJ

Objective

To clarify the way, in which data are exchanged between partners.

Description

Currently, the Allegro activities are conducted based on network of several agreements. A single agreement binding all partners would be helpful. Such agreement would facilitate exchange of data between partners and help improving general knowledge of everyone about what is done in other institutions.

The agreement should also cover the way in which future results of the project are managed.

Level to be reached at the end of various phases

A single step should be sufficient.

Tools

N/A

Input Data

Results from other similar initiatives (JHR?)

Time schedule

See Fig. 2

Manpower

Investment

None

4.1.5 System integration and assessment

Leader and other contributors

VUJE, UJV, MTAEK, NCBJ

Objective

Architecture and integration of the whole plant, consistence of the design.

Description

This task is devoted to the technical coordination among the tasks on each component and system of the plant.
The activities of this task include:

- The definition and documentation of the initial design, based on the "CEA 2009" design.
- The verification of the consistence of the whole plant design by simplified thermal, neutronic and thermalhydraulic analyses from the very beginning of the project including the initial reactor system calculations.
- Definition of geometrical layout of the plant.
- The verification all along the project of the consistency with the design and safety specifications.
- The management of the process of optimization of the initial design, in particular following the recommendations of the ALLEGRO SC /1/, links between components and systems dedicated tasks.
- The management of the list of the required qualification identified on each components and systems dedicated tasks.
- Updating of the whole project time schedule by integrating the status of each task.
- Management of the technical documentation of the entire Project.

Level to be reached at the end of various phases

This is a continuous activity

Tools

CAD software such as Inventor, CATIA, SolidWorks and others.
Simplified models
Database of requirements and documents

Input Data

- All other technical tasks

Time schedule

See Fig. 2

Manpower

Estimate: Min. 48 PM

Investment

CAD software, min. 6 licenses.

4.1.6 Siting and licensing

Leader and other contributors

VUJE, NCBJ, MTA EK

Objective

This "macro" task is added to be considered from the very beginning of the project even if site investigation will be performed only after completing the conceptual design phase. Activities described in the present Roadmap are limited to establishing the basic expectations related to site investigations.

Description

A document has to be prepared by the end of the conceptual design phase that summarizes the basic requirements concerning the investigations needed for site licensing (data to be collected, means of measuring parameters, etc.). It is important to foresee the parameters of loads related to external events (including those of very low probability) in order to provide data both for design of buildings and structures and also for performing full scope Level 1 and Level 2 PSA:

Level to be reached at the end of various phases

See above.

Tools

N/A

Input Data

National siting requirements

Time schedule

See Fig. 2

Manpower

Investment

4.2 REACTOR SYSTEM

4.2.1 Heat transport systems

Leader and other contributors

VUJE, UJV, MTAEK, NCBJ

Objective

1. Setting of the number of circuits and loops.
2. Primary circuit including the DHR system.
3. Secondary circuit.
4. Tertiary circuit
5. Auxiliary circuits of the DHR system.
6. Design of over pressure protection system

Description

Optimization of the basic layout requires iterative calculations, which for each variant considered will specify:

- Pressures and pressure losses along the circuit
- Pipeline diameters
- Heat exchangers basic layout and type (i.e. pipe, u-tube, plate, other…)
- Power requirements for blowers

The resulting document shall provide information about optimum setup from Balance-of-Plant point of view. This setup will then have to be subsequently modified according to more detailed calculations done in 3.10.

Level to be reached at the end of various phases

By the end of the pre-conceptual design phase the document on Heat Transport Systems has to contain the first variant of pressures and pressure losses along the circuit and the heat exchangers basic layout and type. The document has to fix the maximum pipeline diameter in the primary circuit in order to determine the limiting LOCA case. In the conceptual design phase this document has to be refined and pipeline diameters and power requirements for blowers have to be supplemented. Further refinement of the document may take place also in later phases of the design.

Tools

Balance-of-plant analysis tools (eg. Cycle Tempo)

Input Data

CEA Design B-O-P as a starting point.
Initial data from core neutronic and t-h model (flow, temperatures etc.)

Time schedule

See Fig. 2

Manpower

12 PM

Investment

None

4.2.2 Transition from the first core to the ceramic core

Leader and other contributors

VUJE, UJV, MTAEK, NCBJ

Objective

1. Strategy of the technology transition from the low temperature to the high temperature option

Description

The innovative fuels should be used in ALLEGRO based on a progressive qualification approach. The successive core configurations should be employed including different fuel technologies and operating conditions.

At first, the oxide core with metallic clad will be implemented. Still within this phase of preliminary moderate temperature, some ceramic fuel test assemblies will be implemented in core positions with locally higher temperatures. Ceramic core will be implemented whenever the qualification of ceramic fuel makes it possible to license ceramic fuel. Then the core outlet temperature can be increased.

The management plan of fuel must also take into account minimization of costs, resources, time etc.

Level to be reached at the end of various phases

The strategic document has to be fully prepared in the pre-conceptual design phase. It can be refined in later phases of the project.

Tools

Similar 3.3.1.2

Input Data

Tasks 3.3.1.2, 3.3.1.3

Time schedule

See Fig. 2

Manpower

Investment

None

4.2.3 Assessment of vibrations

Leader and other contributors

VUJE

Objective

Assessment of potential vibrations of the primary & secondary circuits (including the GV) due to high velocity of gas flow and possibly also due to blowers.

Description

Vibrations and resonances can become dangerous for complex systems, when not minimized by the design itself. The following analyses will be done:

1. Identification of the most important vibration exciters.
2. Analysis of vibrations up to the level of GV.
3. Proposal of potential recommendations to designers.

Level to be reached at the end of various phases

Pre conceptual: Identification of potential risks

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 24 PM

Investment

TBD

4.2.4 Loads on fuel and components in normal operation

Leader and other contributors

VUJE

Objective

The various loads on fuel, reactor internals and primary circuit components arising in normal operation and in accident conditions (including external events) have to be determined. The present task is devoted only to loads in normal operation (see also Tasks 3.12.2.2 and 3.13 for other loads).

Description

The loads arising in normal operation and in accident conditions represent a structural challenge for fuel, reactor internals and primary circuit components. Loads in normal operation may lead to fatigue and an early deterioration of properties and even to a loss of function of the above components. The design has to ensure that the structures withstand the assumed loads.

Loads in normal operation are static loads, vibrations and other loads.

Level to be reached at the end of various phases

In the pre-conceptual design phase the loads in normal operation have to be defined.

In the conceptual design phase these loads have to be quantified by using thermal-hydraulic and other calculations.

Tools

Thermal hydraulics codes, CFD codes coupled with finite-element codes (e.g. ANSYS).

Input Data

Neutronic and thermalhydraulic results on the core and components.

Time schedule

See Fig. 2

Manpower

Investment

4.3 CORE

4.3.1 Neutronics

4.3.1.1 Review of performed studies

Leader and other contributors

VUJE, UJV, MTA EK

Objective

Summarizing the state-of-the art achieved by CEA and its partners.

Description

1. The review of the existing analyses will minimize the resources to be allocated for solving again issues already resolved.
2. The review will help to formulate additional analyses and indicate where to allocate resources.

Level to be reached at the end of various phases

The summary has to be prepared in the phase of defining basic performance and safety goals.

Tools

N/A

Input Data

1. CEA reports, assumptions, models and results. IPR for this step should be clarified.
2. Consultations with authors of the CEA ALLEGRO 2009 concept.

Time schedule

See Fig. 2

Manpower

12 PM

Investment

None

4.3.1.2 Neutronic calculation and design of the start-up core

Leader and other contributors

MTA EK, VUJE, UJV, NCBJ
Contribution from Budapest Technical University BME NTI (MCNP, SERPENT, SCALE), is expected.

Objective

Taking into account:

- that the basically essential goal of the new project is to achieve the same safety level as that of the present reactors (see also the present non-passivity of some safety systems),
- the close relationship between the safety and the core design (see also reactor power and maximum linear heat rate),

Iterations are necessary between safety analyses of the most relevant initiating events and the core design.
Considering that it was found that the most relevant initial events concerning the present not satisfactory safety level are those where only the decay heat plays role after the very early shutdown of the reactor, the first crude step of the mentioned iteration is to be taken by the safety analyses of the relevant cases (method: only decay heat, one average TH channel, one hot TH channel). The nominal reactor power and the maximum allowed linear heat rate are output of this first step and input to the core design.
The start-up and the transition cores cannot be designed separately, they will be designed together as described in Task 4.3.1.4.

Description

The core design will be determined by standard core diffusion calculation route, which can be supported by Monte Carlo and SCALE/NEWT calculations for validation and to improve accuracy.
Reactor physics frame parameters are to be determined which are to be used in the safety analyses. Some of them are belonging to the nominal state where feedback effects are playing role, consequently this task should be performed conjointly with task 3.3.2.1 "Core thermal hydraulics optimization".
Fuel discharge burn-up should be equivalent to those of fuel used in other fast reactors to limit the qualification needed
Decay heat law (later stage)
Special calculation routes and the corresponding resulting input data for the tasks of the following points of the roadmap: 4.3.1.3, 4.3.1.5, 4.3.1.6, 4.3.2.1, 4.3.2.2, 4.3.3.1, 4.3.3.2, 4.3.4.1, 4.3.4.2, 4.3.4.3, 4.4.1.3, 4.4.1.6, 4.4.6, 4.4.9.2, 4.4.14, 4.7.2,4.7.4, 4.7.5, 4.8.2, 4.8.3.2.

Level to be reached at the end of various phases

In the phase of defining the basic performance and safety goals

- the method of core design will be described
- the safety calculations needed for determining maximum safe reactor power and maximum safe linear heat rate will be performed
- the tools to be used for core design will be selected
- the validation matrix needed for application in ALLEGRO conditions will be determined

In the pre-conceptual design phase the validation has to be completed. For everything else see Task 3.3.1.4.

Tools

ERANOS, KIKO3DMG coupled to the ATHLET3.0 code, MCNP, SERPENT, DYN3D-MG, SCALE (for decay heat)

Input Data

- Specifications file task 3.1.1
- Reactor power and maximum allowed linear heat rate from the first crude step of task 3.11.2
- UOX fuel (to be confirmed)
- S/A geometry and materials are specified in Ref. 12.

Time schedule

See Fig. 2
The reason of the 12 M shift is just the abovementioned first crude step of the safety analyses.

Manpower

51 PM

Investment

None

4.3.1.3 Design of the experimental S/As (ceramic fuel)

Leader and other contributors

MTA EK, UJV Group

Objective

Description

In the pre-conceptual design phase, the state of the art on ceramic fuel designs must be reviewed in a systematic approach:

- The main requirements for the ceramic fuel must be specified (thermal, mechanical and chemical parameters, neutronics).
- The potential pellet and cladding materials must be compared, and the compatibility of cladding and pellet must be checked.
- The advantages and disadvantages of different materials must be evaluated for reactor conditions using numerical models (fuel behavior, reactor physics, thermal hydraulics) and the optimal materials must be selected.
- Geometry requirements should be specified as well, since this may significantly impact feasibility of the refueling machine design.

Level to be reached at the end of various phases

In the conceptual phase the concept of ceramic fuel qualification has to be elaborated and the first steps of designing ceramic fuel have to be done to such an extent that makes it possible to perform the necessary thermal, mechanical, chemical and neutronics calculations and investigations.
In later phases of the project the potential fuel suppliers must be involved:

- The feasibility of fuel fabrication must be checked and the main technological parameters must be agreed.
- Specific samples for testing have to be obtained from the supplier for testing.
- The results of in-pile and out-of-pile testing must be evaluated and the original fuel design may be changed, optimized.

In the final step, considering the feedback from testing, the subassembly design has to be finalized.

Tools

Monte Carlo codes.

Input Data

Reference CEA design, international research (Japan, USA,…)

Time schedule

See Fig. 2

Manpower

Investment

None

4.3.1.4 Design of transition cores

Leader and other contributors

MTA EK, UJV, VUJE, NCBJ
Contribution from Budapest Technical University BME NTI is expected.

Objective

One has to distinguish between initial UOX/SS core, equilibrium UOX/SS core and the ceramic core. Transition from the initial to the equilibrium core is assumed to take place in a limited number of campaigns. It is assumed that the equilibrium cycle will remain basically unchanged while the UOX/SS fuel is used, though the actual core design may change from campaign to campaign due to the various numbers of ceramic probes loaded or other similar reasons. It is too early to speak about the ALLEGRO ceramic cores.

As a result of the UOX/SS core design frame parameters to be used in safety analysis shall be defined. They have to cover the parameters of the equilibrium core's safety and as well those of the initial and transition cores, i.e. only one UOX/SS core should be represented in the safety analysis.

Description

Neutronic calculations of transitions from initial oxide fuel core to mix core (oxide + experimental ceramic fuel) and to final whole core ceramic fuel have to be performed.
Similar outputs than task 4.3.1.2
Concerning the fuel assemblies

- the fuel geometry remains unchanged compared to data used by ESNII+,
- the cladding material remains unchanged compared to data used by ESNII+,
- the fuel pellets will be made of UO2 enriched to less than 20% (if possible). Probably reaching the maximum 20% is advantageous for the design of smaller cores with higher fluxes.

Outputs:

- the core volume and map,
- the position of absorber rods and experimental channels,
- neutron flux in the experimental channels,
- fuel burn-up,
- core reshuffling pattern,
- campaign length in effective full power days,
- frame parameters to be used in safety analysis,
- needs for modifying fuel specifications.
- Decay heat

Special calculation routes and the corresponding resulting input data for the tasks of the following points of the roadmap: 4.3.1.3, 4.3.1.5, 4.3.1.6, 4.3.2.1, 4.3.2.2, 4.3.3.1, 4.3.3.2, 4.3.4.1, 4.3.4.2, 4.3.4.3, 4.4.1.3, 4.4.1.6, 4.4.6, 4.4.9.2, 4.4.14, 4.7.2,4.7.4, 4.7.5, 4.8.2, 4.8.3.2.

Level to be reached at the end of various phases

In the pre-conceptual design phase preliminary results have to be produced which enable the reactor designer to start the design of the reactor, the reactor internals etc.
In the conceptual design phase the core design has to be refined taking into consideration various aspects of the design (structures in the reactor, final fuel rod length, absorber rod design etc.).

Tools

ERANOS, KIKO3DMG coupled to the ATHLET3.0 code, MCNP, SERPENT, DYN3D-MG, SCALE

Input Data

Maximum allowed linear heat rate, reactor power

Time schedule

See Fig. 2

Manpower

101 PM

Investment

4.3.1.5 Gamma heating of structures

Leader and other contributors

NCBJ

Objective

1. Assessment of the gamma heating term (core, RPV, ex-vessel structures).

Description

Experimental:
NCBJ may perform calculation of gamma heating using procedure developed with JHR group from CEA Cadarache and experimentally confirm the parameters used in simulations by performing validation experiment in the reactor MARIA. In the experiments gamma calorimeters based on the construction of KAROLINA calorimeter designed and built in NCBJ will be used, the measuring device will be made from the material studied. Larger devices able to measure gamma heating in ex-vessel structures (e.g. concrete) may be designed and produced as well.
Computational:
Assessment of gamma field within the core.

Level to be reached at the end of various phases

In the pre-conceptual design phase the requirements and criteria concerning the maximum coolable gamma heating have to be clarified.
In the conceptual design phase the gamma heating has to be calculated for the reactor internals and the reactor pressure vessel wall and it has to be determined whether the heating of structures does not exceed the criteria set up earlier. The experimental validation of the calculations may start already in this phase.

Tools

Family of gamma calorimeters of KAROLINA design. Gamma thermometers, SPND, thermocouples etc. NCBJ workshops. Testing and calibration stands.
Monte-Carlo codes

Input Data

List of structural, core and ex-vessel materials
Geometry of the RPV and internals, at least preliminary.

Time schedule

See Fig. 2

Manpower

Up to 3 PY/Y

Investment

To be defined later

4.3.1.6 Radiological protection

Leader and other contributors

NCBJ

Objective

Mapping of doses around the core, the vessel and primary circuits.

Design of protection and operation strategy.

Description

Fundamental to radiation protection is the reduction of expected dose and the measurement of human dose uptake. Routine offsite radionuclide releases must be limited. The various radionuclide source points and release paths should be made in the design phase and developed further. The knowledge of radiation sources is very valuable for shield design in order to provide adequate radiation protection.

This task is related to the design of biological shielding around the reactor, the primary circuit and at other critical points like filters. The source which has to be taken into consideration are the direct radiation of the core, the radiation coming from irradiated structures and other materials, and also the activated impurities and corrosion products circulating in the primary circuit. On the other hand the release of radioactive materials and its environmental consequences have to be investigated in a separate task under Safety.

Considerable attention must be given to spent fuel to provide for adequate design, access and shielding conditions. Knowledge about spent fuel must be well-grounded in data of a source strength, burn-up, cooling time, etc. by support calculations from task 3.3.1.2 and 3.3.1.4.

The types of exposure, as well as government regulations and legal exposure limits are different for each group of workers, so they must be considered separately.

Level to be reached at the end of various phases

In the pre-conceptual design phase the various sources of radiation have to be evaluated quantitatively. These sources are the direct radiation of the core, the radiation coming from irradiated structures and other materials, and also the activated impurities and corrosion products circulating in the primary circuit. In case of lacking informations clear assumptions have to be made and eventually restrictive criteria have to be set up (e.g. the activity of corrosion product in the primary circuit must not exceed a certain value). The attention of the designers has to be called to focus on problematic issues.

In the conceptual design phase the input from the improved design has to be taken into consideration. It has to be demonstrated that the doses around the sources satisfy the corresponding requirements (allowing for continuously serviceable and occasionally serviceable rooms).

Tools

Radiation propagation tools

Input Data

Geometry of the reactor layout (3.5.1)

Time schedule

See Fig. 2

Manpower

Investment

None

4.3.2 Core and subassembly thermalhydraulics

4.3.2.1 Core thermalhydraulics optimization

Leader and other contributors

MTA EK, UJV, VUJE, NCBJ
Contribution from Budapest Technical University BME NTI is expected.

Objective

Parametric studies to define the nominal reactor power and the maximum allowed linear heat rate.
Steady-state thermal-hydraulic analysis of the new core design.
Validation of the codes.

Description

In the phase of defining the basic safety and performance goals the former core thermal-hydraulic design activities and major outcomes for ETDR and ALLEGRO will be reviewed. Computer codes to be applied in this task will be identified and the status of their validation will be summarized.

Also in this phase CATHARE calculations will be performed for the most limiting transients in order to supply input data to core design (see 4.3.1.2). These parametric studies shall adopt a conservative approach in order to come up for calculation uncertainties, when comparing the results with acceptance criteria. The final outputs of these calculations are the proposed nominal reactor power and the maximum allowed linear heat rate to be used in 4.3.1.2.

In the conceptual design phase when the core design will have provided a preliminary definition of the core geometry (including the subassembly and fuel pin geometries) more detailed thermal hydraulic analysis can be carried out focusing on calculation of gas and cladding temperature distributions in nominal conditions in the core, including hot channel, hot spot and core pressure drop calculations. Earlier studies revealed important temperature inhomogeneity within the wire-spaced fuel bundle, especially close to the assembly walls. This calls for a more detailed study to investigate the local effect of the wire spacer on the pin cladding circumferential temperature distribution and on that of the assembly walls. These analyses will provide the boundary conditions to perform the thermo-mechanical analysis of the cladding and the assembly shroud planned in 4.3.3.1. If needed, an optimization of the distance between the assembly shroud and the adjacent fuel pins can be performed for limiting the temperature gradient in this region. This part of the task will be performed partly by CATHARE and partly by FLUENT.

Also in the conceptual design phase the core bypass flow ensuring cooling of the radial reflectors and the radial neutron shields needs to be modelled both for steady-state and for later transient analysis. Optimization of the bypass flow rate should be carried out. Possible tools: CATHARE or FLUENT.
The experimental ceramic GFR fuel sub-assemblies inserted to the first core require additive thermal barriers to protect their stainless steel. Earlier studies proposed a thermal barrier made of a double envelope of hexagonal geometry with internal baffles providing a rigid wrapping filled with static Helium. There is a hexagonal external gap between the wrapper tube and the thermal barrier: this is the Helium bypass cooling zone aimed at reducing the global outer temperature of the fuel subassembly and to maintain an active thermal barrier for the hexagonal metallic tube protection. CFD calculations are needed to optimize the thermal barrier static Helium zone and the bypass flow needed for cooling of the thermal barriers. The FLUENT code can be used for this purpose. This subtask can be started in the conceptual design phase but it may be continues in later phases of the project.
Validation of systems codes and CFD codes was one of the efforts in GoFastR. The activity based on the HE-FUS and L-STAR facilities contributed to better understanding of the reasons of differences among the calculations. Further validation of the codes to be used for core analysis (CATHARE, ATHLET, FLUENT) is needed in the conceptual design phase, especially to model wire-spaced fuel bundles. The validation matrix has to be determined in the pre-conceptual design phase.

The above validation needs experimental support. The minimum requirement is a He-loop with a core model consisting of a full-size subassembly: this would allow testing of bundles of both the initial core (e.g. wire spacing effects) and the experimental GFR bundle (e.g. thermal shield effectiveness). The design of the needed infrastructure has to be prepared in the conceptual design phase but the infrastructure has to become available for experiments only in later phases of the project.

Level to be reached at the end of various phases

See above

Tools

FLUENT or other CFD software + Subchannel analysis
CATHARE (for comparison and boundary conditions), ATHLET, RELAP-3D

Input Data

Axial and radial power distribution (3.3.1).

Time schedule

See Fig. 2

Manpower

Investment

The minimum requirement is a He-loop with a core model consisting of a full-size subassembly: this would allow testing of bundles of both the initial core and the experimental GFR bundle.

4.3.2.2 Fuel bundle thermalhydraulics

Leader and other contributors

VUJE, NCBJ, UJV

Objective

Description of the heat transfer from fuel into coolant and related thermal hydraulic conditions.

Description

1. Prototypic conditions
2. Gagging of the wire-wrapped claddings at the core level (?)
3. Conditions within the core bundles will probably be described by high Reynolds numbers, what can cause problems for RANS-based CFD codes. Therefore either q-DNS methodology (computationally expensive) should be applied, and/or tests in loops should be performed.
4. If loop tests are to be performed, a dedicated bundle section should be prepared, with electric heating and sets of thermocouples for temperature measurements.

Detailed PL-CZ discussion is needed on task sharing between NCBJ and UJV/CVR about helium loops use and equipment available there.

Level to be reached at the end of various phases

Pre conceptual design: Initial CFD calculation should be done, to estimate correlations for heat transfer coefficients from the fuel.

Conceptual design: The above mentioned calculations should be confirmed by experiments.

Tools

Dedicated stand & loop
CFD codes
Loop with some S/As

Input Data

Specifications for dedicated loops at CEA

Time schedule

See Fig. 2

Manpower

12 PM to prepare CFD model of the fuel bundle in helium

Investment

4.3.3 Fuel subassembly and fuel rod design

4.3.3.1 Fuel rod thermomechanical behaviour for UOX and ceramic fuel

Leader and other contributors

MTA EK

Objective

To clarify the adequacy of the fuel rod design from the point of view of thermo-mechanical behaviour up to a given burn-up.

Description

The task applies both to oxide and ceramic fuel. The former CEA design of the fuel rod will be maintained as much as possible for the oxide fuel. The fuel rod length may be increased if the attainable burn-up requires larger free volume than it was assumed in the CEA design. The former CEA sub-assembly design will be preserved (except if another decision is made based on Task 4.3.3.2.)

Numerical models have to be developed and special material property measurements must be taken in order to predict the thermomechanical behavior of fuel in the ALLEGRO core.

- The behaviour of SS cladded UO_2 fuel could be well described by the existing models and available database.
- Additional measurements may be needed with SS cladding, if a new alloy will be used.
- The experience from both fast reactor MOX and PWR UO_2 could be taken into account to develop the applicable models.

- In case of ceramic fuel new challenges are expected due to the brittle nature of cladding.
- The pellet cladding mechanical interaction must be prevented by the design. This requirement must be confirmed by the special measurement and demonstrated in integral test (e.g. power ramp tests).
- Experiments will have to be specified to measure material properties of the cladding and pellet in wide ranges of parameters, including burn-up.

The database on fuel must include enough information on the material properties to cover normal operation and accident conditions.

Level to be reached at the end of various phases

In the pre-conceptual design phase the fuel performance codes which are in principle applicable for ALLEGRO calculations will be supplemented with appropriate data and models as far as the stainless steel cladded UOX fuel is concerned. In this phase the thermo-mechanical behavior of fuel rods will be only estimated. The code validation database will be established in this phase.

In the conceptual design phase the code validation has to be continued and the codes have to be frozen. The first routine thermo-mechanical calculations will be performed. In this phase the main requirements concerning code development related to ALLEGRO ceramic fuel have to be clarified.

Tools

TRANSURANUS, FUROM, FRAPTRAN

Input Data

From tasks on core neutronics and thermalhydraulics

Time schedule

Two phases

1 Oxide

2 Ceramic

See Fig. 2

Manpower

Investment

4.3.3.2 Fuel subassembly design

Leader and other contributors

MTA EK, UJV

Objective

1. Verification of the current S/A design against loads
2. Bottom and top nozzles.
3. Wrapper tube.

Description

In the conceptual design phase the current fuel subassembly design proposed by CEA has to be verified against various loads defined in Tasks 3.3.2.3, 3.12.2.2 and 3.13.

- The subassembly design includes the main components, with the specification of their material and geometry. The main parameters and elements are the followings:
    - pitch size, arrangement of the rods (hexagonal),
    - length of the rods and the bundle,
    - design of bottom and top nozzles, their connections to core plates,
    - control rod/subassembly operation, needed space for control rods in the core,
    - Structural elements of the assembly including shroud.
- The validation of the subassembly design should be based on detailed structural, thermo-mechanical and hydraulic modelling. The modelling may include tests with assembly imitators.

The subassembly design will be finalized by the selected fuel factory in later phases of the project. For simplification of refueling, possibility of shortening fuel assemblies (i.e. dividing them vertically) should be considered. In such case, each assembly should be divided into, for example, three separate sections that would be stacked on top of each other.

Level to be reached at the end of various phases

See above

Tools

ANSYS, ABAQUS for structural analysis

Input Data

CEA design including wrapper tube.

Time schedule

See Fig. 2

Manpower

Investment

4.3.4 Control and shutdown subassembly design

4.3.4.1 Absorbers rod design & behaviour

Leader and other contributors

MTA EK, VUJE

Objective

The current design of absorber rods has to be verified or in case of necessity modified.

Description

The current design of the ALLEGRO control and shutdown systems consists of

- three shut down S/A which are out of the core during operation and the two less worthy S/A can shut down the reactor safely and can maintain sub-criticality on the long run,
- and three control S/A which can be used for reactor control and for the compensation of burn-up.

The shutdown and the control system are to be designed to ensure their complete independence of each other, however, their structure are identical and therefore the two systems cannot be considered to be diverse. In the phase of defining the basic safety and performance goals it has to be decided whether a further independent absorber system has to be introduced beside those which exist in the current CEA design.
In the pre-conceptual design phase

- The requirements for control rod number and worth must be identified by reactor physics calculations. It has to be verified that the absorber rods of the current CEA design satisfy these requirements. In an unsatisfactory case the absorber rod design has to be modified.

In the conceptual design phase

- The changes in the control rod composition during operation must be analyzed and their potential consequences (e.g. swelling) must be considered.

The potential suppliers of control rods have to be contacted and their capabilities have to be reviewed in this phase.

Level to be reached at the end of various phases

See above

Tools

Thermal and mechanical analysis tools

Input Data

Time schedule

See Fig. 2

Manpower

Investment

4.3.4.2 Control subassembly design & behaviour

Leader and other contributors

MTA EK, VUJE

Objective

Verification of the current control S/A design against loads

Description

In the conceptual design phase the current fuel subassembly design proposed by CEA has to be verified against various loads defined in Tasks 3.3.2.3, 3.12.2-2 and 3.13. This task is closely connected with the design of the absorber drives (Task 3.4.1.8).

- The control subassembly design includes the main components, with the specification of their material and geometry. The main parameters and elements are the followings:
    - pitch size, arrangement of the rods (hexagonal),
    - length of the rods and the bundle,
    - design of bottom and top nozzles, their connections to core plates,
    - control rod/subassembly operation, needed space for control rods in the core,
    - structural elements of the assembly including shroud.
- The validation of the control subassembly design should be based on detailed structural, thermo-mechanical and hydraulic modeling. The modeling may include tests with assembly imitators.

The subassembly design will be finalized by the selected fuel factory in later phases of the project.

Level to be reached at the end of various phases

See above.

Tools

ANSYS, ABAQUS for structural analysis

Input Data

Time schedule

See Fig. 2

Manpower

Investment

4.3.4.3 Additional shutdown system

Leader and other contributors

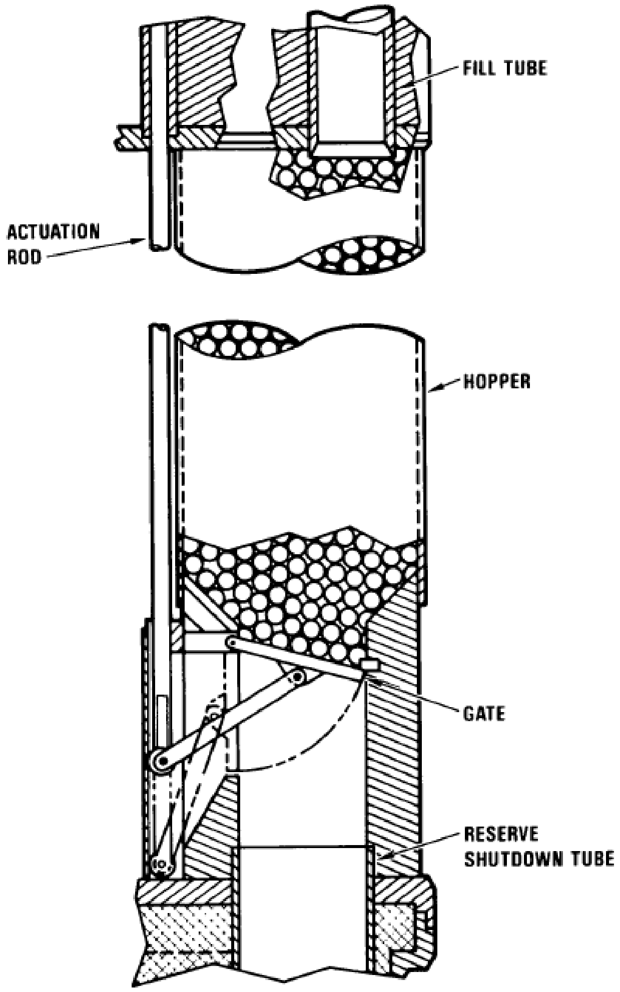
NCBJ

Objective

In the current reactor design the shutdown and control system are not diverse ones as far as the physical principle of their operation is concerned. It seems to be necessary that the reactor shall possess a further separate shutdown systems being fundamentally different from the current ones.

Description

In some of the reactors (HTGRs, some SFRs) reserve shutdown is accomplished by injecting small B_4C pebbles into designated channels inside the core. The pebbles are held in hoppers above the core and released through activation of a latch mechanism.



Ref. 4

Other reserve shutdown systems can be envisaged as well.

Level to be reached at the end of various phases

In the phase of defining the basic safety and performance goals the physical basis of the third shutdown system has to be selected.

In the pre-conceptual design phase the preliminary design of the independent third shutdown system has to be prepared.

In the conceptual design phase the independent third shutdown system has to be designed.

In the basic design phase the mockup of the shutdown system should be built and tested. Changes in the design should be made accordingly.

Tools

Similar 3.3.1.2 and 3.3.4.2

Input Data

Time schedule

See Fig. 2

Manpower

12 PM in pre-conceptual stage

Investment

4.3.5 Qualification of the fuel

4.3.5.1 Specification of the required qualification for the fuel

Leader and other contributors

MTA EK, UJV

Objective

Qualification steps have to be properly defined.

Description

Two different kinds of fuel must be taken into account in the design of ALLEGRO core: high enrichment UO_2 pellets with stainless steel cladding and the ceramic fuel. The main steps of qualification should include the followings:

- identification of the gaps for UO_2 fuel in the available data and specification of the need for further investigations,
- capabilities of potential irradiation facilities must be reviewed, and range of test parameters must be identified,
- testing of new SS alloy cladding may need special testing,
- identification of the main material properties in support of numerical modelling and specification of the need for further investigations,
- out-of-pile testing must be specified (high temperature, pressure, He atmosphere), corrosion
- in-pile testing must be specified and the capabilities of potential irradiation facilities must be reviewed.

Level to be reached at the end of various phases

The qualification needs have to be defined in the pre-conceptual design phase.
The first qualification steps may take place in the conceptual design phase. In this phase the qualification steps needed for future ceramic fuel have to be determined.

Tools

N/A

Input Data

Results of task 1.1.1 and 1.2.1

Time schedule

See Fig. 2

Manpower

Investment

4.3.5.2 Qualification dossier of the start-up core

Leader and other contributors

MTA EK

Objective

The results of fuel qualification have to be collected in a dossier.

Description

This dossier should be based on past experience (BN reactors, CEFR, PX) paying special attention to some PHENIX fuel with low linear power.
The existing data on fast reactor MOX fuel should be considered, but the specific aspects of UO_2 utilization must be specified.
The preparatory work must include the determination of typical ALLEGRO reactor conditions (flux, fluence, temperatures, pressure, linear power).
The main items of the dossier should cover the followings:

- out-of-pile testing of SS cladding to investigate He embrittlement effect and mechanical behavior at high temperature,
- examination of fresh fuel, measurement of main material properties,
- in-pile testing of SS cladding in high flux research reactor,
- PIE and mechanical testing of irradiated cladding,
- in-pile testing of fuel rods in high flux research reactor with online measurement of main parameters,
- PIE and mechanical testing of irradiated fuel.

The selection of applicable reactors for irradiation is a key item. The need for and the scope of irradiation testing has to be evaluated on the basis of existing data.

Level to be reached at the end of various phases

In the pre-conceptual design phase the main steps of qualification have to be determined. It shall be clarified which steps can be covered by the existing data and these data have to be collected (recognizing the difficulties with IPR). The ALLEGRO specific conditions to be preserved in the various steps have to be determined in detail.
In the conceptual design phase the dossier shall be established and filled with the existing data. The plan for further steps of qualification to be performed during later phases of the project has to be prepared.

Tools

For further irradiations MARIA?, JHR? (if needed)

Input Data

Time schedule

See Fig. 2

Manpower

Investment

4.3.6 Fuel fabrication

4.3.6.1 Fuel specifications for the fabrication

Leader and other contributors

MTA EK

Objective

To prepare a specification for the selected fuel factory which enables the factory to prepare the fuel , fuel S/A and control S/A design and which also contains all the requirements concerning the design.

Description

The specification must cover UO_2 fuel with stainless steel cladding. A similar specification can be prepared later for the ceramic fuel. The main items of the specification are as follows:

- Review of UO_2 fuel utilization experience in fast reactors and applicability of the existing fuel data for the ALLEGRO conditions, comparison of UO_2 fuel characteristics produced by different suppliers,
- Specification of UO_2 fuel parameters for normal operation and accident conditions including loads on fuel, fuel S/A and control S/A (based on the results of reactor physics and thermal hydraulic calculations).

The specification must include specific lists for cladding, pellet, complete fuel rod and assembly.

Level to be reached at the end of various phases

The above specification has to be prepared by the end of the conceptual design phase.

Tools

N/A

Input Data

All tasks related to core design
Vibrations, bowing, other loads.

Time schedule

See Fig. 2

Manpower

Investment

4.3.6.2 Fabrication of the start-up core

Leader and other contributors

MTA EK
Industrial partner

Objective

By the end of the conceptual design phase the fuel factory can be selected and preliminary discussions may start. The real work will take place in later stages of the project.

Description

The fabrication of the fuel for start-up core could be discussed with different fuel suppliers.
The potential suppliers will be asked to declare their capabilities to produce highly enriched UO_2 fuel in SS cladding, and provide information on the experience of the use of similar fuel in nuclear reactors. The production of control rods must be included in their offers.
The optimal supplier must be selected on the basis of technical and financial criteria. These criteria have to be developed in the early phase of the project.

Level to be reached at the end of various phases

See above as Objective.

Tools

N/A

Input Data

Time schedule

See Fig. 2

Manpower

Investment

To be evaluated

4.4 SYSTEMS, STRUCTURES AND COMPONENTS

4.4.1 Reactor pressure vessel (RPV)

4.4.1.1 RPV Layout

Leader and other contributors

UJV, NCBJ, VUJE

Objective

Design of the RPV including:

1. Geometry (drawings).
2. Proposal of suitable materials.
3. Stress, strain, dose (DPA) & corrosion analyses.
4. Design of over pressure protection system

Description

The design of the RPV will respect the requirements from both the engineering as well as the material point of view. This process can start only when draft information is known from at least the following areas:

1. Thermal parameters including the architecture (layout) of the whole ALLEGRO.
2. Internals of the RPV (core, reflector, neutron & thermal shielding, support plate, core barrel, …).
3. Fuel handling system.

In MHTGR, the material for RPV and other components of the primary system is SA533 (plates) and SA508 (forgings). These steels will be taken as first choice for the RPV materials.

Level to be reached at the end of various phases

Pre-conceptual design stage: Basic data such as diameter, height etc.
Conceptual design stage: Drawings with dimensions taking into account interfaces with other systems (supports, outlets etc…). Lump and/or Finite-element analysis of the vessel. Monte Carlo analysis of the dose (taken from 3.3.1.5)
Basic design stage: Detailed drawings with tolerances
Detailed design stage: Fabrication process of parts of the vessel and their subsequent welding.

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.
Task 3.3.1.5 Gamma heating (for doses)
Task 3.8 FUEL HANDLING SYSTEMS.

Time schedule

See Fig. 2

Manpower

Min. 60 PM.

Investment

TBD

4.4.1.2 RPV thermalhydraulics

Leader and other contributors

UJV, NCBJ, VUJE

Objective

Analysis of the flow & temperature field at the inner surface of the RPV in nominal conditions focused on cooling of the RPV by the cold helium.

Description

The asymmetry of the primary loops in the CEA ALLEGRO 2009 creates a risk of excessive non-uniformity of thermal field within the RPV.
Moreover, proper mixing of outflowing helium is not assured. Lack of such mixing may result in constant fluctuations of outlet temperature, which in turn may result in thermal fatigue of components downstream. This problem was encountered in HTGRs and is usually dealt with by introducing intricate mesh of small channels and plenums in graphite below the core (helium flow in HTGRs is downwards). In other solution, the lower plenum is filled with numerous pillars supporting the core structure. The pillars establish a “forest” which mixes the flow well. In ALLEGRO, where flow is directed upwards, such approach is not possible. Therefore, another solution for establishing proper mixing should be found.
It is suggested to use the reflector part of the subassemblies for mixing of the helium.
The objective of the task is to assess and possibly improve such design. The main task will be:

1. Assess flow conditions in the downcomer and upcomer (space between thermal shield and RPV).
2. Optimize the opening cross section at the top of the thermal shield dome.
3. Assess the temperature non-uniformities and fluctuations at the inner surface of the RPV.

Level to be reached at the end of various phases

Pre conceptual design stage: CFD of the core using CEA2009 proposed assemblies to assess the level of problems described above. Establishing proposed solutions (and estimating size of such solutions)
Conceptual stage: CFD of the updated design

Tools

CFD code (ANSYS, FLUENT,…)

Input Data

Geometry of the RPV including internals.
Thermal parameters of ALLEGRO.

Time schedule

See Fig. 2

Manpower

Min. 24 PM

Investment

TBD

4.4.1.3 RPV Internals

Leader and other contributors

VUJE, UJV

Objective

Assess the:

1. Design of all structures
2. Dilatation of structures inside RPV.

Description

Thermal and mechanical design and analysis

Level to be reached at the end of various phases

To be prepared in-line with preparing Description

Tools

Mechanical codes

Input Data

The loads are determined in Tasks 3.3.2.3, 3.12.2.2 and 3.13.

Time schedule

See Fig. 2

Manpower

24 PM

Investment

None

4.4.1.4 Thermal insulation of primary, secondary and DHRS circuits

Leader and other contributors

VUJE

Objective

Development and design of efficient thermal insulation of primary, secondary and DHRS circuits

Description

Insulation should be applied wherever is the possibility of unexpected heat transfer or even loss of it. In GFRs the primary insulated parts will be e.g. hot gas duct, heat exchangers (primary and in decay heat removal system), core barrel, lower/upper support plate and reactor pressure vessel.

Level to be reached at the end of various phases

Pre-conceptual: Sections to be insulated, materials and geometry.

Tools

Thermal analysis codes

Input Data

RPV and primary circuits design

Time schedule

See Fig. 2

Manpower

24 PM

Investment

None

4.4.1.5 RPV & primary circuit seals

Leader and other contributors

NCBJ

Objective

To specify the way in which primary circuit (particularly the vessel head) is sealed.

Description

The vessel head will probably be sealed using single-use metallic O-rings. Other places where seals are needed also have to be listed with their respective parameters such as pressure and temperature in normal and accident conditions.

Level to be reached at the end of various phases

Pre conceptual design stage: Identification of sealing points. Review of strategy of their Sealing in MHTGR.
Conceptual design stage: Choice of sealing strategy for above-mentioned points.
Basic design: Specifying seal dimensions
Detailed design stage: design of seals, manufacturing of prototypes.

Tools

None / irradiation of materials

Input Data

Literature review of sealing techniques in HTGRs

Time schedule

See Fig. 2

Manpower

Up to 6 PM in pre-conceptual and conceptual stages.

Investment

None in pre- and conceptual stages.

4.4.1.6 Structural materials inside the RPV

Leader and other contributors

NCBJ

Objective

Assess the influence of irradiation on properties of main structural materials (identified by reactor designers).

Description

Main structural materials used may be subjected to compositional changes caused by irradiation, e.g. via Radiation Induced Segregation (RIS) mechanism. The main objective of the study will be to determine main effects caused by RIS by using ion irradiation combined with SEM/EDS and SIMS methods. Mechanical properties of materials exposed to radiation damage will be studied on ion-irradiated samples by using a nanoindentation technique. The results obtained will be compared with selected measurements performed on samples irradiated in MARIA reactor.

Level to be reached at the end of various phases

Pre conceptual design: literature review (probably focused on Incoloy 800H) with gap analysis.
Conceptual design: irradiations and tests conducted according to gaps identified in the step before.

Tools

SEM/EDS, SIMS, Ion Irradiation, nanoindentation, mechanical tests

Input Data

List of structural materials and working conditions (temperature, vibration, corrosive gases, radiation dose)

Time schedule

See Fig. 2

Manpower

Up to 24 PM

Investment

TBD

4.4.2 Guard vessel (GV)

4.4.2.1 GV Layout

Leader and other contributors

UJV, NCBJ, VUJE

Objective

Design of the GV including:

1. Geometry (drawings).
2. Proposal of suitable materials.
3. Stress, strain
4. Design of over pressure protection system
5. Penetrations

Description

The design of the GV will respect the requirements from both the engineering as well as the material point of view. This process can start only when draft information is known from at least the following areas:

4. Thermal parameters including the architecture (layout) of the whole ALLEGRO.
5. Internals of the GV (core, reflector, neutron & thermal shielding, support plate, core barrel, …).
6. Fuel handling system.

In MHTGR, the material for RPV and other components of the primary system is SA533 (plates) and SA508 (forgings). These steels will be taken as first choice for the RPV materials.[1]

Level to be reached at the end of various phases

Pre-conceptual design stage: Basic data such as diameter, height etc.
Conceptual design stage: Drawings with dimensions taking into account interfaces with other systems (supports, outlets etc…). Lump and/or Finite-element analysis of the vessel. Monte Carlo analysis of the dose (taken from 3.3.1.5)
Basic design stage: Detailed drawings with tolerances
Detailed design stage: Fabrication process of parts of the vessel and their subsequent welding.

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.
Task 3.8 FUEL HANDLING SYSTEMS.

Time schedule

See Fig. 2

Manpower

Min. 60 PM.

[1] Probably GV can use another materials as well.

Investment

TBD

4.4.2.2 Cooling of the RPV and heat removal from the GV atmosphere

Leader and other contributors

UJV, VUJE, NCBJ

Objective

Preclude overheating of the RPV and design of reliable heat removal from the guard vessel

Description

1. The safety demonstration of ALLEGRO relies on the cooling by gas in normal and abnormal conditions. The RPV will have insulation from inside and contact with guard vessel atmosphere from outside. Therefore any heat from RPV will be rejected to the guard vessel atmosphere. It has to be proven, that heat rejection rate will be sufficiently high to offset heat flux from inside coupled with gamma heating in both operating and abnormal conditions. This is very similar to what is done in HTGRs which rely on atmospheric cooling of RPV for decay heat removal. Similar work is being currently conducted at NCBJ.
2. Heat must be removed from the GV to fulfill the acceptance criteria of the concrete structures.
3. A system of heat exchangers must be designed together with the GV atmosphere management system.

Level to be reached at the end of various phases

Pre-Conceptual design stage: Basic estimate of dimensions followed by simplified CFD of the guard vessel showing heat rejection rate.
Basic design: More advanced analysis.

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 48 PM

Investment

TBD

4.4.2.3 GV structures

Leader and other contributors

VUJE

Objective

Design of structures, supporting all systems and components inside the guard vessel

Description

Supporting structures should ensure reliable positioning of all objects in the guard vessel. Vibrations of it should be kept under acceptable limits in the whole ranges of temperature and pressure, taken into account for guard vessel operation, DBA and BDBA situations.

Dilatations of crossing pipes trough the GV

Level to be reached at the end of various phases

Conceptual design: Identification of loading points with their estimated loads.

Tools

Mechanical codes

Input Data

Loads are determined in Tasks 3.3.2.3, 3.12.2.2 and 3,13, For vibrations see 3.4.2.4.

Time schedule

See Fig. 2

Manpower

24 PM

Investment

None

4.4.3 Heat exchangers

4.4.3.1 Design and testing of main heat exchangers

Leader and other contributors

VUJE, CVR

Objective

Development of the main helium/gas heat exchanger (HX) between the primary and the secondary circuit.
The R&D will be influenced by the choice of the secondary gas (nitrogen, argon, steam …) defined in task 3.2.1

Description

VUJE as main designer will together with CVR ensure the development of the main HXs for both temperature options of ALLEGRO:

1. Low temperature option with oxide fuel.
2. High temperature option with refractory fuel.

Level to be reached at the end of various phases

Pre conceptual: First design and identification of qualification

Tools

Routine engineering tools used in the industry and experimental facilities

Input Data

Task 3.1.1 Specifications
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 144 PM

Investment

TBD

4.4.3.2 Design and testing of DHRS heat exchangers

Leader and other contributors

VUJE

Objective

Design of heat exchangers to transfer fission products decay heat and other residual heat from the reactor core.

Description

The rate of decay heat removal has to be arranged in such a way that both fuel design limits and the design basis limits of the reactor coolant pressure boundary specified in the design are not exceeded. Dedicated DHR loops are connected to the primary circuit operating in forced or natural circulation. These loops are put into operation after isolation of the main loops by valves actuation. Secondary coolant is pressurized liquid water for the time being and heat is rejected via natural circulation in a water pool.
VUJE as main designer will ensure the development of this type of HXs for both temperature options of ALLEGRO:

1. Low temperature option with oxide fuel.
2. High temperature option with refractory fuel.

Level to be reached at the end of various phases

Pre conceptual: First design and identification of qualification

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.
Task 3.7.2 System transient analysis: DC and DEC (in particular LOCA + Blackout)

Time schedule

See Fig. 2

Manpower

Min. 100 PM

Investment

TBD (experimental facility)

4.4.3.3 Design and testing of Guard Vessel heat exchangers

Leader and other contributors

VUJE, CVR

Objective

Design of heat exchangers to remove heat from the GV atmosphere.

Description

The primary circuit (even if insulated) is a source of heat. To maintain the temperature of the GV atmosphere below its design limit this heat must be continuously removed. The cooling medium will probably be water.
VUJE as main designer will together with CVR ensure the development of this type of HXs for both temperature options of ALLEGRO:

1. Low temperature option with oxide fuel.
2. High temperature option with refractory fuel.

Level to be reached at the end of various phases

Pre conceptual: Preliminary design
Conceptual design: estimate size, type and location of the exchangers
Basic design: basic design of the exchangers
Detailed design: workshop drawings (blueprints) of the exchangers

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.
Task 3.4.2.2 Heat removal from the guard vessel atmosphere.

Time schedule

See Fig. 2

Manpower

Min. 60 PM

Investment

TBD

4.4.4 Blowers

4.4.4.1 Primary circuit blowers

Leader and other contributors

UJV, ATEKO a.s.

Objective

Development of the primary circuit blowers for both the low temperature option (oxide fuel) and the high temperature option (refractory fuel).

Description

The main primary circuit blowers are integrated into the main heat exchangers in the CEA ALLEGRO 2009 concept and this solution remains unchanged for this moment. The blowers are expected to work at the cold helium temperature.
Technology for blower bearings has to be chosen. In case of oil-lubricated bearings, oil leakage into the system has to be minimized.
Improvement of the inertia.

Level to be reached at the end of various phases

Pre conceptual: Preliminary design (Type, size,…), main characteristics.

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 120 PM.

Investment

TBD

4.4.4.2 Secondary circuit blowers

Leader and other contributors

UJV, ATEKO a.s.

Objective

Development of the secondary circuit blowers for both the low temperature option (oxide fuel) and the high temperature option (refractory fuel).

Description

The secondary circuit blowers are integrated in the plant as described in task 3.1.5 System integration and assessment.

Level to be reached at the end of various phases

Pre conceptual: Preliminary design (Type, size,…) main characteristics

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 50 PM.

Investment

TBD

4.4.4.3 DHRS blowers

Leader and other contributors

UJV, ATEKO a.s.

Objective

Development of the DHR blowers for both the low temperature option (oxide fuel) and the high temperature option (refractory fuel).

Description

The DHR blowers are integrated in the plant as described in task 3.1.5 System integration and assessment.

Level to be reached at the end of various phases

Pre conceptual: Preliminary design (Type, size,…) main characteristics

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 120 PM.

Investment

TBD

4.4.5 Valves

4.4.5.1 Main isolation valves

Leader and other contributors

VUJE (with CVR?)

Objective

Design of main isolation valves

Description

It is necessary to isolate the main loops with a high reliability level. Valves should be located on the primary loops, close to the RPV. Basic function is to stop helium circulation if necessary. Status of valves (open/close) should be monitored from main control room.
The valve used may be a gravity-assisted check valve

Level to be reached at the end of various phases

Pre design: first design (type and parameters)

Tools

None

Input Data

Strategy of closing the valves.
Studies of usage and operating modes of Allegro and of purpose and using of main isolation valves.

Time schedule

See Fig. 2

Manpower

24 PM

Investment

None

4.4.5.2 DHRS valves

Leader and other contributors

VUJE (with CVR?)

Objective

Design of DHRS valves

Description

It is necessary to open the DHR loops with a high reliability level. Valves should be located on DHRS loops. It should be driven by passive mechanism and status of valves (open/close) should be monitored from main control room.
The isolation valve is required to isolate the main circuits while a check valve is supposed to open and activate the loop itself.

Valves and check-valves are therefore critical components of the GFR. Qualification test of candidate technologies for these components are needed and must be performed on a dedicated helium loop. Check valves are localized in an inferior annular plate and based on a gravity mode of opening.

Level to be reached at the end of various phases

Pre design: first design (type and parameters)

Tools

None

Input Data

Strategy of closing the valves.
Studies of usage and operating modes of Allegro and of purpose and using of DHRS valves.

Time schedule

See Fig. 2

Manpower

24 PM

Investment

None

4.4.5.3 Safety valves

Leader and other contributors

VUJE (with CVR?)

Objective

Design of safety valves in all pressurized components

Description

Specification of the required flowrate capacities.

Level to be reached at the end of various phases

Pre design: first design (type and parameters)

Tools

Input Data

Strategy of closing the valves.
Studies of usage and operating modes of Allegro and of purpose and using of DHRS valves.

Time schedule

See Fig. 2

Manpower

24 Pm

Investment

None, to be added later in case of experimental programs.

4.4.6 Control rod drive mechanisms

Leader and other contributors

NCBJ, VUJE

Objective

Design of the mechanisms for moving control subassemblies.

Description

The reactor will have several control and shutdown subassemblies. Each of them will have its own control rod drive mechanism (CRDM). The design of CRDMs is complicated because of:

- high temperature
- radiation
- helium environment
- high reliability requirement
- shutdown capability requirement
- problems with lubrication

The reliability requirement of the CRDM is obvious. In ALLEGRO, its significance will be further increased due to small number of control assemblies and high worth of a single assembly.

The way of lubrication of the mechanism is very important. Oils cannot be used since they would evaporate in high temperatures. Dry lubricants have to be used instead (possibly: molybdenum disulphide). HTGRs have accumulated experience in this field, which has to be reviewed (Ref. 13). Since helium environment precludes creation of oxide film on surfaces, friction of bare metal surfaces increases and therefore seizing may occur. Use of very hard materials (with matching hardnesses) on surfaces where friction occurs limits friction and is recommended to preclude seizing in case lubrication is lost.

The two above mentioned challenges can be partially relieved by use of stepper motors, which simplify the whole setup. Mechanisms using such motors were successfully applied in HTR-10.

Additional difficulty comes from the fact, that control rods are inserted from below the core. This requires additional shutdown mechanism much more complicated than simple clutch used when control rods are operated from above the core. Such mechanism (hydraulic pistons operated with water, which is pre-pressurized with nitrogen) is employed in BWRs, but probably not applicable to ALLEGRO (because of water). A novel approach has therefore to be found.

Alternatively, a way to reposition control rods above the core may be found. In such case interaction between control rods (and their CRDMs) and refueling machine has to be resolved.

Moreover, a way to remove the control subassembly from the core along with its CRDM has to be established (shielded transfer cask with proper transportation ways)

Level to be reached at the end of various phases

Pre-conceptual design: answers for challenges listed in “description” provided
Conceptual design: mechanism designed mechanically
Basic design: prototype of the CRDM built and tested

Tools

Standard tools used for mechanical and electric design
Irradiation and helium environment tests for lubricants

Input Data

Literature review of HTGR experience.

Time schedule

See Fig. 2

Manpower

60 PM

Investment

4.4.7 Decay heat removal systems (DHRS)

4.4.7.1 DHRS design - Conditioning in nominal conditions

Leader and other contributors

UJV, VUJE, MTA EK, NCBJ

Objective

Design of a conditioned DHR system, i.e. a system ready to start heat removal by natural circulation with minimum delay.

Description

1. The CEA ALLEGRO 2009 concept does not ensure conditioning of DHR loops (temperature difference between the hot and cold DHR branches in nominal conditions). CFD study of the DHR loop is needed (temperature field).
2. Revised design is needed to ensure functioning of the system in:
    a. ALLEGRO start-up (demonstration of disc valves closure due to the available pressure drop on the core).
    b. At the transition from operational to accident conditions under loss of active systems (natural convection).
3. Experimental demonstration of the DHR system is needed.
4. Studies in operational conditions:
    a. Functionality in nominal conditions.
    b. Functionality in off-normal conditions (HX tube failure).

Level to be reached at the end of various phases

Pre conceptual: Propose a functional and feasible design available for thermal hydraulic analysis

Tools

Distribution of temperature, stress and other thermomechanical parameters can be simulated by CFD software.

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 96 PM

Investment

TBD

4.4.7.2 DHRS - Experimental testing

Leader and other contributors

UJV, VUJE, CVR?

Objective

Qualification.

Description

Need a loop for ALLEGRO DHRS testing.

One option is to use S-ALLEGRO proposed loop.

1. The functionality of the DHR system was never experimentally tested (SALSA loop at CEA was fabricated but not commissioned).
2. CVR (CZ) plans to build a helium loop (phase I) within the SUSEN project to test the DHR system for CEA as proposed by CEA. UJV provided a pre-conceptual idea of this loop for the bid.
3. Pre-design analysis of SUSEN S-ALLEGRO (phase I) is pending.
4. Definition of the test matrix for the S-ALLEGRO loop (phases I and II).

Remark: S-ALLEGRO loop
Phase I: 1 main loop + 1 DHR loop (2018)
Phase II: whole plant

Level to be reached at the end of various phases

To be completed later.

Tools

SUSEN / S-ALLEGRO ?

Input Data

Other DHRS tasks

Time schedule

See Fig. 2

Manpower

300 PM

Investment

In case of S-ALLEGRO:

2,5 M€ Phase I

8 M€ Plase II

4.4.7.3 Gas injection system

Leader and other contributors

UJV, MTA EK

Objective

Design of the gas injection system

Description

Design, choice of gas (N?, other gases?) and operating conditions (degree of passivity ?)

Level to be reached at the end of various phases

Pre conceptual: Feasibility
Conceptual design: Preliminary design

Tools

Distribution of temperature, stress and other thermomechanical parameters can be simulated by CFD software.

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.
Gard Vessel

Time schedule

T0+12 to T0+60
See Fig. 2

Manpower

Min. 96 PM

Investment

TBD

4.4.8 Fuel handling systems

Leader and other contributors

VUJE, NCBJ

Objective

Design of the fuel handling system

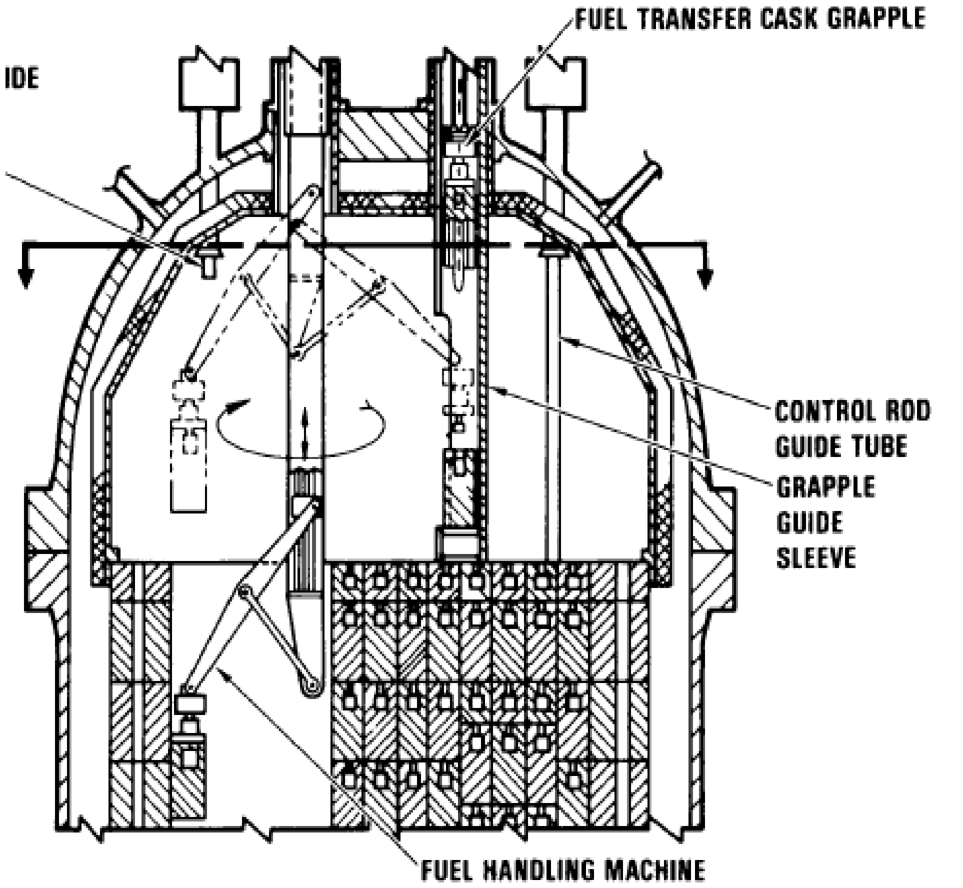
Description

The fuel handling system should be based on loading and unloading fuel elements using lock chambers, vessels and arms. The fuel handling starts a few days after normal shutdown of the reactor in pressurized conditions inside closed reactor vessel. During fuel handling, the sub-assemblies should be cooled with a forced circulation of cold gas.

In general, ALLEGRO fuel handling system can be similar to fuel handling system in prismatic HTGR, with exceptions for different size of subassemblies and different level of cooling necessary. In such reactor, fuel handling apparatus is placed within the reactor in place of removed control assemblies. For this purpose, control assemblies' worth should be sufficient for having two of them temporarily removed. This solution reduces exposure on fuel handling equipment (which normally is outside the core) and simplifies maintenance.

It has to be decided, whether ALLEGRO will use the original CEA design (control mechanisms below the core and machine above the core) or HTGR approach is used instead (with machine inserted in place of sequentially removed CRDMs). The latter approach requires more redundant control rods (more of them) but is more scalable and removes the challenge associated with inserting control assemblies from the bottom. It would also probably decrease size of the RPV.

A facility is needed to qualify these handling solutions in representative situations.



Example handling system[2]

During storage of spent fuel assemblies in the spent fuel shaft it is necessary to ensure:

- adequate cooling of fuel assemblies,
- subcriticality in normal and abnormal operation,
- sufficient shielding of spent fuel assemblies so that the radiation protection of operators would be assured,
- filtration and make-up of the coolant in the cooling system,
- prevention of heavy objects drop on a fuel assembly (e.g. by definition of the restricted area for equipment handling above the spent fuel shaft.

Level to be reached at the end of various phases

Pre-concpetual design: General agreement on how the system is supposed to operate. Consultations with authors of the 2009 design in order to understand their way of optimization.
Conceptual design: Dimensions of the main components in the system. Cooling and shielding analyses. Design of the machine (crucial point).
Basic design: Prototype of the machine built and tested
Detailed design: Blueprints of the final machine and other equipment

Tools

2 HTR projects https://inlportal.inl.gov/portal/server.pt?open=space&name=Dir&id=1&psname=Opener&psid=0&cached=true&in_hi_userid=2&control=DirRepost&page=DirCardProperties&cardID=73178

U.S. Archiving services: papers HTGR-86-***, and DOE-HTGR-86-***

Mechanical analysis tools

Input Data

Quite detailed description of what can be used is in Ref. 14.

Time schedule

See Fig. 2

Manpower

120 PM

Investment

4.4.9 Fuel management

4.4.9.1 Fresh fuel storage and transfer

Leader and other contributors

VUJE

Objective

Design of facilities for the handling and storage of fresh fuel.

Description

Fresh fuel after reception is placed at dry storage. Fresh fuel is controlled and prepared for utilization. Main characteristics of fresh fuel are higher reactivity and markedly lower radiation level in comparison with fresh (uranium) fuel. Higher radiation protection is inevitable if fuel is produced of reprocessed uranium or of recycled fissile material.

Tools for fresh fuel manipulation and storage should be constructed in such a way, that its integrity and qualities are secured. Basic safety functions of the tools must protect operation personal health and protect public again irradiation. It shroud be done by maintaining of fuel configuration subcritical and by limitation of radioactive substances movement.

Level to be reached at the end of various phases

Pre-concpetual design: General agreement on how the system is supposed to operate.

Conceptual design: General layout of the facilities, including: space requirements, transportation routes within the plant, basic cask concept etc.

Tools

Routine engineering tools used in the industry

Input Data

Time schedule

See Fig. 2

Manpower

80 PM

Investment

4.4.9.2 spent fuel transfer and storage

Leader and other contributors

VUJE

Objective

The design and operation of the spent fuel handling and storage.

Description

Construction of tools for spent fuel manipulation and storage must ensure fuel integrity. Basic safety functions of the tools must protect operation personnel health and protect public against irradiation effects. It should be done by maintenance of fuel configuration subcriticality in the whole fuel route, by radioactive substances movement limitation and by removal of spent fuel decay heat. Adequate and continued cooling of fuel should be ensured during handling and storage. Ability of decay heat removal must be sufficient to prevent unacceptable pressure increase in fuel rods and fuel damage with consequent radioactive substances leakage from it. Ability of decay heat removal must be specified and secured.

Level to be reached at the end of various phases

Pre-conceptual design: General agreement on how the system is supposed to operate.

Conceptual design: General layout of the facilities, including: space requirements, transportation routes within the plant, basic cask concept etc.

Tools

Routine engineering tools used in the industry

Input Data

Time schedule

See Fig. 2

Manpower

80 PM.

Investment

4.4.10 Containment

Leader and other contributors

VUJE

Objective

Design of the reactor containment DB and DEC conditions

Description

Confinement safety functions, and its design will be based on a number of considerations including:

- The residual pressure required to maintain adequate natural circulation in the event of a primary circuit depressurization,
- Leak-tightness requirements,
- Volume requirements,
- Insulation requirements.

Level to be reached at the end of various phases

Pre conceptual design: First design

Tools

CFD codes

Input Data

Core catcher

Time schedule

See Fig. 2

Manpower

100 PM

Investment

None

4.4.11 Core catcher

Leader and other contributors

UJV, VUJE

Objective

Design of several alternatives of core catcher.

Description

The existing concept CEA ALLEGRO 2009 is unable to mitigate the consequences of severe accident conditions such as core melting, especially for the first core with oxide fuel in stainless steel claddings. As „beyond design" accidents are no more accepted by WENRA, consequences of all accidents that cannot be "practically excluded" must be mitigated by the design. One of potential provisions to mitigate consequences of massive core melting is to use a core catcher in the design of the demonstrator. As mentioned above, this topic is composed of two parts:

1. Feasibility study for various core catcher options, if any (e.g. internal and/or external core catcher).
2. Core catcher design, dimensioning and incorporation into the whole ALLEGRO design.

Level to be reached at the end of various phases

Pre conceptual design: Feasibility study for various core catcher options including main design characteristics.
Conceptual design: Design of the selected options.

Tools

Routine engineering tools used in the industry.

Input Data

Specifications, Heat transport systems, Core design, System integration and assessment, Safety studies, Guard vessel design.

Time schedule

See Fig. 2

Manpower

120 PM

Investment

None

4.4.12 Power supply systems

4.4.12.1 Normal power supply

Leader and other contributors

VUJE

Objective

Design of normal power supply system

Description

Power supply systems should be able to supply all equipment that is required during considered operation modes for a required time.

Off-site sources are determined to supply all site in normal operation. This includes non-technological equipment. Off-site sources are preferred sources. On site sources are used, when off-site sources are lost. It is required to have at least two independent links from transmission grid. Links should be from different switchyards of the transmission grid. Each link has to be able to supply all site loads at maximum load.

On site distribution system consists of interconnected networks. Networks are divided according classification of consumers and requirements to reliability of supply.

Level to be reached at the end of various phases

Pre conceptual design: First design

Tools

N/A

Input Data

- Operating modes of reactor unit (e.g. start-up of the unit, normal operation, planned shutdown, shutdown with reactor protection, operation on house load power, station blackout, long term station blackout, severe accident, etc.) and requirements to electrically supplied equipment.
- Parameters of (main) consumers of electricity (power requirements, start-up current, belonging to systems, safety/ non safety /safety related classification, required functionality according unit’s modes, etc.).
- Parameters (expected lifetime cumulative dose, temperature…) for equipment, which is in the containment (because of cables, terminals…).
- Scenario (power requirements) for unit’s modes without off-site power for a long time (up to one month).
- Scenario during severe accident (temperature, dose rate, withstand time for equipment).

Time schedule

See Fig. 2

Manpower

40 PM

Investment

4.4.12.2 Emergency power supply

Leader and other contributors

VUJE

Objective

Design of emergency power supply system

Description

It is most reliable distribution system. It supplies safety and safety related consumers with requirements not to allow an interruption of power supply longer than fractions of second in all operation modes.

Emergency sources are accumulator batteries and UPSs (rectifier + inverter).

There are 2 voltage systems: 220 V DC and 230/400 V /50 Hz.

It is expected there will be three independent trays (it copies number of redundant safety systems).

All components have to be qualified for use in safety systems.

Level to be reached at the end of various phases

Pre conceptual design: First design

Tools

N/A

Input Data

- Operating modes of reactor unit (e.g. start-up of the unit, normal operation, planned shutdown, shutdown with reactor protection, operation on house load power, station blackout, long term station blackout, severe accident, etc.) and requirements to electrically supplied equipment.
- Parameters of (main) consumers of electricity (power requirements, start-up current, belonging to systems, safety/ non safety /safety related classification, required functionality according unit's modes, etc.).
- Parameters (expected lifetime cumulative dose, temperature…) for equipment, which is in the containment (because of cables, terminals…).
- Scenario (power requirements) for unit's modes without off-site power for a long time (up to one month).
- Scenario during severe accident (temperature, dose rate, withstand time for equipment).

Time schedule

See Fig. 2

Manpower

100 PM

Investment

4.4.12.3 Battery back-up for accident management

Leader and other contributors

UJV, MTA EK, VUJE

Objective

Development of a battery back-up.

Description

If the off-site electricity is lost together with the diesels, the battery backup should be able to feed all the DHR blowers for a defined time period. The following should be taken into account:

1. Feasibility of the battery backup.
2. Scalability to GFR2400.

Level to be reached at the end of various phases

Pre conceptual design: Feasibility
Conceptual design: First design

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications (grace time)
Task 3.6.1 DHRS design - Conditioning in nominal conditions.

Time schedule

See Fig. 2

Manpower

Min. 24 PM.

Investment

TBD

4.4.13 Gas turbomachinery coupling with primary blowers

Leader and other contributors

VUJE

Objective

Development of the gas turbo machinery on the secondary side electrically coupled with primary blowers

Description

Various power conversion systems exist for a non condensable gas reactor. The turbine drives an alternator, that produces electricity, and primary blowers, that imposes a gas flow rate in the primary circuit.
The main aim is the increase the passive safety of the ALLEGRO reactor during transient and accident conditions.

Level to be reached at the end of various phases

Pre conceptual design: Main requirements and first design characteristics

Tools

N/A

Input Data

Design and Safety Specifications

Time schedule

See Fig. 2

Manpower

100 PM

Investment

None

4.4.14 Reactor protection system

Leader and other contributors

MTA EK (For the conceptual design), VUJE

Objective

The ALLEGRO Reactor Protection System (RPS) has to protect automatically the equipment and the environment in accident conditions. Reactor safety has to be guaranteed automatically (without operator actions.) by the RPS whenever the limits of normal operation are exceeded and also during anticipated operational occurrences. In case of postulated accidents RPS has to provide assurance for safe reactor shut-down. It is suggested that the start-up of safety systems with the functions of cool-down and confining radioactivity will be also carried out by the RPS. RPS has to be designed taking care of potential operation actions.

Description

Functions of RPS have to be defined on the basis of safety analysis. The design has to be based on a selected group of measurements also used by the Reactor Control System. The measured values initiating RPS actions have to be carefully chosen. The parameters of control rod drive systems and other safety systems have to be appropriately reflected when their actuation from RPS is designed. Redundancy and diversity requirements have to be considered from the very beginning. The design of RPS has to take into account the planned actions of the Reactor Control System and also the viability of operator actions.

In the Pre-conceptual design and Conceptual design phases the tasks to be performed by RPS have to be determined in the above sense (required measurements, signals leading to RPS actions, actuation of control rod drives and safety systems).

In the Conceptual design phase the protections, interlocks, actuations should be designed satisfying the design requirements of I&C systems. Iteration with safety analysis will be unavoidable.

In the Basic design phase one has to finalize the design, determining the information available in the Control Room and also the electricity supply needs of RCS together with the measurements.

Level to be reached at the end of various phases

To be prepared in-line with preparing Description

Tools

The Reactor Protection System will be designed without any special design tool.

Input Data

Input is required partly from safety analysis (actuation needs) and partly from the design of the safety systems and those systems which have to be protected by RPS. Substantial amount of the input may come from earlier safety analysis but it has to be actualized for the new design and also it has to have a form required by the design of RPS.

Time schedule

See Fig. 2

Manpower

Investment

4.5 GAS MANAGEMENT

4.5.1 Primary helium quality management

Leader and other contributors

UJV, CVR, NCBJ

Objective

1. Define operating modes & ranges for the gas quality management system.
2. Maintain the primary circuit atmosphere within the required range of impurities level.
3. Ensure a capability of the system to remove activity from the primary coolant (fission products from leaking fuel rods and activated corrosion products).
4. Design protection tools against corrosion and erosion.

Description

The existing gas quality management systems of the primary circuit in HTGR's are able to maintain the required helium quality. The gas management system in the primary circuit of ALLEGRO will have to take into account the following specific features:

1. Different materials within the primary circuit.
2. Potentially high levels of active fission products from leaking fuel rods resulting from abnormal or accident conditions.

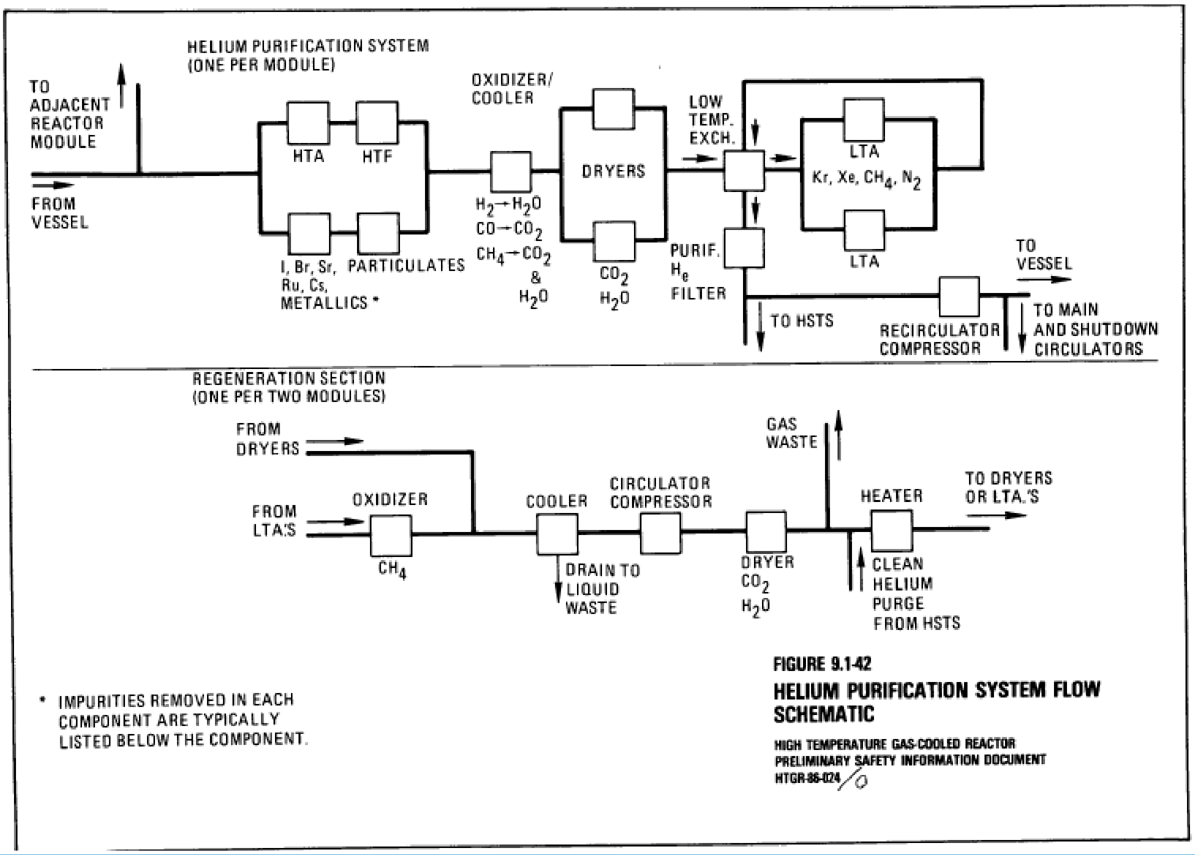
The gas management system has in fact two fundamental functions:

1. Remove substances that are harmful to primary circuit (dust, activity, humidity, …).
2. Dose substances needed to minimize the corrosion of the primary circuit materials.

A special attention should be given to the ability of the system to process abnormal situations associated with the requirement to test new types of fuel.

In general, the gas quality management system has to remove radioactive FPs as well as other contaminants from helium during normal operation (through bypass) as well as process the helium inventory from the reactor during its depressurization.

The purified helium should be blown into places, where avoiding contamination is the most important, such as area of the circulator motors. This will reduce the dose associated with their replacement.



Example layout of helium purification system (Ref. 14)

Level to be reached at the end of various phases

Pre conceptual stage: specification of preliminary requirements (capacity)

Conceptual: block diagram of system, size and location of components estimated. Supply chain analysis

Basic: Specification for layout of components established.

Detailed: Blueprints

Tools

TBD

Input Data

Task 3.1.1 Specifications.

Geometry & materials in the primary circuit.

Nature and acceptable level of ALLEGRO impurities in the primary circuit.

GoFastR design.

Time schedule

See Fig. 2

Manpower

Min. 100 PM

Investment

TBD

4.5.2 Secondary gas quality management

Leader and other contributors

UJV, CVR, NCBJ

Objective

1. Define operating modes & ranges for the gas quality management system.
2. Maintain the primary circuit atmosphere within the required range of impurities level.
3. (Treatment of activity ?)
4. Design protection tools against corrosion and erosion.

Description

The gas management system of the secondary circuit will be determined by the secondary gas. Its functions will be basically similar to the system for the primary circuit. A question remains to answer, whether activity will be treated in this system or not (case of failed primary gas/gas heat exchanger).

Level to be reached at the end of various phases

Pre conceptual design: Main requirements and first design characteristics

Tools

TBD

Input Data

Task 3.1.1 Specifications.
Type of gas and geometry & materials in the secondary circuit.

Time schedule

See Fig. 2

Manpower

Min. 50 PM

Investment

TBD

4.5.3 Guard vessel atmosphere management

Leader and other contributors

UJV, CVR, NCBJ

Objective

1. The GV atmosphere must be maintained within required limits: Dust, humidity, oxygen, radioactivity, helium, pressure (temperature).
2. Leaked helium from the primary circuit (& auxiliary helium systems) can be recycled.

Description

The GV atmosphere management (ventilation) must be able to control the composition including the pressure of the GV atmosphere. The temperature is controlled by another system of heat exchangers. There are three basic functions to be ensured by the current system:

1. Recycling of the helium leaked from the primary circuit & auxiliary systems.
2. Control of the atmosphere impurities through the purification system able to remove also radioactive substances leaked from the primary circuit.
3. Pressure control.

Level to be reached at the end of various phases

Pre conceptual design: Main requirements and first design characteristics

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications
Maintenance procedures.

Time schedule

See Fig. 2

Manpower

Min. 100 PM.

Investment

TBD

4.5.4 Transport & deposition of activity

Leader and other contributors

UJV, NCBJ

Objective

Assessment of the transport & deposition of activity inside the primary circuit.

Description

Although a purification system is installed for the primary circuit, activated corrosion products, dust and fission products may deposit preferably on certain surfaces and thus resist to the purification process. As the composition of the solid particles in GFR differs from that in the VHTR, a separate research is required on this topic with the aim to predict the activity deposited inside the primary circuit. It is to mention that re-suspension of once deposited contaminants can occur under abnormal or accident conditions. The following areas are expected to be studied:

1. Transport of activity through the primary circuit.
2. Deposition of activated substances on surfaces of the primary circuit.
3. Conditions of the potential re-suspension of the deposited contaminants.

Remarks:

1. Quantification of the deposits requires detailed knowledge of the primary circuit geometry.
2. This topic is known in HTGR-community, where lot of attention is paid to graphite dust issues.

Level to be reached at the end of various phases

Pre conceptual design stage: literature review to gain knowledge on the issue.
Conceptual design stage: Models applicable for this issue chosen
Basic design: Simulation of dust transport, deposition and resuspension to assess its location and influence on doses during maintenance and releases in accident conditions.
Detailed design: Recalculation for final geometry.

Tools

SPECTRA, designed for dust transport in HTGRs. Applicability of this tool for GFR conditions is to be verified.

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

T0+12 to T0+48
See Fig. 2

Manpower

Min. 60 PM.

Investment

For SPECTRA, approx 40k€/y

4.5.5 Gas storage & make-up system

Leader and other contributors

UJV, NCBJ

Objective

Dimensioning and design of the gas storage & make-up systems.

Description

In gas-cooled reactors, gases need to be stored in storage tanks and equipment must be available for transport of these gases to -and from the target volumes (e.g. primary circuit) in operational, abnormal and accident conditions. The following areas must be covered:

1. Identification of the gases to be stored including their amount and storage conditions.
2. Dimensioning of the storage tanks.
3. Identification & dimensioning of the transport & make-up systems and procedures.

This topic includes at least gases for the primary & secondary circuits and guard vessel in both normal & accident conditions.

Level to be reached at the end of various phases

Pre conceptual design: Estimate of required capacities and general solutions.
Conceptual design: Block diagrams of the system. Estimate of diameters of main pipelines, and general layout. Inclusion of failure modes of this system into the PSA.
Basic Design: ?
Detailed Design: Blueprints of the system

Tools

Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 60 PM.

Investment

TBD

4.6 Waste MANAGEMENT

4.6.1 Filters & waste management

Leader and other contributors

UJV, CVR, NCBJ

Objective

Assessment of procedures on waste management in ALLEGRO.

Description

The gas management systems (I. & II. circuits, guard vessel, containment) remove from the concerned gases (among others) also radioactive substances. This complicates the design, service & maintenance of this equipment, especially the maintenance of filters in the space-limited environment of the demonstrator. A first-of-the-kind assessment of procedures associated with this topic is, therefore, necessary for the general designer. It contains at least the following parts:

1. Activity-related issues in the design & maintenance of gas management systems (space & shielding, …).
2. Issues related to regeneration & replacement of the I. circuit & GV filters.
3. Waste management in the whole demonstrator.

Level to be reached at the end of various phases

Pre conceptual design: First functional definition.

Tools

TBD

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 60 PM.

Investment

TBD

4.6.2 Other waste management

Leader and other contributors

UJV, CVR, NCBJ

Objective

Assessment of procedures on waste management in ALLEGRO.

Description

The waste generated at the plant will be consisted of several streams:

- Spent fuel, including strategy for management of failed elements. This is discussed elsewhere.
- Solutions from washing the fuel (if it is decided to do so) and other things.
- Filters from atmosphere management systems
- Various waste from helium purification system. This may include liquid and gaseous waste.
- Other waste (clothes, gloves, broken components and tools. etc)

For each of types of waste, a management strategy should be adopted.

Level to be reached at the end of various phases

Pre-conceptual: Requirements (classification etc.)
Conceptual: General drawings of waste management facilities (location, size, technology applied etc.).

Tools

TBD

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 60 PM.

Investment

TBD

4.7 INSTRUMENTATION AND CONTROL

4.7.1 Core outlet temperature, pressure, flowrate monitoring: and determination of heat balance

Leader and other contributors

VUJE, NCBJ, MTA EK

Objective

Design of the core outlet temperature, pressure and flowrate monitoring system.

Description

Development of special optical measurement techniques or other innovative reactor technologies systems for core outlet temperature monitoring with the aim to ensure safety and fuel cladding integrity.

Development of special measurement techniques for pressure and flowrate monitoring.

Level to be reached at the end of various phases

Pre-conceptual design: Identification of measurement places with associated techniques.

Conceptual design: Identification of measurement solutions (commercially available or requiring development)

Basic design: manufacturing of prototypes of measurement equipment where needed

Detailed design: blueprints of the system.

Tools

N/A

Input Data

Time schedule

See Fig. 2

Manpower

300 PM

Investment

Experimental verification needed.

4.7.2 Neutron flux measurements

Leader and other contributors

VUJE, MTA EK, NCBJ

Objective

To provide information about neutron flux during shutdown, low power, and full power operation.

Description

The neutron flux can be measured inside the core, or outside of it. Due to high temperature inside core, outside meters located in reflector are suggested. These meters should be multiple, placed symmetrically around the core.
For measurements inside the core, insertable meters will be used. These meters will be able to provide information about axial flux distribution. A mechanism for periodic insertion of these meters has to be designed, probably based on what is commercially used in BWRs (a set of small pipes leading to various locations inside the core. The self-powered neutron detector is inserted into one of these pipes on a cable).

Level to be reached at the end of various phases

Pre conceptual design: First functional specifications and design.

Tools

N/A

Input Data

Core design

Time schedule

See Fig. 2

Manpower

100 PM

Investment

4.7.3 Monitoring the reactor atmosphere, cladding failure detection

Leader and other contributors

NCBJ, MTA EK

Objective

To provide information about contamination of helium and early warning about leaks

Description

The reactor should be equipped with analyzer of the primary helium content, with set points launching alarms, when activity is exceeded.

Moreover, some novel solutions based on neuron networks may be used in order to gain knowledge about position of leak sources within the core. Such a system may analyze pattern of contamination in helium and based on this, identify zone of the core in which failure occurred. Specific failure location should be made by designated detector, possibly cooperating with CCTV equipped robotic arm. This system may utilize arms used normally for refueling.

The monitoring equipment itself is commercially available. The biggest problem is probably to ensure possibility of replacement of broken components.

Level to be reached at the end of various phases

Pre-conceptual design: Review of monitoring equipment available
Conceptual design: Location of monitors and requirements specified
Basic design: Suppliers chosen or shortlisted
Conceptual design: Blueprints of fixtures for equipment & circuitry

Tools

N/A

Input Data

Linked to 2.1.2 and 2.2.1

Time schedule

See Fig. 2

Manpower

12 PM (for pre conceptual design phase)

Investment

None in early stages

4.7.4 Reactor control system

Leader and other contributors

VUJE, MTA EK

Objective

The ALLEGRO Reactor Control System (RCS) has to protect automatically the equipment and the environment in normal operation and accident conditions. RCS has to collect all the information necessary for the operation of the reactor and has to keep the reactor within the normal operational limits in normal conditions automatically. RCS has to provide appropriate signals to the operators in the control room whenever the reactor parameters are as close to normal operational safety limits that safety margins deteriorate.

Description

Technical design of RCS involves the determination of the necessary protections, interlocks, loops of automatic control. The measurements necessary to perform the tasks of the RCS have to be defined on the basis of a careful analysis. Viability of operator actions has to be taken into account.
In the Pre-conceptual design and Conceptual design phases the tasks to be performed automatically or by the operating staff have to be determined in the following steps:

- The ***permissible*** combinations of all the state variables describing the state of the equipment shall be determined. These combinations form an area in the state space and we should define the surface covering all the ***safe states*** of the equipment. The safe states of the reactor are determined by the safety analysis, while safe states of any other equipment is derived from their respective design data. Satisfactory engineering safety margins have to ensure that the described above surface would not be violated by the given equipment during normal operation.
- Functions of the RCS have to be determined e.g. as follows
  - to keep the equipment safe in cold shut-down state
  - to perform the stepwise start-up with heating, reaching the well-defined intermediate states and defining the necessary conditions to start for the next step: reaching the next intermediate state
  - operation on nominal power, respecting the criteria of stable steady state operation,
  - power changes reaching stable stationary states at different power levels and temperatures
  - stable and safe step-wise shut-down of the equipment defining intermediate states and criteria and recognition of reaching them
  - reaching the final shut-down state which can be kept on for long period of time; criteria, recognition and control of this state
  - to perform the operations necessary during the cold shut-down state (re-fueling, maintenance and repair – even parts of the I&C system itself)
- Functions of RCS related to handling of malfunctions and recognizing the early phase of accident scenarios have to be determined:
  - recognition of the malfunctions - even in the I&C equipment - and tasks to be performed for these situations
  - control of the neutron power in case of different malfunctions
  - recognition of hurting the safety margins of normal operational limits and of hurting the normal operational limits, fulfilling the tasks prescribed for these conditions taking into consideration the start-up of the Reactor Protection System.

In the Conceptual design phase the protections, interlocks and control loops of the particular units mentioned above should be designed together with I&C requirements according to these conditions determined for the particular equipment. It should be fixed which technological parameters are to be measured and controlled and how they are to be handled by the protections, interlocks and control loops. Next the necessary levels of redundancy and diversity have to be determined: how to ensure the principles of “stepwise degradation” and “defense in depth”.

In the Basic design phase one has to finalize the design, determining the information available in the Control Room and also the electricity supply needs of RCS together with the measurements.

Level to be reached at the end of various phases

See description.

Tools

RCS will be designed without any special design tool.

Input Data

Safety analysis related to normal operational modes.
List of measurements designed in the various phases of the design.

Time schedule

See Fig. 2

Manpower

24 PM (For the pre conceptual design)

Investment

4.8 SAFETY

4.8.1 Review of existing analysis of transients

Leader and other contributors

MTA EK, UJV, VUJE, NCBJ

Objective

1. The review of the existing analyses will minimize the resources to be allocated for solving again issues already resolved.
2. The review will help to formulate additional analyses and indicate where to allocate resources.

Description

Analysis based on past GoFastR and CEA studies

Level to be reached at the end of various phases

All the work should be done in pre-conceptual stage.

Tools

Consultations with authors of the CEA ALLEGRO 2009 concept.

Input Data

CEA Reports with assumptions, models and results

Time schedule

See Fig. 2

Manpower

Investment

4.8.2 System transient analysis: DC and DEC (in particular LOCA + Blackout)

Leader and other contributors

UJV, MTA EK, NCBJ, VUJE

Objective

- Safety assessment of the design.

Description

- Definition of the list of Design Basis (DB) and Design Extension Conditions (DEC) protected and not protected scenarios not excluded by the design and selection of bounding critical transients.
- Definition of the acceptance criteria and verification of their fulfillment. The usual approach of prescribing more strict criteria for rather frequent cases has to be applied.
- Analysis of the most severe accident scenarios (covering other) in an iterative manner in support to the design process.
- The bounding reactor power and linear heat rate have to be estimated by transient calculations still in the phase of Definition of the basic safety and performance goals to provide these values for core design (see Task 3.3.1.2).

The tools applied for accident analysis have to be validated and refined if needed in all phases of the project.

Level to be reached at the end of various phases

In the pre-conceptual and conceptual design phases the bounding critical transients have to be repeatedly analyzed in order to help the design activity and the fulfillment of the acceptance criteria has to be checked. Each DB and DEC scenario of the full list has to be analyzed at the end of both phases in order to prepare the corresponding safety analysis report. It has to be pointed out that the respective acceptance criteria are fulfilled for every case.

Tools

CATHARE, RELAP, ATHLET – KIKO3D

Input Data

Task 3.1.1 Specifications.
Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

12 PM for initial calculations

Min. 150 PM

Investment

TBD

4.8.3 Severe accidents

4.8.3.1 Severe accidents assessment plan

Leader and other contributors

UJV, MTA EK, VUJE, NCBJ, NUBIKI

Objective

Formulation of the severe accidents assessment plan (phenomenology, models, codes, input data), for different fuels

Description

There is very little experience with simulation of severe accidents in a GFR for both the oxide and the refractory fuels. For this moment, only MELCOR is capable of simulating a severe accident with core melting (oxide core only). Models for severe fuel damage in the refractory core are not available. The assessment plan will, thus, consist of the following parts:

1. Analysis of the phenomenology for MOX, UOX and ceramic fuels.
2. Selection of scenarios potentially leading to severe accidents.
3. Assessment of applicability of existing codes to GFRs (MELCOR, …).
4. Unification of input decks, initial and boundary conditions used by different teams.

Remark: NUBIKI offers 1) Reviewing the existing models & material property data in MELCOR, 2) Assessment of needs in SA models and HT-material property data for ALLEGRO.

Level to be reached at the end of various phases

To be prepared in-line with preparing Description

Tools

N/A

Input Data

VUJE documents (availabilily TBC)

Time schedule

See Fig. 2

Manpower

Min. 36 PM

Investment

N/A

4.8.3.2 Severe accidents calculations

Leader and other contributors

UJV, MTA EK, VUJE, NUBIKI

Objective

Assessment of both the severe core damage and the source term.

Description

The following areas will be covered in this chapter:

1. Assessment of in-vessel degradation.
2. Assessment of ex-vessel degradation.
3. Assessment of re-criticality (oxide fuel, refractory fuel).

The following issues should be studied:

1. Criticality issues.
2. Pressure and temperature loadings on the RPV, primary circuit, GV and containment.
3. Source term (later phase of the project).

Remark: NUBIKI offers participation in 1) Development of a MELCOR input deck for ALLEGRO, 2) Testing & validation of the pilot input decks, 3) SA calculations.

Level to be reached at the end of various phases

To be prepared in-line with preparing Description

Tools

MELCOR + neutronics

Input Data

Task 3.2.1 Heat transport systems.
Task 3.1.5 System integration and assessment.

Time schedule

See Fig. 2

Manpower

Min. 108 PM

Investment

TBD

4.8.3.3 Severe accidents management

Leader and other contributors

UJV,, MTA EK, VUJE, NCBJ

Objective

1. Definition of severe accident management provisions for ALLEGRO (for both types of fuel) with regard to WENRA requirements.
2. Assessment and evaluation of severe accident management procedures as basis for elaboration of Severe Accident Management Guidelines.

Description

The existing concept CEA ALLEGRO 2009 is unable to mitigate the consequences of severe accident conditions such as core melting, core compaction etc., especially for the first core. As „beyond design" accidents are no more accepted by WENRA, consequences of all accidents that cannot be "practically excluded" must be mitigated by the design. As mentioned above, this topic is composed of two parts:

1. Assessment of the required SA related systems, structures and components that must be incorporated into the design.
2. Formulation of appropriate SA management procedures through calculations of various scenarios with various provisions used in certain phases of the accident.

Level to be reached at the end of various phases

Pre-conceptual phase: Definition of SAM systems to be used for SA mitigation, first draft of SAM procedures.

Conceptual phase: Analysis of proposed SAM procedures and their improvements.

Basic design phase: Elaboration of SAMGs.

Tools

Severe accident system codes (MELCOR)
Routine engineering tools used in the industry.

Input Data

Task 3.1.1 Specifications.

Time schedule

See Fig. 2

Manpower

Min. 150 PM

Investment

TBD

4.8.3.4 Severe accidents tests

Leader and other contributors

To be defined in a later stage if needed

Objective

Core and core catcher behavior
To be defined in a later stage if needed

Description

To be defined in a later stage if needed

Level to be reached at the end of various phases

To be prepared in-line with preparing Description

Tools

To be defined in a later stage if needed

Input Data

To be defined in a later stage if needed

Time schedule

To be defined in a later stage if needed
See Fig. 2

Manpower

To be defined in a later stage if needed

Investment

To be defined in a later stage if needed

4.8.4 Loads on fuel and components in accidental conditions

Leader and other contributors

MTA EK, UJV

Objective

The loads on fuel, RPV, reactor internals and primary circuit components have to be calculated for the transient and accident scenarios.

Description

The loads on fuel, RPV, reactor internals and primary circuit components have to be calculated for the transient and accident scenarios. The critical scenario(s) must be chosen for each component. The relevant node in the safety calculation characteristic for the given component has to be carefully chosen.

Level to be reached at the end of various phases

A preliminary load catalogue has to be prepared in the pre-conceptual phase based on the calculations carried out in the framework of Task 3.12.2.1. This catalogue may serve as a basis for strength calculations in the conceptual design phase. The catalogue has to be refined by the end of the conceptual design phase.

Tools

If needed in addition to the calculations made on transient calculations task: CATHARE, RELAP, ATHLET – KIKO3D

Input Data

Transients calculation results
Outputs of this task are inputs of components design tasks.

Time schedule

See Fig. 2

Manpower

24 PM

Investment

None

4.8.5 Releases and environmental consequences

Leader and other contributors

UJV, MTA EK

Objective

The radioactive releases during transients and accidents have to be determined. It has to be pointed out that neither the releases of radioactivity not the environmental consequences exceed the corresponding limits.

Description

The source term for various types of radioactive releases shall be determined (including releases from severe accidents). Source terms have to be associated with transients and accidents. It has to be proven that the releases do not exceed the respective limits. The source terms can be refined during every phase of the project.
The environmental consequences have to be evaluated for the chosen source terms. This can be done only whenever the site is determined. The transfer function between releases and environmental consequences can be determined once and for ever.

Level to be reached at the end of various phases

During the pre-conceptual design phase the methodology shall be fixed. Presumably, at this stage source terms will not be determined from deterministic calculations but they will be chosen in a way to satisfy the requirements.
In the conceptual design phase the source terms will be determined from deterministic calculations. The transfer functions between releases and environmental consequences will be determined for the proposed site. It has to be pointed out that releases and consequences remain below the relevant limits.

Tools

Input Data

Core calculations

Time schedule

See Fig. 2

Manpower

60 PM

Investment

4.8.6 PSA

Leader and other contributors

UJV, MTA EK, NCBJ, VUJE

Objective

The general objective of this task is to perform a design stage level 1 probabilistic safety assessment (PSA) for the ALLEGRO reactor as part of safety analyses and safety demonstration

Description

As given above, the general objective of this task is to perform a design stage level 1 PSA for the ALLEGRO reactor. The specific objectives of the analysis include:

- development of the ALLEGRO PSA methodology
- evaluation of design alternatives by probabilistic safety assessment
- development of requirements regarding supporting deterministic TH safety analyses
- reliability analysis and risk evaluation of selected passive systems
- evaluation of redundancy and diversity features
- modelling and evaluation of the role of humans and human interactions in ensuring safe reactor operation
- development of a computerized PSA model that can be used to identify design weaknesses from risk point of view and to support design modifications, decisions
- quantification of risk in terms of core damage frequency as an overall measure to describe operational risk
- identification and evaluation of important risk contributors (operating modes, initiating events, accident sequences, system and component failures, human failure events, etc.) using point estimates, importance, sensitivity and uncertainty analyses
- sensitivity analysis regarding the main assumptions made in ALLEGRO risk analysis model
- fulfillment of licensing requirements related to PSA.

The PSA model development and risk quantification will consist of the key steps commonly followed in level 1 PSA:

- identification and probabilistic description of initiating events
- delineation of accident sequence / event tree models
- system analysis and fault tree development
- analysis of dependent failures
- human reliability analysis
- development of a component reliability data base
- risk quantification
- interpretation and evaluation of results.

The general PSA methodology needs to be modified and customized to appropriately reflect the design features as well as the intended uses and the corresponding operational characteristics of the ALLEGRO demonstration reactor. Although a full scope PSA is to be aimed at with respect to reactor operating modes and initiating events, a gradual approach will be adapted to achieve this goal. Two important factors that justify this gradual development are as follows:

- The reactor design will be evolving parallel to performing the PSA.
- Risk assessment for external hazards is site specific, therefore a meaningful analysis can only be performed when the site is selected and site specific data for external hazards become available.

Also, the following aspects need to be addressed in the development of the methodology:

- How to use PSA in the different phases of the ALLEGRO project with distinction between PSA development during the various design phase (from pre-conceptual design to detailed design) in particular.
- What is the expected analysis scope and what are the main limitations.

- What are the main sources of uncertainty and their effects.

The analysis is broken down into distinct stages as milestones:

1. Development of level 1 PSA methodology applicable to ALLEGRO
2. Construction of a PSA model for internal initiating events: loss of coolant accidents
3. Construction of a PSA model for internal initiating events: transients
4. PSA model finalization, data base development and risk quantification for internal events
5. PSA for internal hazards
6. PSA for external hazards

UJV and NUBIKI will be responsible for PSA model development and risk quantification, while UJV and MTA EK will jointly work on deterministic safety analyses needed in support of constructing the accident sequence models in PSA.

Level to be reached at the end of various phases

The ALLEGRO methodology document (Stage 1) should be prepared during the pre-conceptual design phase. An initial PSA model for internal initiating events (Stage 2 and Stage 3) representing available design information in terms of responses to transients, types and operational characteristics of systems and components, as well as the expected role of humans has to be developed and quantified (Stage 4) during conceptual design. Generic component reliability data are likely to be used. The major aim of the analysis will be support to design and to the choice between design options in this phase. (Later the PSA models can be developed further and risk quantification can be updated during the phases of basic design and detailed design, respectively.)

Tools

Risk Spectrum or SAPHIRE PSA computer codes, computer codes for deterministic safety analyses

Input Data

Reactor design – The availability of a pre-conceptual reactor design is a precondition for PSA modelling.

Results of deterministic safety analyses – Design basis and beyond design basis conditions/accidents need to be analyzed in such a scope and level of detail that enables event tree construction for the internal initiating events that are in the scope of PSA.

Initiating event frequencies – These will mostly be based on expert judgment (no data for GEN_IV IE frequencies). For selected events (loss of electric power) some statistical analysis will be done, while generic data will be used for IEs with loss of piping integrity. PSA data from the MHTGR programme are publicly available and can be re-used. These data are not up-to-date, but can be used in case nothing better was available.

Component reliability data – For most components data are available from industrial data (both nuclear and non-nuclear). Generic data will be used, for “new” components. In addition, expert judgment will have to be made to determine reliability data for unique ne components.

Common cause failures – Generic data will be used (MGL or alpha factors, the use of alpha factors is preferred).

Human errors and human error probabilities – Suitable HRA methods representing good practices will be used based on generic inputs (UJV specialists are familiar with the methods THERP, ASEP, decision trees, CREAM, SLIM… the method(s) will be selected on the basis of types of human actions to be analysed).

There is a code on PSA for advanced non-LWRs: *ASME/ANS RA-S-1.4-2013: Probabilistic Risk Assessment Standard for Advanced Non-LWR Nuclear Power Plants*

Time schedule

The starting date of PSA should be specified in coordination with other parts of the ALLEGRO engineering support in an optimum manner. Similarly, the timing of PSA tasks should be coordinated with other technical tasks of ALLEGRO to the greatest possible extent. As a baseline estimate, three years is seen as a reasonable time span to perform a meaningful initial analysis for internal events. Use

can be made of interim PSA results within this period to yield insights that can support design and specification of further TH analyses, if necessary. A good distribution of analysis tasks and coordination among partner are a precondition for performing PSA in a timely manner.
The following time schedule is restricted to the PSA for internal events relative to T0 and to the availability of a pre-conceptual reactor design (T1):

- Stage 1: Development of level 1 PSA methodology applicable to the ALLEGRO reactor: T0+18 months. An initial methodology document for internal events PSA can probably be produced within a shorter time period, say within T0+12 months. However, it is not seen necessary because
    - The key condition is that a consolidated methodology become available by the end of the conceptual design phase.
    - The achievements in other technical areas of the project during conceptual design must be reflected in the methodology.
- Stage 2: Construction of a PSA model for internal initiating events: loss of coolant accidents: T1+24 months. If necessary, a preliminary model of LOCA accidents could be created in T1+16 months. Such a model could be further improved later as additional design information about ALLEGRO emerges.
- Stage 3: Construction of a PSA model for internal initiating events: transients: T1+36 months. If necessary, a preliminary model of transients could be created in T1+26 months. Similarly to the LOCA accident sequences, this model can be improved subsequently as ALLEGRO design evolves.
- Stage 4: PSA model finalization, data base development and risk quantification for internal events: T1+36 months. Indeed, the final model is to be ready in T1+36 months. During this last analysis phase the LOCA and transient parts of the model will be finalized.

Planning of the tasks for the internal hazards PSA (Stage 5) can be made when detailed information becomes available about those features of the reactor design that are important with respect to the

- identification and probabilistic description of internal hazards
- assessment of plant vulnerability to hazard induced loads.

It is envisaged that initial work on PSA for internal hazards can start during the basic design phase and the analysis can be completed in the detailed design phase. Therefore, this roadmap does not address the details of scheduling PSA for internal events.
The schedule for the external hazards PSA (Stage 6) can be determined when

- The reactor site is selected,
- Site specific data on external hazards are made available
- Design details important to assessing vulnerability of systems, structures and components to hazard induced loads are known.

All these conditions imply that a meaningful external events PSA can, in general, be scheduled similarly to the internal events PSA or later.
See Fig. 2 for scheduling the PSA tasks for internal events.

Manpower

84 PM - Estimation made in IAEA Safety Series 50-P-4 for “reactor-full power PSA” performed by experienced PSA team, what is expected to be the case (external hazards analysis not included)

56 PM – Estimation made for PSA covering other operational regimes

20 – 64 PM – Estimation made for external hazards PSA (can be concretized after the reactor site is selected)

36 PM – PSA applications in the design phase - evaluation of design alternatives on request, etc.

196 – 240 PM - in total

Investment

4.9 SUMMARY OF THE DISTRIBUTION OF TASKS

●: Leader, ○: Contributor

Task	Title	VUJE	UJV	MTA EK	NCBJ
4.1	WHOLE PROJECT ACTIVITIES				
4.1.1	Design specifications and objectives	●	●	●	●
4.1.2	Safety requirements and objectives	●	●	●	●
4.1.3	Business Plan	●	●	●	●
4.1.4	Legal matters (IPR & general NDA)	●	●	●	●
4.1.5	System integration and assessment	●	●	●	●
4.1.6	Siting and Licensing	●		○	○
4.2	REACTOR SYSTEM				
4.2.1	Heat transport systems	●	○	○	○
4.2.2	Transition from the first core to the ceramic core	●	○	○	○
4.2.3	Assessment of vibrations	●			
4.2.4	Loads on fuel and components in normal operation	●			
4.3	CORE				
4.3.1	Neutronics				
4.3.1.1	Review of performed studies	●	○	○	
4.3.1.2	Neutronic calculation and design of the start-up core	○	○	●	○
4.3.1.3	Design of the experimental S/As (ceramic fuel)		○	●	
4.3.1.4	Transition cores	○	○	●	○
4.3.1.5	Gamma heating of structures				●
4.3.1.6	Radiological protection				●
4.3.2	Core and subassembly thermalhydraulics				
4.3.2.1	Core thermalhydraulics optimization	○	○	●	○
4.3.2.2	Fuel bundle thermalhydraulics	○	○		○
4.3.3	Fuel subassembly and fuel rod design				
4.3.3.1	Fuel rod thermomechanical behavior (UOX and ceramic)			●	
4.3.3.2	Fuel subassembly design		○	●	
4.3.4	Control and shutdown subassembly design				
4.3.4.1	Absorbers rod design & behaviour	○		●	
4.3.4.2	Control subassembly design & behaviour	○		●	
4.3.4.3	Additional shutdown system				●
4.3.5	Qualification of the fuel				
4.3.5.1	Specification of the required qualification for the fuel		○	●	
4.3.5.2	Qualification dossier of the start-up core			●	
4.3.6	Fuel fabrication				
4.3.6.1	Fuel specifications for the fabrication			●	
4.3.6.2	Fabrication of the start-up core			●	
4.4	SYSTEMS, STRUCTURES AND COMPONENTS				
4.4.1	Reactor primary vessel (RPV)				
4.4.1.1	RPV layout	○	●		○
4.4.1.2	RPV thermalhydraulics	○	●		○
4.4.1.3	RPV internals	●	○		
4.4.1.4	Thermal insulation of primary, secondary and DHRS circuits	●			
4.4.1.5	RPV & primary circuit seals				●
4.4.1.6	Structural materials inside the RPV				●
4.4.2	Guard vessel (GV)				
4.4.2.1	Layout	●	○		○
4.4.2.2	Cooling of the RPV and heat removal from the GV atmosphere	●	○		○
4.4.2.3	GV structures	●			

Task	Title	VUJE	UJV	MTA EK	NCBJ
4.4.3	Heat exchangers				
4.4.3.1	Design and testing of main heat exchangers	●			
4.4.3.2	Design and testing of DHRS heat exchangers	●			
4.4.3.3	Design and testing of Gard Vessel heat exchangers	●			
4.4.4	Blowers				
4.4.4.1	Primary circuit blowers		●		
4.4.4.2	Secondary circuit blowers		●		
4.4.4.3	DHRS blowers		●		
4.4.5	Valves				
4.4.5.1	Main isolation valves	●			
4.4.5.2	DHRS valves	●			
4.4.5.3	Safety valves	●			
4.4.6	Control rod drive mechanisms	○			●
4.4.7	Decay Heat Removal Systems (DHRS)				
4.4.7.1	DHRS design - Conditioning in nominal conditions	○	●	○	○
4.4.7.2	DHRS - Experimental testing	○	●		
4.4.7.3	Gas injection system		●	○	
4.4.8	Fuel handling systems	●			○
4.4.9	Fuel management				
4.4.9.1	Fresh fuel storage and transfer	●			
4.4.9.2	Spent fuel transfer and storage	●			
4.4.10	Containment	●			
4.4.11	Core catcher	○	●		
4.4.12	Power supply systems				
4.4.12.1	Normal power supply	●			
4.4.12.2	Emergency power supply	●			
4.4.12.3	Battery back-up for accident management	○	●	○	
4.4.13	Gas turbomachinery coupling with primary blowers	●			
4.4.14	Reactor protection system	○		●	
4.5	GAS MANAGEMENT				
4.5.1	Primary helium quality management		●		○
4.5.2	Secondary gas quality management		●		○
4.5.3	Guard vessel atmosphere management		●		○
4.5.4	Transport & deposition of activity		●		○
4.5.5	Gas storage & make-up system		●		○
4.6	WASTE MANAGEMENT				
4.6.1	Filters and waste management		●		○
4.6.2	Other waste management		●		○
4.7	INSTRUMENTATION AND CONTROL				
4.7.1	Core outlet temperature, pressure, flowrate and determination of heat balance	●		○	○
4.7.2	Neutron flux measurements	○		○	○
4.7.3	Monitoring of the reactor atmosphere, cladding failure detection and localization systems			○	○
4.7.4	Reactor control system	●		○	
4.8	SAFETY				
4.8.1	Review of existing analysis of transients	○	○	●	○
4.8.2	System transient analysis: DC and DEC (in particular LOCA + Blackout)	○	●	●	●
4.8.3	Severe accidents				
4.8.3.1	Severe accidents assessment plan	○	●	○	○
4.8.3.2	Severe accidents calculations	○	●	○	

Task	Title	VUJE	UJV	MTA EK	NCBJ
4.8.3.3	Severe accidents management	○	●	○	○
4.8.3.4	Severe accidents tests				
4.8.4	Loads on fuel and components in accidental conditions		○	○	
4.8.5	Releases and environmental consequences		○	○	
4.8.6	PSA	○	●	○	○

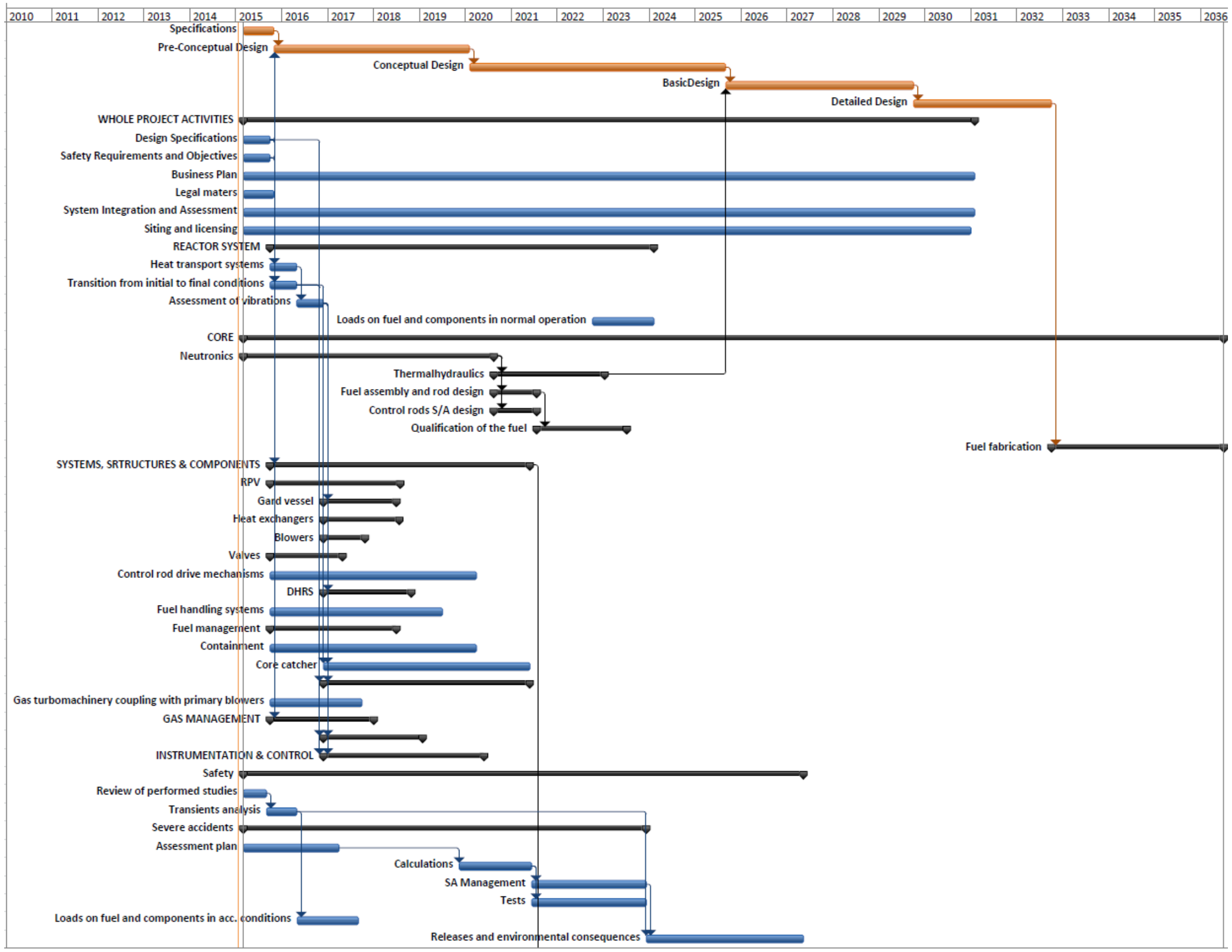


Fig. 2 ALLEGRO time schedule

5 ABBREVIATIONS

CRDM: Control rod drive mechanism
DHRS: Decay Heat Removal Systems
FSAR: Final Safety Analysis Report
GV: Gard Vessel
HX: Heat Exchangers
ISAR: Introductory Safety Analysis Report
N/A: Non Applicable
PSA: Probabilistic Safety Assessment
PSAR: Preliminary Safety Analysis Report
RCS: Reactor Control System
RPS: Reactor Protection System
RPV: Reactor Pressure Vessel
SC: Steering Committee
SPSAR: Simplified Preliminary Safety Analysis Report
SRO: Safety Requirements and Objectives
V4G4: Visigrad Consortium (Slovakia, Czech Republic, Hungary and Poland) for the development of Gen IV systems

REFERENCES

1. V4G4 Steering Committee. Tihany, Hungary, September 2nd, 2014
2. K. Stum: „Design Intent and Basis of Design: Clarification of Terms, Structure, and Use". Symposium, ASHRAE in Transactions, vol. 108, pt. 2, HI-02-20-1 (2002).
3. C. Poette: ALLEGRO Preliminary viability report. NT DER/SESI/LCSI/NT DO12 (2009).
4. F. Bentivoglio, N. Tauveron : Preliminary design and study of an innovative option for gas demonstrator ALLEGRO. NURETH-15, paper-079, Pisa, Italy, May 12-15, 2013.
5. IAEA-TECDOC-626: "Safety related terms for advanced nuclear plants" (1991).
6. Safety of Nuclear Power Plants: Design, IAEA Safety Standards Series NS-R-1, 2000.
7. E. Wattelle, Proposal for a harmonization of the safety assessment practice, SARGEN-IV Report PSN-SRDS/2012-00088, 2014.
8. European Utility Requirements for LWR Nuclear Power Plants. Volumes 1, 2 & 4, Rev. D, 2012.
9. Safety of new NPP designs. WENRA Study by Reactor Harmonization Working Group (RHWG), 2013
10. ANSI/ANS-53.1-2011: Nuclear Safety Design Process for Modular Helium-Cooled Reactor Plants.
11. WENRA RHWG, Report: Safety of new NPP designs, March 2013.
12. ALLEGRO core specifications. ESNII Plus Deliverable D6.1.12 – MTA EK October 2014.
13. J. M. Beck & L. F. Pincock: High Temperature Gas-Cooled Reactors Lessons Learned Applicable to the Next Generation Nuclear Plant, NL/EXT-10-19329.
14. HTR projects https://inlportal.inl.gov/portal/server.pt?open=space&name=Dir&id=1&psname=Opener&psid=0&cached=true&in_hi_userid=2&control=DirRepost&page=DirCardProperties&cardID=73178. U.S. Archiving services: papers HTGR-86-***, and DOE-HTGR-86-***