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Project objectives and Success criteria

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1 Introduction

1.1 Purpose

RAPHAEL is an Integrated Project launched by the European Commission to address the viability and performance issues of a modular V/HTR for the production of electricity and co-generation of heat and electricity. The large financial commitments of the European Commission and the RAPHAEL Partners require a tight follow-up and review of the implementation of the project objectives and the results obtained towards the objectives. Success criteria have to be defined to evaluate the progress. This report summarises the success of the sub-projects at the work package level and the progress towards the objectives.

1.2 Objectives of RAPHAEL

In order to pursue an active R&D to assess the viability of the nuclear option for sustainable development, in particular on gas-cooled fission reactors, the evaluation of concepts satisfying market, environmental and social needs is required. The gas-cooled reactor technology has the advantage of offering prospects for a variety of applications. In this area Europe is not starting from scratch but can rely on decades of efforts starting from the first high-temperature reactors (DRAGON) in the UK to the developments in Germany realised in an experimental reactor (AVR) and a power reactor (THTR). These developments evolved towards modular designs such as the HTR Modul. They have been complemented by the operation of a large number of test facilities including large helium test facilities. Furthermore, investigations have been performed on modular HTR for process heat production (PNP).

The project objectives of the Integrated Project RAPHAEL take account of this experience in at first consolidating base generic V/HTR technologies (temperatures below 1000^{o}C). Furthermore promising options and advanced solutions for improving V/HTR performances shall be explored for

- higher temperatures up to and above 1000^{o}C
- improved fuel performance and higher fuel-burn-up $\geq$ 15% FIMA
- selection of materials for very high temperature applications
- developing key components and testing of selected mock-ups
- assessing and improving knowledge of V/HTR behaviour in accident conditions and develop further specific safety approach
- improved competitiveness
- extending the domains of application (electricity → co-generation of heat and electricity)

In order to successfully realise the objectives, the project is structured into eight sub-projects: coupled reactor physics and core thermo-fluid dynamics, fuel technology, backend of the fuel cycle, materials development, component development, safety, system integration and project coordination and management.

Two advisory groups provide advice on requirements from the users point of view (Industrial Users Advisory Group (IUAG) - utilities, process heat users, but also from nuclear industry) and a Safety Advisory Group (SAG) including Safety Authorities and IAEA.

Worldwide HTR development is progressing in particular in China where an experimental reactor HTR-10 is under operation and a demonstration reactor is engineered, and in Japan with its experimental HTTR. Furthermore there is a comprehensive development programme established in South Africa with the aim of constructing an HTR for electricity production in 2010.

Also the US is investigating in its NGNP programme the viability of V/HTR for electricity and process heat production.

1.3 Success criteria for the RAPHAEL project

RAPHAEL has implemented a system for monitoring the progress of the project consisting of status of deliverables and milestones. The status will be presented after each project year in the annual reporting. Furthermore individual success criteria are defined at the work package level on which the progress and fulfilment of the objectives are measured.
Chapter 2 provides an overview of the status of the project.

2 Overview of objectives and criteria in the RAPHAEL sub-projects

WP	General objective	Specific measurable objective	Success criteria	Time line	Contingency plan
CP1	Validation of HTR core physics codes against HTR-10 transient experiment	Write benchmark definition	Availability of experimental results by AVR, and burnup calculational results by FZJ	year 2	
		Build models in partner's respective codes	Transient modeling capability	year 3	
		Write benchmark report containing results and comparison		year 4	
CP1	Validation of HTR core physics codes against HTR-10 transient experiment	Write benchmark definition	Availability of experimental results by INET	year 1	Use benchmark definitions of IAEA CRP5
		Build models in partner's respective codes	Transient modeling capability	year 2	
		Write benchmark report containing results and comparison		year 3	
CP2	Validation of the capability of reactor physics code systems to predict isotopic composition of V/HTR fuel at high burnup	Write benchmark definition	Successful execution of HTR-EU1bis experiment by JRC-IE	year 1	
			Availability of benchmark cross section and PIE results by NRG	year 2	
			Successful transport of irradiated smaples from Petten to Karlsruhe	year 2	
			Succesful execution of isotopic analysis by JRC-ITU	year 3	
		Build models in partner's respective codes	Burnup modeling capability	year 3	
		Write benchmark report containing results and comparison		year 4	
BF1	Collection of past experimental data on spent fuel characterisation	Preservation of existing knowledge & use for comparison with new data	Availability of data	year 2	not necessary

	High precision characterisation with recent instrumentation	Experimental validation of spent fuel characteristics	Determination of barrier function of coatings, radioisotope inventories and their distribution	year 3-4	Different transport options and optional choices of samples
BF2	modelling of spent fuel degradation under corrosion attack	prediction of C.P. stability in different repository conditions	Adaptation of analytical models which were used for C.P. evaluation at high temperatures and accident conditions	year 3	Development of a specific model
	geochemical modelling & performance assessment	waste package stability in different repository conditions	Exclusion of significant Instant Release Fractions	year 2 & 4	Modification of waste package conception
BF3	Separate effect tests on corrosion and leaching of spent HTR fuel	reproducible, reliable data on corrosion & leaching effects	Extrapolation to long time periods	year 4	Prolongation of experiments to achieve improved data
FT1	TRISO particle improvements (fabrication & control) related to VHTR requirements	Feasibility study of UCO kernel manufacturing	encouraging tests results	18 (report issued M20)	not necessary
		ZrC coating process optimization (on dummy kernels)	deposit of stoechiometric ZrC without impurities	36	final optimization delayed (before M48)
		Weak irradiation test feasibility (particles tightness control)	feasibility achieved in HFR	18 (report issued M22)	feasibility not reached in HB8 with reasonable irradiation time - additional funding could be considered for studying an in-core device
FT2	Materials (PyC) behaviour under irradiation	PYCASSO irradiation at T>1000°C up to a few 10E25 n/m2 with particles shrinkage measurement	1st in-pile launching before M33 - EU particles 1st diametral measurement before M42 - Japanese (J) & Korean (K) materials launched too - contribution to GIF	48	Final fluence decreased in case of difficulty with EU objects providing or device manufacturing or irradiation running or materials activation after irradiation or... But no delay accepted due to J or K providing difficulties
FT3	Safety Testing and Post Irradiation Examinations (PIE)	EU1 bis: KÜFA tests	EU1 bis : KÜFA tests completed	36	EU1 bis & EU1 : no specific difficulties anticipated for tests & exams after those FP5 irradiations unless alea with laboratories devices (if
		EU1: PIE and KÜFA tests	EU1 : PIE completed	36	
			EU1 : KÜFA tests completed	42	

					so : possible delay to M48)
FT4	Fuel modelling	Models development	statistical approach: 1st identification of key parameters for in-pile leakage risk evaluation	6 (report issued M12)	not necessary
			deterministic FP release study: achievement of predictive calculations and uncertainty discussion	12 (report issued M18)	not necessary
			statistical approach: 2D modelling	24	delay
			models and properties update	24	no update until new reliable data are available
			statistical approach: description	36	delay
			codes qualification	48	continue within FP7 - if necessary plan experiments dedicated to specific issues
		Database development	BN past experience results gathering	12 (draft report M24)	not necessary
			users satisfaction regarding base upgrading and maintenance	24	take into account users remarks and make required improvements consistent with funding
			all data made accessible on the web site	48	data available at least in report form for some of them
ML	Near term deployment: meeting Generation 4 targets	Select and identify material limits of suitable (manufacturability) key VHTR components for the required environment (e.g. vessel steel, heat exchanger & turbine, core) – in-conjunction with components activities.	Material selection issues addressed in deliverables. No suitable industrially developed material available for IHX at 950 C.	year2 & 4	Programme of IHX test work includes some initial development work on ODS and TiAl materials.
		Establish full fluence data curves for potential graphites at VHTR temperatures and interpret these for use in parts of the VHTR core.	preliminary curves to be established for priority gra-hites at 750 and 950 C	48	Latest graphites added to second phase of tests. Prolongation of experiments to achieve improved data

		Establish guidelines for near term application of data results on new materials (metallic & C-based).	Initial draft of Guidelines to be based on UK experience.	48	Guidelines being developed in conjunction with ASME Code Committee.
		Identify and prioritise remaining issues and tests to confirm suitability (near term) – successful collaboration within Generation 4 to minimise R & D	programme to establish a set of curves over a range of temperatures (between 600 and 1100 C)	48	A few additional data points at alternative temperatures included in 750 and 950 C tests
ML	Longer term (near term limits not satisfied)	Development of materials capable of meeting more aggressive limits & environment (includes C/C Composites (Control Rod) – ceramics, microscopic and macroscopic architecture, metallics (advance temperature limits of key VHTR components. N.B For this the Extremat-IP provides an important input.	Microstructural modelling activities to understand behaviour and key parameters. Feedback from EXTREMAT developments - industrialisation potential for Fission components	48	Longer term input from collaboration within Generation IV and from Fission-Fusion exchanges.
CT	The main objectives are to develop innovative technologies for the main components and systems of a V/HTR, accounting for strong requirements on system competitiveness, acceptability and safety	IHX design	Compactness Integrity Thermal efficiency	36 48 48	Recommendations on the allowable temperature limit for the IHX. Increase of the IHX size (reduction of the compactness) Different materials for low and high T stages
		Gas circulator design	Efficiency MB capabilities Power	36 and 48	Limitation of the size of the machine (state of the art around 4 MW). Several blowers in // for a large power HTR (600 MWth). Electric motor located outside the vessel and with a rotating seal for the shaft.

		Tribology	Test results (friction wear fretting)	36 and 48	Re-orientation of the programme on new materials Modifications of the design (to avoid sliding at high T).
ST1	Validation of thermalhydraulic codes : comparison between system-wide analysis codes	Write benchmark definition	Availability of experimental results by HE-FUS3/EVO loops	year 2	Limit the exercise to one set of data Explanation of the discrepancies (limit conditions not well-defined, code weaknesses) Recommendations for the improvement of the code models.
		Build models in partner's respective codes	Transient modeling capability	year 3	
		Write benchmark report containing results and comparison	Successful comparison of the evaluated codes results	year 4	
ST2	Fission products phenomenology	Understanding of the phenomenon's. Development of theoretical models	Identification of the data that are still missing and of experiments that should be done in the future..	year 4	
ST3	Air ingress experiment	Realisation of a controlled experiment Understanding of the phenomenon's.	Test conditions are controlled. Experiment follows the expected scenario	year 3	Preliminary tests show the feasibility. If the experiment should fail, determination of the conditions to be improved for a future tentative.
ST4	Air ingress experiment – models validation	Successful prediction and reproduction of the test results (pre- and post-calculations)	Explanation of the discrepancies (not well-defined test conditions, inaccurate measurements)	year 3	
			Recommendations for improvement of the code models.	year 4	
ST5	Safety Approach	Achievement of a common position.	Identification of the reasons and of the points of disagreement.	year 4	
SI1	Reference plant design data		Balanced delivery of sufficiently detailed boundary data from both "block" and "pebble" projects.		Data from available publications related to VHTR applications
SI2	Core design – Parameter investigations		Feasibility of design solutions to further increase the core outlet temperature		Explanation of limitations, recommendations for further investigations.

SI3	Overall integration		Effective contribution from all sub-projects		No
PM3	Knowledge dissemination	Execution of the 3 EUROURSE seminars	more than 40 participants, participants overall satisfaction >75%	M23, M31, approx. M40	Not necessary at this point