EUROPEAN COMMISSION
5th EURATOM FRAMEWORK PROGRAMME 1998-2002
KEY ACTION : NUCLEAR FISSION

HTR-M1

European Project for the development of HTR Technology - Materials for the HTR

CONTRACT N°

FIKI-CT-2001-00135

Request for HTR-M1 Contract Extension from the Partnership

D.E. Buckthorpe

NNC Ltd.

UK

Dissemination level : CO
Document Number: HTR-M1 05/03 P 0 0 37

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Adding value through knowledge

Our ref : 7139-DB-JB
Your ref :

8 March 2005

Dr. Sylvie Casalta
Research Directorate J: Energy
Unit 4: Nuclear Fission and Radiation Protection
European Commission
Research Directorate-General
75, rue Montoyer (5/47)
B-1050 Brussels

Dear Sylvie

HTR-M1 programme Justification and agreement of the HTR-M1 co-ordinator to the request for an extension of to end of December 2005.

Please find attached the information you requested regarding the HTR-M1 Project request for extension of the HTR-M1 programme to the end of December 2005.

Justification & programme

This is given in Atachment1. The principal reason for the extension is to enable the work being done on graphite irradiation by NRG to be fully completed and reported within the HTR-M1 project. The work could not be done in the original time frame because of a decision to include more specimens in the experiment, and because of the extra care needed in preparation/ pre-characterisation to make sure the rig and specimens were capable of being reloaded for the higher dose in the 6th framework programme.

The irradiated samples are due to be removed from the core of HFR in April 2005 and following a period of cooling will undergo post irradiation examination (PIE). The results of that examination will be reported in December 2005. This is the first phase of the 750°C graphite irradiation work (up to 8dpa), which is planned to continue in 2006 within the VHTR-IP up to full fluence levels of around 25 dpa. Note that a further irradiation will also take place within the VHTR-IP at a much higher temperature (~950°C) and this will be the focus of the early part of the VHTR-IP work. The late finish of the current irradiation has already been taken into account in the planning of the VHTR-IP programme.

Revised table of deliverables

These are given in Tables 1 & 2

Cont ....

.... Cont/2

New budget breakdown

There is no change to the budget at the moment, but discussions at the next Progress Meeting may lead to some minor adjustments

References

1. D.E. Buckthorpe, et al.
European Project for the development of HTR Technology
Minutes of 7th HTR-M plus HTR-M1 Progress Meeting
Report No. HTR-M1-04/06-M-0-0-93

2. D.E. Buckthorpe, et al.
European Project for the development of HTR Technology
Minutes of 8th HTR-M plus HTR-M1 Progress Meeting
Report Mo. HTR-M1 04/11 M 0 0 24

3. E-mail message to S. Casalta from D. Buckthorpe dated 3rd December 2004.

Agreement of the Co-ordinator to the extension

Please accept this letter as confirmation of my agreement to the extension of the HTR-M1 programme to 31st December 2005.

Yours sincerely

Derek Buckthorpe
HTR-M1 Co-ordinator

Table 1. Revised HTR-M1 Deliverables list (WP1)

Deliverable No	Deliverable title	Delivery date	Current planned	Date Achieved	Main Organisation
D1	Report on selection of materials & testing requirements	12	01/10/2002	11	CEA
D2	Report on specimen fabrication and procurement & testing requirements	18	01/04/2003	17	CEA
D3	Intermediate report on material testing	47	31/07/2005	-	CEA
D4	Final report on blade alloy properties	51	31/12/2005		CEA
D5	Review of results and updating of data base	51	31/012/2005	Suppressed not needed	CEA
D6	Final Report summary	51	31/12/2005	-	FRA

Table 2. Revised HTR-M1 Deliverables list (WP2)

Deliverable No	Deliverable title	Delivery date	Current planned	Date Achieved	Main Organisation
D7	Report on selection of graphites and testing requirements	12	01/10/2002	14	NNC
D8	Report on specimen fabrication and procurement	18	01/04/2003	18	NRG
D9	Report on irradiation and post irradiation tests	51	31/12/2005	-	NRG
D10	Review of results and updating of data base	51	31/12/2005	-	NRG
D11	Assessment of results and suitability	51	31/12/2005	-	FZJ
D12	Final Report Summary	51	31/12/2005	-	NNC

Figure 1 Revised programme for HTR M1 Graphite Irradiation tests

	April	May	June	July	August	September	October	November	December
End of graphite Irradiation Experiment	■								
Cooling and dismantling		■							
Post irradiation testing (Screening): • Mass • Dimensions • Thermal Diffusivity • Thermal Expansion •			■	■	■	■	■	■	
Reporting								■	■

Attachment 1

Justification for HTR-M1 extension plus revised programme

A key feature of existing and future high temperature reactors is the use of industrial graphite for the neutron reflector. It was recognized that graphite grades used in nuclear plants in earlier decades are no longer available and new grades and associated data plus a qualification programme has to be established for new nuclear graphites envisaged for future Very High Temperature Reactors (VHTR's). A major part of the HTR-M1 programme is this re-establishment of experimental facilities within Europe plus the completion of a first phase of irradiation tests (with PIE) on graphites recommended by manufacturers for the VHTR. This work is being done by NRG with the use of the High Flux Reactor at Petten. Several grades of graphite are being irradiated at a temperature of 750°C up to fluence equivalent to around 8dpa (11 to 15 HFR cycles). The second phase of the work is planned to continue in 2006 as part of the VHTR-IP up to the completion of full fluence level of 25 dpa.

The work includes development of the loading rig (INNOGRAPH1), pre-characterisation of the test pieces, installation and removal of the loaded rig from HFR plus PIE in shielded facilities. The work could not be done in the original time frame because during the programme it was decided to include 200 instead of 150 specimens in the irradiation experiment. In addition the design of the irradiation experiment took more time because of the need to take account of the re-irradiation of the specimens to a higher dose in the 6th framework programme. Keeping the specimens as clean as possible and making the rig loading as easy as possible were aspects that needed extra attention.

The revised schedule for completion of the graphite irradiation work is shown in figure 1. It is planned to move the dates for the deliverables from the graphite irradiation work (D9 to D12) to the end of December 2005. The revised dates for the remaining deliverables from this work package are shown in table 2.

The programme extension also enables the creep tests on blade alloys started within HTR-M (long term tests + condition denoted as I_{mod} in the test matrix) to be completed in addition to the planned HTR-M1 tests (creep and tensile properties after long term ageing for IN 792). A revised schedule for this is given in attachment 2. The revised dates for the remaining deliverables from this work package are shown in table 1.

The need for the extension was discussed at the May 2004 HTR-M/M1 progress meeting following confirmation from NRG of the loading of the specimens in HFR in February 2004. This need was subsequently indicated at an HTR-C meeting in July 2004 and the final agreement with all partners confirmed at the November 2004 HTR-M/M1 meeting. An e-mail message was sent to Mrs. Sylvie Casalta on 3rd December 2004 to formally convey the request and asked for confirmation of the procedure and information required.

Attachment 2

Updated programme on turbine materials for HTRM-1 extension

CEA Activities on turbine blade materials.

CEA work is focused on tensile and creep evaluation of two turbine blade alloys : CM 247 and IN 792. Some work was already done on these grades within HTRM project.

An extension of HTRM1 project up to the end of 2005 would allow:

- 1) CEA to finish creep tests on blade alloys started within HTR-M (long term tests + condition denoted as I_{mod} in the test matrix).
- 2) CEA to finish the work initially planned within HTR-M1 (creep and tensile properties after long term ageing for IN 792).

The detailed technical work will include :

1) HTRM-1 test matrix on IN 792 DS aged **5000 h** at 850°C : 4 tensile tests (20-750-800-850°C) + 2 creep tests (1000h).

2) HTRM-1 test matrix on IN 792 DS aged **8000 h** at 850°C (ageing ends in 02/05) : 4 tensile tests (20-750-800-850°C) + 2 creep tests (1000h).

3) From HTRM program : 3 long term creep tests on IN 792 and CM 247 (9000h) are still in progress. These tests will be stopped and analysed, and the data will be entered in the database.

4) From HTRM program for condition I_{mod} (corresponding to the initial heat treatment + the 1000h/950°C thermal cycle associated with carburization performed at JRC) :

- 4 tensile tests (20-750-800-850°C) on both CM 247 and IN 792
- 2 creep tests at 850°C on both CM 247 and IN 792 (1000-3000h)

Deliverables :

As the test will continue up to the end of 2005, we suggest to modify the CEA deliverables as following :

- D3 : intermediate report on mechanical testing : 07/05
- D4 : Final report on blade alloy properties (+ comments on the update of the JRC database) : 12/05.
- D5 : suppressed (the data are sent to JRC on a CD-Rom and no specific report is needed for this part of the work)

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NNC
Adding value through knowledge

Our ref : 007138DC-JB
Your ref :

8 March 2005

Extension of the HTR-M1 Programme

There is a requirement for an extension of the HTR-M1 programme because of delays to the graphite irradiation program at NRG in Petten.

NNC agrees to requesting an extension of the HTR-M1 programme to DG RTD, in time only, until 31.12.2005.

Frazer don Carolis

Frazer don Carolis
General Counsel &
Company Secretary

NRG
AN ECN KEMA COMPANY

NNC Limited
Attn. Mr. D.E. Buckthorpe,
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Petten, 7 March 2005

our reference : 20787/05.65503 FCS/LR/lr
your reference : HTR-M1 (FIKI CT2001-0135)

subject : Extension of HTR-M1 Programme

Dear Mr. Buckthorpe,

We understand there is a requirement for an extension of the HTR-M1 programme because of delays in the graphite irradiation and the need to include all the results from the graphite irradiation test work.

NRG agrees to your requesting an extension of the HTR-M1 Programme to EU DG RTD until the 31.12.2005.

Yours sincerely,

A.M. Versteegh
Director

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Booths Hall, Chelford Road
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UNITED KINGDOM

For the attention of Derek BUCKTHORPE

Grenoble, 2005 march 7th

N/Réf : LITEN/BC/05-093 / yhd
Objet : Contract n° FIK1-CT-2001-00135
Extension of HTR-M1 Programme

Dear Mr. Buckthorpe,

We understand there is a requirement for an extension of the HTR-M1 programme because of delays in the graphite irradiation and the need to include all the results from the graphite irradiation test work.

CEA agrees to your requesting an extension of the HTR-M1 Programme to EU DG RTD until the 31.12.2005.

Yours Sincerely

Anne FALANGA
Director of CEA/LITEN

Commissariat à l'énergie atomique
Centre de Grenoble - 17, rue des Martyrs - 38054 Grenoble Cedex 9
Tél : (33) 04 38 78 32 26 - Fax : (33) 04 38 78 51 32 – Courriel : yves.hussenot@cea.fr

EMPRESARIOS AGRUPADOS

EMPRESARIOS AGRUPADOS
INTERNACIONAL, S.A.

Magallanes, 3 28015 Madrid - España
Tel. (34) 91 309 81 00 Fax (34) 91 591 26 55

7 March, 2005
Ref.: 092.105-C-EA-SV-05/0001

NNC
Booths Hall, Chelford Road
Knutsford
UK-WA 16 8QZ Cheshire

Attn.: Mr. Dereck Buckthorpe

EXTENSION OF HTR-M1 PROGRAMME

Dear Mr. Buckthorpe,

We understand there is a requirement for an extension of the HTR-M1 programme because of delays in the graphite irradiation and the need to include all the results from the graphite irradiation test work.

EMPRESARIOS AGRUPADOS INTERNACIONAL, S.A. agrees to your requesting of an extension of the HTR-M1 Programme to EU DG RTD until the 31.12.2005.

Yours Sincerely,

Adolfo García Rodríguez
Managing Director

AREVA

N N C Limited
Booth hall
Chelford Road
Knutsford
CHESHIRE WA16 8QZ - ENGLAND

For attention to Mr BUCKTHORPE

N/Réf. : NFPVED LT 05 0075

Affaire suivie par : B. RIOU s/c de M. SPERANDIO

Téléphone : 04 72 74 73 60

Télécopie : 04 72 74 73 25

Lyon, 7th march 2005

Objet : Extension of HTR-M1 Programme

Dear Mr. Buckthorpe,

We understand there is a requirement for an extension of the HTR-M1 programme because of delays in the graphite irradiation and the need to include all the results from the graphite irradiation test work.

FRAMATOME-ANP agrees to your requesting an extension of the HTR-M1 Programme to EU DG RTD until the 31.12.2005.

Yours Sincerely,

B. RIOU

FRAMATOME ANP
Une coentreprise AREVA et Siemens
ETABLISSEMENT DE LYON
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Forschungszentrum Jülich

in der Helmholtz-Gemeinschaft

Forschungszentrum Jülich GmbH · 52425 Jülich
Fracht-/Paketanschrift: Leo-Brandt-Straße · 52428 Jülich

Natioanl Nuclear Corporation
Mr. D.E. Buckthorpe
Booths Hall
Chelford Road
WA16 8QZ KNUTSFORD, CHESHIRE

United Kingdom

- Ihr Ansprechpartner: Anne Bosch
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- Telefon: 02461 61- 4236
- Telefax: 02461 61- 2118
- E-Mail: a.bosch@fz-juelich.de
- http://www.fz-juelich.de

Jülich, March 7, 2005

Extension of HTR-M1 Programme

Dear Mr. Buckthorpe,

We understand there is a requirement for an extension of the HTR-M1 programme because of delays in the graphite irradiation and the need to include all the results from the graphite irradiation test work.

Forschungszentrum Juelich GmbH agrees to your requesting an extension of the HTR-M1 Programme to EU DG RTD until the 31.12.2005.

Yours Sincerely
Forschungszentrum Jülich GmbH

i.V. [signature] i.A. Anne Bosch [signature]

Dr. Wolfgang Jaek Anne Bosch

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE
Institute for Energy
Institute Director

Petten, 1 March 2005
HFR/KT/HR D(05)4769- DIR73

Dr. Derek Buckthorpe
NNC Ltd.
Booths Hall
Chelford Road
Knutsford
Cheshire WA16 8QZ
U.K.

Subject: Extension of the HTR-M1 Programme

Dear Dr Buckthorpe,

I understand the requirement for an extension of the HTR-M1 programme because of delays to the graphite irradiation program at NRG in Petten.

We agree to your requesting for an extension of the HTR-M1 programme to DG RTD, in time only, until 31.12.2005.

K. TÖRRÖNEN

CC: R. May, M. Fuetterer, J. Rantala, O. Petre, M-A Deleglise

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ANNEX I

“DESCRIPTION OF WORK”

Materials for the High Temperature Reactor - extension of HTR-M activities

HTR-M1

PROPOSAL N°: **FIS5-2001-00028**

CONTRACT N°: **FIKI-CT-2001-00135**

PROJECT COORDINATOR: **NNC Ltd.**

CONTRACTORS:

Framatome s.a.	**F**
Commissariat a Energie Atomic `	**F**
European Directorate General Joint Research Centre	**NL**
Nuclear Research and Consultancy Group	**NL**
Forschungszentrum Juuelich GmbH	**D**
Empresario Agrupados Internacional s.a.	**E**

DURATION: **5142 MONTHS**

Project Summary

The need for reliable material data and properties is a key issue in the development of any innovative reactor technology and is especially important for those areas where safety considerations are upper most. A project to investigate materials for the High Temperature Reactor (HTR-M) is currently underway to examine the material requirements for the main safety related components and to provide an understanding of the behaviour and manufacturing requirements for some of the new materials that will be needed for such developments. This project will extend the materials platform further with a special emphasis on the effects of creep and irradiation damage focusing specifically on the high temperature materials for the turbine and selection of graphite for the core.

The work programme considers two Work-Packages:

WP1 investigates the materials for the high temperature regions of the helium turbine (discs and blades). Short term tensile and creep tests are planned within HTR-M as part of the material selection process to identify most promising material options. The HTR-M1 work looks at the intermediate term creep effects to confirm the suitability of the alloys chosen for longer-term high temperature exposure. Testing is planned at temperatures up to 850^{o}C with testing times up to 10^4 hrs. The expected number of tests will cover specific grades, fabrication routes and heat treatments. Tests will also be carried out on aged material. ~~Damage~~ Aanalysis ~~and lifetime modeling~~ will be performed and the results incorporated in the developing HTR-M database. The HTR-M1 project will also take benefit from the parallel work being performed within the HTR-E project on the turbine. The HTR-E project will provide complimentary information and expertise on turbine operating conditions and manufacture and the presence of the turbine manufacturer within the HTR-M and HTR-E projects will ensure compatibility and a consistent and smooth extension of understanding into longer term creep behaviour.

WP2 will focus on graphite selection since most of the graphites used in previous core designs are no longer available commercially or appear unsuitable. Most graphites used in previous core designs are no longer available because the coke used as the raw material has either run out and the manufacturer's experience lost, or production techniques and equipment no longer exists within Europe or elsewhere. The work of HTR-M will provide a review of current and past graphites and some initial steps towards selection. HTR-M1 will take that further and involve discussions and investigations with possible suppliers of graphite who are willing to participate in further development and short listing of a graphite for the HTR. The work covers the procurement of test pieces for tests to be carried out in the Petten High Flux Reactor to verify the physical and mechanical properties. The tests are performed over a three-year period. Evaluation of the tests will include extrapolation to higher doses making use of the results from the HTR-M material database as a basis for estimation. A task with a limited effort will also assess the feasibility of corrosion and irradiation resistant coating on fuel matrix material to reduce the danger of graphite burning in the case of air ingress. Similar activities are ongoing in China and Japan and cooperation with these groups in this area is under negotiation. This WP will serve to re-install graphite irradiation and qualification methods within Europe while the available experience and facilities exist.

The HTR-M1 project therefore provides:

Information on medium term creep behaviour of the most promising candidate turbine alloy
Information on the physical properties of candidate graphites under irradiation

Improved information for the materials data base
Identification and confirmation of materials for further R& D
A broadening of the materials R& D programme to involve manufacturers.

TABLE OF CONTENTS

Note: Additional chapters and especially sub-chapters are added in accordance with the resulting structure of the "Description of Work"

1. Objectives

This project is part of a European project of development of High Temperature Reactor (HTR) technology. The HTR related projects are:

- HTR-C Co-ordination and synthesis
- HTR-M / M1 Materials
- HTR-F / F1 Fuel technology
- HTR-N / N1 Reactor physics
- HTR-L Licensing
- HTR-E Components

The objective of HTR-M1 is the further development of materials information for the turbine (blade & discs) and graphite core. HTR-M1 is an extension of HTR-M addressing issues that were not possible to address in the first call due to budget and scheduling constraints. The addressed are medium term creep behaviour of turbine materials and selection and irradiation properties of graphite material for the core.

The development of Advanced HTR concepts requires material data information and an understanding of material behaviour under representative reactor operating conditions. Key issues with regard to material validation remain to be solved for the modular concepts of the high temperature reactor (HTR) in the areas of high temperature steels for turbine discs and blades and for the primary circuit graphite. Creep and deformation under high temperature and irradiation are important mechanisms to be taken into consideration in the material selection for these areas.

For the materials of the turbine blades and discs, creep along with fatigue is the most significant mechanism affecting failure and gross deformation. Temperature gradients and imposed mechanical loads give rise to stress and distortions which may result in creep and creep/ fatigue induced damage and cracking or failure. The influence of irradiation may also lead to a reduction in creep strength for these materials. The situation for the graphite is more complex because it undergoes dimensional change when subjected to fast neutron irradiation, the amount depending on the cumulative irradiation dose and irradiation temperature. Since dimensional changes will vary spatially within the graphite components, differential strains and hence stresses arise and the components distort. Fortunately, creep (which is irradiation induced) relaxes the strains and hence stresses, but has little effect on overall component distortions which have to be accommodated by the graphite and interfacing structures. Fast neutron irradiation also affects many of the physical properties of graphite such as strength, coefficient of thermal expansion (CTE) and thermal conductivity. The variation of CTE within a component can give rise to significant thermal stresses when the reactor cools down, and these together with any stresses due to external loading, are additive to the irradiation induced stresses already present.

The objective of this proposal is to focus specifically on the materials used in these two areas under the specific considerations of creep, deformation and irradiation. Such considerations are not covered in the ongoing HTR-M project and are considered to be an additional fundamental requirement to the HTR-M ongoing activities and necessary within the 5th FW time scale in order to validate the material selections.

The components of the primary circuit operate at temperature above 600°C and up to 950°C in order to reach high-energy efficiency. A significant effort in terms of alloy development is required for the highly stressed turbine components. The current HTR-M project focuses on selection based on a review of current and previous experiences and evaluations based on short term tests (tensile, short term creep, creep / fatigue) in air and helium. Such testing will provide a valuable pre-selection for the material and lead to the short listing of most likely candidates. However further intermediate term creep testing and lifetime analysis will be required as a pre-qualification of the material choices and as a pre-cursor to understanding requirements and the effects of ductility and embrittlement in longer tem tests (>$3x10^4$ hours) necessary to validate the materials. This proposal will focus on such tests and ~~damage~~ analysis ~~and lifetime modeling~~ for the super alloys to be chosen to ensure safe working for long operating times.

The need for reliable graphite data is a crucial issue for existing and any new HTR projects in Europe. Graphite plays an important role as a moderator and structural component and has important safety implications because of structural and other property changes that occur when it is irradiated. Its selection also has important consequences for future decommissioning activities. Specialist information and experience are scarce. Most of the European experts familiar with past work and the existing sources of information have retired or are no longer available. The situation is made more acute because of the scarcity of high flux reactors to perform any new testing (the high cost of testing also makes the already existing data very valuable). The current HTR-M project provides a limited review of existing graphite information. It will establish a database from available and accessible data sources so as to identify gaps in data and testing requirements. Many of the graphites used in previous core designs are no longer manufactured commercially, and currently available grades of graphite are limited to a few specific sources of raw materials. Very few of the grades may turn out to be suitable or desirable for a European based modular HTR and discussions will be held with graphite manufacturers to investigate the possibility of producing small quantities of alternative graphites (in the laboratory) which would have a better combination of desirable properties. The current project will be completed in one year, at which point an initial selection of candidate graphites for use in future HTRs will be made. However this latter activity falls far short of the ultimate selection criteria for the graphite, which will mainly be based on long-term irradiation behaviour. There is therefore an immediate need to begin the groundwork for final graphite selection while the expertise and facilities are available in Europe. This proposal therefore focuses on initiating an irradiation programme on chosen graphites to determine the variations in their physical and mechanical properties up to low/medium irradiation doses (making use of the results from HTR-M as a basis for estimation and extrapolation to higher doses). The proposal will establish the groundwork for continuation of the irradiation programme on the most desirable graphite(s). It will make use of valuable diminishing experience from experts in design, experiments and testing of graphite within Europe serving to reinstall graphite irradiation and qualification methods within Europe while the available experience and facilities exist.

In summary the main objectives are the:

- Substantiation of material choice for turbine blades and rotor
- Selection and irradiation properties of graphite for primary circuit components

The work will be performed taking advantage of existing international collaboration projects in this field and archiving of existing know-how will continue from established data bases of material information.

2. Project work-plan

2.1 Introduction

The key objectives of this HTR-M1 project are to collate and obtain material data and information necessary for the development of advanced HTR's. The project concentrates on key areas affecting feasibility:

- high temperature materials of the turbine
- graphite structures under irradiation and oxidation

To achieve these objectives an overall work plan has been formulated as shown in Figure 2.

The programme covers a period of 5142 months.

2.2 Overview of Project Work Plan

The overall project work plan in Figure 1 gives the planning in terms of two work package areas split according to the type of materials and conditions experienced on the HTR. They include issues associated with obtaining reliable HTR material data for steels and graphite taking account of HTR environment (irradiation damage and temperature), loading, fabrication (welding), and degradation. The complete package is aimed at selection and confirmation of materials and supporting the developing database of HTR-M for the key component areas for feasibility investigations on future innovative concepts.

This proposal is part of a European project of development of High Temperature Reactor (HTR) technology:

The key objectives of this HTR-M1 project are the substantiation of material selection for turbine blades and rotor and the selection of graphite for primary circuit components. The proposal concentrates on key areas affecting feasibility (see section B3):

To achieve these objectives an overall work plan has been formulated as shown in Figure 1 and an outline of technical co-ordination given in Figure 2. Detailed planning is shown in terms of individual activities associated with two Work Packages.

The work involves seven partners. The work packages have been split according to the type of materials and conditions experienced on the HTR. They include issues associated with HTR material data for steels and alloys and for graphite taking account of HTR environment (irradiation damage and temperature), loading, fabrication (welding), and degradation. The complete package is aimed at the substantiation of material selection for turbine blades and rotor and graphite components. The co-ordination task will be performed by NNC Ltd who will organise the meetings and ensure overall technical and managerial co-ordination of the project and a central focus for exchange and communication of information.

2.2.1 Turbine Materials

Time independent and time dependent strength at elevated temperature are important requirements for materials of turbine blades and discs. The time independent property needs are being addressed in HTR-M to provide a first selection of the most favourable alloys, processes, microstructure, etc. The time dependent properties are being addressed mainly in the HTR-M1 project, which extends and supports the alloy selection by focussing on creep strength using intermediate creep tests with lifetime assessment models to establish the suitability of chosen alloys for long operating times. It is important to start some longer term tests early to obtain first results within a few years and develop life time methods (based on mechanical testing and micro structural evaluations) for prediction and extrapolation. CEA will co-ordinate the work

Creep and deformation are important mechanisms that must be taken into account in the development of materials for the HTR turbine discs and blades. Short listing of available alloys to provide the selection of the manufacturing processes, alloy grades and heat treatments is underway in HTR-M. This is being done through a review of current and previous experiences and short-term tests (tensile, short-term creep, creep / fatigue) in air and helium. However intermediate creep testing (up to 10^4 hrs) and lifetime analysis will be required to understand requirements and confirm the suitability of selected alloys for longer term tests (> $3x10^4$ hours) necessary to validate the materials for long operating times.

Note that the selection process within HTR-M is based on preliminary design information provided by Framatome, with more detailed specifications (fluctuations, environment) obtained through the HTR-E project. The turbine manufacturer Aubert & Duval (who have expertise on alloy compositions and industrial manufacturing capabilities, elaboration of small scale ingots) is participating in both the HTR-M and HTR-E projects and therefore has an active role in the material selection in HTR-M. HTR-M1 will focus on intermediate creep material testing of the HTR-M selected materials and material lifetime modeling under HTR conditions concentrating on the blade material (where the temperature and stresses are the highest).

Review materials and testing needs

The first task therefore is to confirm and review the selection of the alloys and possible suppliers and specify intermediate term tests to be performed. These activities will be carried out within the first six months of the project in order to procure the material in time to complete the tests within the programme. The task to define the testing requirements will utilise experience in design, experiments and test piece manufacture led by CEA and cover any preparatory work required for the test equipment. Aubert & Duval participation in the HTR-M and HTR-E projects will provide the necessary materials information to review and support the intermediate creep tests as described below. Information from HTR-E will be sought to substantiate the test programme selection and conditions.

Material procurement and test piece manufacture

Procurement of test pieces, machining and performing of tests will be carried out by CEA & JRC, who together with Framatome & EA will bring specific experience in creep testing and requirements of alloy steels in air and helium for turbines at temperatures up to 850°C and testing times of 10^4 hrs. Existing material samples from HTR-M will be used where appropriate and where possible. The Material procurement will focus on the blade material and specimen machining is expected to cover 1 / 2 grades, 1 fabrication route, 1/2 heat treatments.

Intermediate creep tests and testing after ageing

The intermediate creep tests will cover medium term creep tests (up to 850^{o}C and 10000 hours) of as received material. Approximately 10 tests will be performed. These tests are simple but time consuming for the creep machines. These tests are additional to the creep tests in HTR-M rather than extensions to them. They evaluate the stress to failure over a longer time period. Although some creep / fatigue tests are performed in HTR-M these will only be with short term dwells and not address creep strength for time periods of up to say 1h.

Mechanical tests (2/3 tensile + 2/3 creep tests per material batch) will also be carried out on aged material (equivalent to up to 10,000 hours ageing) to confirm its suitability to long term exposure at temperature.

~~Damage analysis and modeling~~

~~Damage analysis will be performed mainly by CEA in conjunction with JRC and EA and include development of a theoretical life prediction model following micro-structural evaluation. Approximately 10 specimens will be used for this analysis. The use of specially designed specimens (axisymmetric notched samples) that allow a correlation with finite element calculations will enable theoretical damage models with various stress triaxiality ratios to be used together with SEM imaging of fracture surfaces from the creep tests.~~

Synthesis and up dating of data base

This activity includes the summarising of the work and the introduction of the findings and test data into the developing HTR materials database. The activity will cover any new information obtained and the data from the alloy samples tested within the HTR-M1 project. The work on the database will be performed mainly by NNC who is leading the data base development within HTR-M.

The work on turbine materials will yield the following results:

- Substantiation of alloy selection for blades & discs.
- Procurement of material and testing at high temperature and intermediate times for a selected grade, fabrication route and heat treatments for HTR design / feasibility.
- ~~Damage a~~Analysis and lifetime assessment ~~modeling~~ for HTR relevant conditions.
- Assessment for long term exposure (ageing) and its effects on structural stability for HTR relevant conditions.

2.2.2 Graphite

The work package on graphite will focus on substantiation of selection and the performing of tests to establish the variation in physical and mechanical properties under irradiation doses. NNC will co-ordinate the work.

Most of the graphites used in previous core designs are no longer manufactured commercially or available because the coke used as the raw material has either run out and the manufacturer's experience lost, or production techniques and equipment do no longer exist within Europe or elsewhere. Neither the natural Gilsonite coke or the coke for the former exhaustively tested German reference graphites and for the UK fuel sleeve graphite that came form the coking plant (VfT) are still disposable (this coking plant was closed more than 10 years ago due to environmental reasons). A new source with a similar coke was found in Japan from which graphite could be produced suitable for the production of fuel sleeves for AGRs. However, the working conditions as well as the production methods for these tubular graphite components are very different and possibly less challenging than the requirements expected of HTR's. Also, the database on physical properties with respect to neutron irradiation is not extensive at present.

Today's HTR projects - HTTR (Japan) and HTR 10 (China) - use a Japanese graphite (IG-110). This graphite has extremely high strength however because of its brittleness which is prohibitive for very high neutron exposures it may only be considered for exchangeable core components and low neutron fluence applications. For other HTR projects presently under discussion no suitable graphite has yet been identified to have properties that have proven to be satisfactory.

Review graphites and testing needs

The first task therefore is to confirm the selection of possible graphites obtained from the HTR-M graphite property review and identify suppliers of graphite willing to participate in the further development of graphite for the HTR. The tests to be performed will be defined within the first six months of the project in order to procure the material in time to complete tests within the specified period. The number of tests will be limited (<100 in total). The task will be performed mainly by NNC, NRG and FZJ who will bring together specific experience in graphites for HTR and commercial gas cooled reactors. The task to define the testing requirements will utilise experience in design, experiments and test piece manufacture led by NRG supported by Framatome, CEA, FZJ and cover any preparatory work required for the test equipment. Representative properties include dimensional change, apparent density, electrical resistivity, thermal conductivity, thermal expansion, Young's Modulus.

Material procurement and test piece manufacture

The work on material procurement and test piece manufacture will be done following discussions with Graphite manufacturers willing to participate and work in conjunction with NRG as subcontractor in supplying suitable material for specimens for testing. Only small amounts of material will be needed and the numbers of material test specimens will be limited by the range of tests needed to be carried out. Any machining will be done in conjunction with the graphite manufacturers and NRG.

Irradiation of test specimens and post irradiation tests

The work will then focus on performing tests to verify the physical and mechanical properties of the chosen graphite. This test work will involve pre-irradiation of test pieces in the High Flux Reactor facility at Petten under low / medium irradiation doses for specified periods and temperatures followed by testing in a shielded facility to obtain physical and mechanical properties. A concrete shielded facility will be used for dismantling the irradiation rig and disposal of waste parts and a lead shielded facility for post irradiation measurements. The work will be carried out at NRG who will provide the scientific programme supported by partners NNC& FZJ as appropriate. Included will be some measurements of thermal conductivity in the FLASH facility at FZJ. The thermal conductivity is determined from thermal diffusivity measurements using a laser flash method (temperatures between 20 and 1500^{o}C). The facility is capable of measurements in vacuum, helium and an oxidising atmosphere.

Assessment of results and suitability

Assessment of the suitability of the graphites will be made by considering the effect of irradiation damage on the graphite crystal. Ideally, the graphite chosen for HTR designs should be reasonably isotropic, exhibit small dimensional change behaviour, and have a low CTE (crystal thermal expansion), a high thermal conductivity, a high irradiation creep constant, a low Young's modulus and a high strength. The problem is that many of these properties are not compatible in practice for normal commercial graphites e.g. graphites with high strength also have a high Young's Modulus. Other factors affecting the choice of graphite would be impurity levels, cost and machinability. Evaluation of the tests will performed by extrapolation of the results to higher doses making use of the results from HTR-M as a basis for estimation.

Irradiation with corrosion resistant coatings

A task with limited effort is also included to assess the feasibility of corrosion and irradiation resistant coating on graphite and on fuel matrix material to reduce the danger of graphite burning in the case of air ingress. One of the main hypothetical accidents for HTR is a massive air ingress to the primary circuit. Counter measures are needed to either limit the ingress of the air (consequences for the confinement or accident management) or by coating the graphite and fuel to avoid corrosion. Similar activities are ongoing in China and Japan and cooperation with these groups in this area is under negotiation through HTR-C actions. Good results have been obtained in Japan with respect to coating of IG-110. Corrosion and irradiation work has been done for other graphites but for the A3-3 graphite for the fuel matrix they have only been partially successful. A limited amount of work will be performed to identify ways to improve the bond of the coating on the graphite before new irradiation tests should be undertaken. Corrosion tests on the pebbles are done the CORA test facility within the hot cells at FZJ.

Synthesis of results and up dating of data base

This covers the reporting and summarising of the work and the introduction of the findings and test data into the developing HTR materials database. The activity will cover any new information on current graphites and the data from the graphite samples tested within the HTR-M1 project.

The work package on graphite will establish the groundwork on which to continue the evaluation of the most desirable HTR graphites and serve to re-install graphite irradiation and qualification methods within Europe while the available experience and facilities exist.

In summary the work on graphite materials will yield the following results:

- Substantiation of graphite selection for European HTR.
- Procurement of material and testing following exposure within the High Flux Reactor facility at Petten at temperature and intermediate dose levels.
- Estimation of suitability of physical and mechanical properties for long term exposure.
- Re-establishment of graphite irradiation and qualification methods within Europe while the available experience and facilities exist.

Figure 1 Description of Overall Work plan

WP 1	**Turbine materials**		2001	2002	2003	2004	2005
	Task	Sub-task					
	1	Review materials & testing needs					
	2	Material procurement & machining					
	3	Intermediate creep tests & testing after ageing					
	4	~~Damage a~~Analysis & asessemnt~~modeling~~					
	5	Synthesis & updating of data base					
WP 2	**Graphite**		2001	2002	2003	2004	2005
	Task	Sub-task					
	1	Review graphites & testing needs					
	2	Material procurement & test piece manufacture					
	3	Irradiation of specimens & post irradiation tests					
	4	Assessment of results & suitability					
	5	Irradiation with corrosion resistant coatings					
	6	Synthesis of results & updating of data base					

Table B1. Work-package list

Work-package No & task	Work-package title	Lead contractor No	Person-months	Start month	End month	Deliverable No
WP1	**Turbine materials**	3				
T1.1	Review of material and testing needs		3.5	3	12	D1
T1.2	Material procurement & specimen machining		6	9	18	D2
T1.3	Intermediate creep tests and testing after ageing		18.9	12	5142	D3
T1.4	Damage aAnalysis and assessment of the blade alloy resultsmodelling		6	12	5142	D4
T1.5	Synthesis & updating of data base		4	30	5142	D5 & D6
	TOTAL		38.4			

Table B1. Work-package list

Work-package No	Work-package title	Lead contractor No	Person-months	Start month	End month	Deliverable No
WP2	**Graphite selection**	1				
T2.1	Assess potential and availability of new graphites & testing requirements		6.2	3	12	D7
T2.2	Material fabrication , procurement & test piece manufacture		6	9	18	D8
T2.3	Irradiation of specimens & post irradiation tests		16	12	5142	D9 & D10
T2.4	Assessment of results and suitability		6	12	5142	D11
T2.5	Corrosion & irradiation resistant coating		2	3	12	D11
T2.6	Synthesis &updating of data base		4	30	5142	D12
	TOTAL		40.2			

Table B2. Deliverables list (WP1 on turbine materials)

Deliverable No	Deliverable title	Delivery date	Nature	Dissemination level
D1	Report on selection of materials & testing requirements	12	Re	RE
D2	Report on specimen fabrication and procurement & testing requirements	18	Re	RE
D3	Intermediate Rreport on material testing	5142	Re / Da	RE
D4	Final report on blade alloy propertiesDamage analysis & modelling	5142	Re/Da	RE
D5 D5	Results data provided on CD-RomReview of results and up-dating of database .	-4251	Re / Da Re/ Da	RE RE
D6	Final report summary.	5142	Re	PU

Table B2. Deliverables list (WP2 on graphite)

Deliverable No	Deliverable title	Delivery date	Nature	Dissemination level
D7	Report on selection of graphites & testing requirements	12	Re	RE
D8	Report on specimen fabrication and procurement	18	Re	RE
D9	Report on irradiation and post irradiation tests	~~42~~ 51	Re / Da	RE
D10	Review of results and up dating of data base	~~42~~ 51	Re / Da	RE
D11	Assessment of results and suitability	~~42~~ 51	Re / Da	RE
D12	Final Report Summary	~~42~~ 51	Re	PU

Form B3.	**Work-package description**

Work-package number :	WP 1 materials for turbine						
Partner number:	1	2	3	4	5	6	7
Person-months per partner:	2	1.5	15.0	12.9		3	4

Objectives

- Intermediate creep testing and lifetime assessment of high temperature resistant alloys (Ni base super alloys, etc…) for the turbine disc and blades.
- Evaluation of suitability / future test requirements for selected alloys and insertion in database.

Description of work:

A significant effort in alloy development is required for the highly stressed turbine components. Time independent and time dependent strength at elevated temperature are necessary requirements and HTR-M addresses material selection based on current and previous experiences and short term strength tests (tensile, short term creep, creep / fatigue) in air and helium. Time dependent (creep) evaluation is also required and intermediate creep testing and lifetime analysis is addressed in HTR-M1 as a pre-qualification of the material choices and as a pre-cursor for more long tem tests (>3x10^4 hours) necessary to substantiate the materials. The work in HTR-M1 covers:

1. Review / confirmation of alloy choice and testing needs. This will be done in conjunction with HTR-M and HTR-E and utilise turbine manufacturer experience. The test programme will cover the most likely grades / fabrication route / heat treatments.

2. Procurement of material and tests pieces performed by CEA & JRC for the specific material grades chosen and tests programme. Existing HTR-M samples will be used where appropriate.

3. Intermediate creep tests and tests after ageing on creep machines up to 850°C and 10000 hrs at JRC and CEA on as-received material. Mechanical tests, creep & tensile, (approx. 10 samples) will also be carried out for lifetime model evaluation and prediction.

4. ~~Lifetime modeling and damage a~~Assessment of the blade alloy results ~~fracture faces~~ will be carried out by CEA~~ to provide the evaluation and the means for predicting long term behaviour~~. Future test requirements for long term qualification will be identified.

5. The results of the experiments and review will be reported and introduced into the developing HTR-M data base and provide a platform for future development of the selected alloys.

Deliverables	
D1 Report on review of materials & testing requirements D2 Report on specimen fabrication & procurement D3 Intermediate ~~R~~report on tests	D4 Final report on blade alloy properties~~Damage analysis & modeling~~ ~~D5 Review of results & updating of data base~~ D5 Results data provided for data base on CD-Rom D6 Final report summary

Milestones and expected result

D1 will be available at t0+12 months
D2 will be available at t0+18 months
D3, D4 & D5 will be available at t0+51~~42~~ months
D6 will be available at t0+51~~42~~ months

Form B3.	**Work-package description**

Work-package number :	WP 2 Graphite						
Partner number:	1	2	3	4	5	6	7
Person-months per partner	8	1			19.2	12	

Objectives

- Assessment of and irradiation testing of selected graphites for HTR
- Preliminary estimation of feasibility of graphites and insertion within the data base.

Description of work:

This focuses on pre-selection and implementation of an irradiation testing programme within the High Flux Reactor (H.F.R.) facility at Petten to determine variations in their physical and mechanical properties of selected graphites up to low/medium irradiation doses. This will make use of valuable diminishing experience from experts in design, experiments and testing of graphite within Europe while the experience and facilities exist. The work is split into a series of tasks:

1. Review / confirmation of graphites and testing needs in conjunction with suppliers (e.g. SGL (European based manufacturer).
2. Procurement of material and test pieces in conjunction with NRG and graphite manufacturers for the test programme in the HFR.
3. Pre-irradiation of test pieces and post irradiation tests. NRG will provide the scientific programme and carryout post irradiation tests in their shielded facilities at Petten. Carry out thermal conductivity measurements on post-irradiated specimens in the FZJ laser FLASH facilities.
4. Assess the suitability of graphites using data results of HTR-M as a basis for estimation and extrapolation to higher doses. This will establish the groundwork for continuation of the irradiation programme on the most desirable graphite(s).
5. Perform work dealing with corrosion of A3-3 coated Pebbles at FZJ to identify ways in improving the coating. This work is a potential cooperation item within the international collaboration on HTR's with China and Japan being developed through HTR-C / HTR-TN.
6. The results of the experiments and review will be reported and introduced into the developing materials database of HTR-M and provide a platform for future development.

Deliverables	
D7 Report on graphites & testing requirements D8 Report on specimen fabrication & procurement D9 Report on tests	D10 Review of results / updating of data base D11 Assessment of results and suitability D12 Final report summary

Milestones and expected result

D7 will be available at t0+12 months
D8 will be available at t0+18 months
D9 and D10 will be available at t0+5142 months
D11 assessment of results including irradiation resistant coatings at t0+5142
D12 will be available at t0+5142 months

3. SCIENTIFIC AND TECHNICAL PROSPECTS

Economic usefulness, contribution to the competitiveness of European industry

The economic prospects for modular HTR are very favourable due to the fact that the inherent safety features offer the opportunity of minimising safety grade active systems. If the licensing criteria will be adopted to the specifics of HTR there will be a chance for significant simplification and cost reduction without affecting the safety level. A precondition for competitiveness of modern HTRs in Europe could be a European regulatory concept taking the inherent safety features of the modular HTRs fully into account. Such a development would be in line with other European initiatives and the modularity allows for standardisation and series production of components resulting in short erection periods and competitive cost. This may be the most important aspect in building nuclear power plants in future deregulated markets.

The thermal efficiency of fossil-fired plants has been considerably augmented in recent years especially by combined gas- and steam turbine cycles and by co-generation of heat and power. HTR have the potential to apply direct cycle gas turbines with thermal efficiencies near to 50%. They can also be operated in a co-generation mode like competing conventional plants and thus can open new market segments for nuclear energy in Europe and abroad.

Broader international collaboration will not only widen the basis for work-shared R&D but also for the supplier side with the possibility to chose the most cost effective offers within a defined quality assurance. This fact is broadly used in conventional power plants and will also have to be applied to make nuclear competitive in comparison to other alternatives on a global market.

Waste issues have a strong impact on the economics and acceptance of nuclear power plants. They have to be analysed in early stages of the technology development for minimising the generation of waste instead of managing waste streams later on. Several fuel cycles have to be investigated for minimising the generation of long-lived radiotoxides and/or to optimise the burning of military and civil plutonium without intermediate reprocessing. In this sense, HTR could offer a symbiosis to other reactor lines for closing the fuel cycle and reducing the stockpiles of plutonium. The fact that a simple, very safe and potentially cheap route to direct disposal of HTR fuel seems practicable has also to be confirmed.

A very positive signal on economic competitiveness of modular direct cycle HTRs has been given in South Africa with the commitment of the local Utility ESKOM to go ahead with the industrialisation of its PBMR project, even with the competition of cheap coal fired stations under South African conditions.

The large participation of European nuclear industry in international projects, in the European Project of Development of HTR Technology and in HTRTN shows that there is an increasing interest of the European nuclear industry for the industrial development of this type of reactor, both for the European market and for export.

Other sectors of industry can find an interest in the developments of some of the technologies that are planned in the proposals of the European Project. In particular the results from investigations of high temperature materials may have many applications in different sectors of industry: the fact that one manufacturer (Aubert & Duval), which is a world leader for providing materials to the aeronautics turbine industry is an assistant contractor in the Project

(HTR-M, HTR-E and HTR-C) shows that the developments planned in this field will actually benefit other industrial sectors. The development of a large power gas turbine operating at 850°C without internal cooling is a challenge and can have many applications for other types of turbines than the only HTR turbines. The development of high performance compact plate heat exchangers can also have many applications in different sectors of industry (oil, aeronautics...).

Exploitation of the results of the programme

The industrial development of new reactor systems is a long-term task, even though, as for HTRs, many aspects of the technology have been developed in the past. It can be considered that, even if some prototypes can be built earlier, a large industrial introduction of this type of reactors could be expected in Europe only after 10 to 15 years of development. Therefore it is the right time now to start the development of HTRs because, after 15 years, most of the oldest of the present gas cooled reactors in operation in Europe will reach the end of their lifetime. Such a development of a new type of reactor is a challenge and needs a broad international collaboration to overcome the threshold for market introduction.

The development of new reactor systems needs a broad international collaboration to overcome the threshold for market introduction. The establishment of international consortia including European partner organisations around the PBMR and GT MHR projects as well as the envisaged creation of a European HTR Technology Network (HTR-TN) are first steps into this direction. European licensing authorities with experience in HTR and GCR safety evaluations are also involved in the new projects. Broader international collaboration will not only widen the basis for work-shared R&D but also for the supplier side with the possibility to choose the most cost effective offers within a defined quality assurance. This fact is broadly used in conventional power plants and will also have to be applied to make nuclear competitive in comparison to other alternatives on a global market.

Moreover, in comparison to other advanced reactor systems, it is important to consider that two new HTR test reactors are actually going to be commissioned in Japan and in China. These reactors represent real technological milestones despite their power size, as they demonstrate the passive safety features of HTR module reactors and new annular core geometry as well as the use of the high temperature heat. They will provide new data to validate the codes and to reduce conservatism in the design of commercial modular HTR. Both countries, Japan and China, offer the results of their test reactors to the European side and have each signed a Memorandum of Understanding on collaborative programmes. Thus the fact that there is no European HTR in operation any more can be compensated by close international collaboration. The access to this operational data will also strengthen the trust in the HTR technology and could be a basis for a further renaissance of HTR in Europe and elsewhere.

But the participation of European organisations within international projects is not sufficient to maintain HTR technologies in Europe. The drastic reduction in HTR programmes in Europe in the last ten years and the condition of HTR projects elsewhere, suggests that there is an urgent need to conserve and advance the HTR-specific know-how that has been created with high public and industrial funds in the past. This know-how is declining or will be fully transferred to other parts of the world if no actions are undertaken in due time. Starting a common European HTR initiative now will put the leading position in this area back into European hands.

The European HTR programme proposed concentrates on HTR-related key technologies and innovation potentials that can improve the chances of HTR in the market and may offer European suppliers and organisations a basis for marketing specific innovative systems, know-how and analytical tools. This approach also ensures that European organisations strengthen the capability to design innovative HTR and to evaluate their safety and operational features. Following this strategy, European organisations will be engaged in any HTR project anywhere in the world and keep the capability to re-start own projects.

The European Projects for the Development of HTR technology concentrate on HTR-related key technologies and innovation potentials that can improve the chances of European industry if HTRs come out in the market. It will be, for European suppliers, the first step for the development of innovative industrial HTR systems. Further steps will be needed beyond the 5th Framework Programme. The creation between the partners of the European Project for the Development of HTR Technology and the Joint Research Centre (JRC) of the European Commission of the European HTR Technology Network (HTR-TN) which is now a reality will help to stabilise the European HTR partnership in the long term.

The existence of strong co-ordinated European and of the European HTR Technology Network will be very important for Europe to be considered as a major partner in international scientific or industrial co-operations. This will be a precondition to maximising benefits in terms of experience and knowledge for the European nuclear industry. This approach will ensures that European organisations strengthen the capability to design innovative HTRs and to evaluate their safety and operational features.

The strong co-ordination and the integration that will be provided by HTR-C is important to maintain a long-term consistency of the whole Project in the long term. The results of the work planned in the different proposals will be evaluated by the Steering Committee of HTR-C in the perspective of the strategic orientations of the industrial development of HTRs. Moreover the priorities for future developments to be proposed for future calls for proposals will not be defined separately in each technical working group, but by the Steering Committee in view of the objectives of the whole Project. The work of the Work Package on technical-economic synthesis will bring the main expert support to these evaluations.

Intended policy on securing intellectual property rights or granting licensing for results

At the end of the project the dissemination of the results of the work will be by the issue of the identified project reports to the Commission and the Partners in this Project and to other bodies nominated at the discretion of the Commission and the Partners. It is expected that presentations will be made to meetings and conferences as well as to other international forums, if and when the need arises. The originating partners will seek to exploit the results of this work by using them to improve reactor safety measures in their own countries and encouraging others to do so. The codes and methodologies developed within the HTR activities and the Fifth Framework Program will be disseminated amongst the partners. The results of calculations and measurements however, will be publicised on scientific conferences and in scientific papers.

The partners are not aware of any agreements or commitments that might limit or hinder subsequent use or exploitation of the results of this project.

Background information:

Each participant may disclose to other participants, on a royalty-free basis, his background information for the implementation of the European Project for the Development of HTR Technology.
But each participant shall remain the owner of his own background information. If such background information is needed by another participant for any other use than the implementation of the European Project, he should request a license from the owner of the background information on conditions to be mutually agreed upon.

Foreground information:

The foreground information generated shall be disclosed to all the participants of the European Project for the Development of HTR Technology. Disclosure of the foreground information to parties outside the European Project will be possible only subject to agreement of the SC.
Each participant or group of participants generating an invention may file a patent or take any measure to protect his invention. For any use of an invention other than the implementation of the European Project, the inventor on conditions to be mutually agreed upon could grant a license.

TIP delivery

The approach to the exploitation of results will be defined in a Technological Implementation Plan (TIP). A Preliminary Tip will be put in place at the beginning of the project, after initial consultation with the partners, and discussed at the Kick-off meeting. The TIP will be revised at mid-term and finalised on project completion. The versions to be delivered are listed in Appendix A to this Annex.

4. Project Management

The overall co-ordination of the project will be the responsibility of the **Main Co-ordinator**. A work plan and detailed schedule will be established at the beginning of the project to define the various project interfaces, input and output information, deliverables, etc. It will also identify clearly the organisations responsible for each task and sub task, so as to facilitate project progress monitoring and co-ordination of the different tasks.

All partners are experienced in performing complex multi-partner projects on a research and industrial level. They have all been already involved in European Commission funded projects as co-ordinators or partners and are acquainted with the funding and reporting regulation.

The **Main Co-ordinator** will be responsible for:

- Technical Co-ordination
- Chairing and inviting the Project Management Meetings (PMM)
- Providing and distributing the minutes of the PMMs
- Co-ordination of information exchange within the project
- Control of work schedules and deliverables
- Quality control of results
- Compilation and dissemination of final and periodic reporting
- Budget control
- Administrative matters

Work Package Managers have been assigned for each of the different work areas for:

- Technical lead in the work package
- Chairing and inviting meetings on specific work package
- Co-ordination of information exchange within the work package
- Control of work schedules and deliverables related to the work package
- Quality control of results within the work package
- Compilation of final and periodic reporting on the work package
- Administrative matters concerning the work package

Each partner will assign a permanent member to the PMM. All Work Package Managers or their deputies will participate in the PMMs and report to the PMM on the status of the work packages. The PMM decides on the main technical orientation of the project and on necessary actions to be undertaken for fulfilling the objectives of the project. Decisions will be taken on a consensual basis or two third majority votes.

Partners within the work packages decide on specific technical choices and actions concerning their work package. Notes will be taken on necessary technical and procedural modifications or adaptations by the Work Package Managers and sent to the main co-ordinator.

The flow of information within the project will mainly be done by electronic mail and complemented by the application of computer supported collaborative work tools. Final and topical reports will be prepared in consistency with EC regulations and distributed within the partnership.

There will be a kick-off meeting to ensure that there is a common understanding of their roles, the extent of their interactions, and the time scales for completion of Tasks and Sub Tasks. It will also establish a common understanding of all available information relevant to the Project. The detailed programme and contents of the work within the grouping might be adjusted as a result of this interaction. The work will be organised to ensure optimum technology transfer and fulfilment of the objectives.

4.1 Time schedule and resources

The work package managers will monitor the spending of the resources and its coherence with the time schedule. They will report the progress once every three months to the project co-ordinator who will decide whether the distribution of resources over the work packages will need adjustment.

Details of time schedule and resources are given in table 4.1

4.2 Organisation

HTR-M1 will be clustered to HTR-M in order to optimise their common management (i.e. common meetings, revised and unique schedule, single reporting etc.).

The participants will act as a project manager of their specific part of the work within their organisations. They will bear the responsibility that the work is being carried out in their specific organisations, either by themselves, or by others. They will report their technical and organisational progress to the work package co-ordinator. The work package co-ordinator may appoint task co-ordinators for those tasks where this is appropriate, e.g. for a code validation benchmark with more than two participants.

4.3 Quality Assurance

Within the Network HTR-TN quality and management strategies and the corresponding programme will be established and used for each of the technical tasks to be supported and / or controlled by the network.

The quality of the delivered work will be secured by the QA system of the participant organisations. Additionally, the work package manager and the project co-ordinator will approve the deliverable (in the form of a report) before publication as a product of the European consortium. Both the work package co-ordinator and the project co-ordinator will approve developed models and methodologies before carrying out analyses with them.

4.4 Obligations / Schedule for Meetings and Reporting

The obligations and schedule for meetings and reporting are, for convenience, summarised in Appendix A to this Annex.

4.5 Co-ordination of the Project

There will be three/ four levels of co-ordination with respect to the work organisation:

- Overall HTR project co-ordination (HTR-C) - Co-ordinators
- Overall HTR-M1 Co-ordination (NNC)
- Materials - work co-ordination - WP Leaders
- Materials - Technical discussion co-ordination - All

The attached figure2 illustrates the co-ordination between work packages, the technical co-ordination strategy and co-ordination with the current HTR-M Project and the HTR-E Project.

HTR-M1 will be "clustered" to the HTR-M project in order to optimise their common management (i.e. common meetings, revised and unique schedule, single reporting etc.).

An information meeting on the HTR-M1 project as a whole will be held once a year. Issues discussed will be the overall progress of the tasks within the work packages and the cross-fertilisation between the tasks and work packages. The project co-ordinator will take the initiative for this.

Additionally, meetings will be organised twice yearly to exchange more detailed technical information within the work package or even separate tasks. The work package managers will take the initiative for this.

Co-ordination will be done through scheduled meetings as specified in Appendix A. Four of the meetings will coincide with the organisation of HTR-C meetings. The venue for the remaining meetings will be rotated to visit the experiments (if possible) and provide the opportunity for the home company to invite any additional specialists concerned with the work or experiments (without large travel costs).

Unfortunately it is not possible to visit all the sites therefore for EA, and Framatome if they wish to invite additional technical personnel, will choose one of these sites or Paris.

If required a co-ordinators meeting will be arranged for ½ day prior to the technical discussion meeting

With regard to attendance at technical discussion meetings:

- Each WP co-ordinator will attend each meeting.
- A representative from each participating company will attend the kick-off and wind-up meetings.
- Attendance at other meetings will be according to programme and work requirements.

It may not be possible for all organisations to attend each meeting because of budget restrictions, however all participating companies are invited:

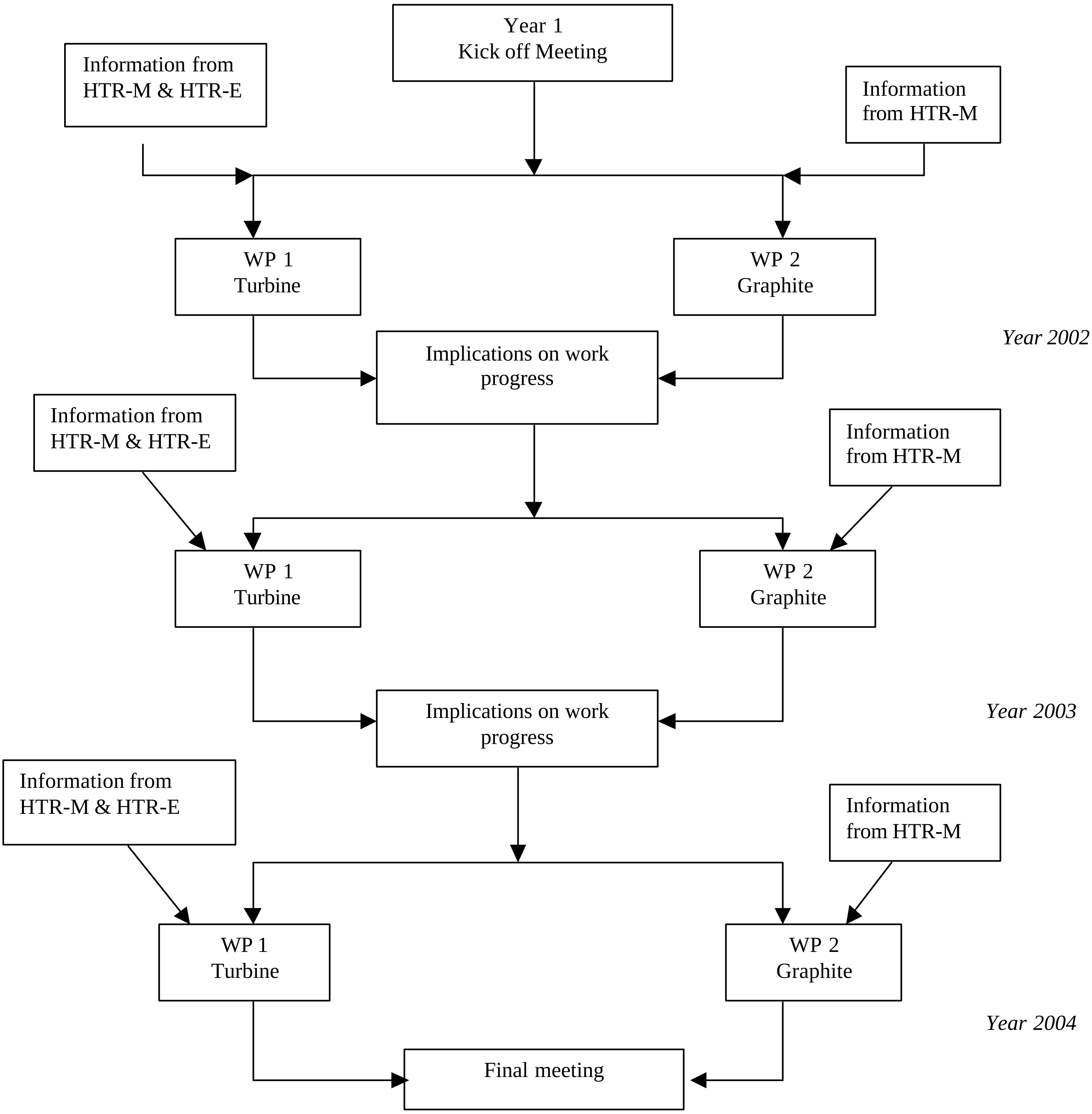
4.5 Co-ordinator management capability

The project co-ordinator has been involved in European projects and investigation of high temperature structures and materials and codes for more than 15 years. Also through R&D Programmes on innovative nuclear reactor technologies and in co-ordination of and participation in different multi-partner European projects. The co-ordinator has experience in project management of other European Studies through participation in the Codes and Standards Study Groups of DGX1. Within the project, about three person months have been reserved for co-ordination per work package, and six additional person months for overall co-ordination and organisation of final documentation.

Table 4.1 Time schedule and resources

Work Package and Task	Manpower (man months)										
	NNC 1	Fra 2	CEA 3	JRC 4	NRG 5	FZJ 6	EA 7	8	9	10	Total
Co-ordination	3.5										3.5
WP2High Temp materials - Turbine materials	2	1.5	15	12.9	-	3	4				38.4
WP 3 Graphite - Graphite evaluation - Corrosion	8 -	1 -	- 	- 	19.2 -	10 2	- -	- -	- -	- -	38.2 2
TOTALS	13.5	2.5	15.0	12.9	19.2	15	4.0		-	-	82.1

Figure 2 TECHNICAL CO-ORDINATION



5. Description of the Consortium

The consortium is built up from appropriate members of the whole European Project for the Development of HTR Technology. Improvement of nuclear safety affects the European Union as a whole and is no longer a topic of national R&D programmes. A common European approach co-ordinated by HTR-C and subsequently through the direction of a European HTR Technology Network (HTR-TN) is to be established to enable and encourage work-shared structures in this nuclear R&D field. A considerable synergy will be gained from the collaboration of different national research and industry organisations as well as from the common use of test facilities and know-how. This also enables the European partners to take a significant role in global collaboration. For example bringing together partners with experience of licensing with their local Safety Authorities at the beginning of the European development of HTR's, will bring different approaches and enrich the consensus for building a uniform international safety approach for modular HTRs. In order to get a still wider international base for this consensus; co-operation with IAEA will be sought. If such an approach is started right from the beginning of the development of HTRs, and not after the full development of industrial designs, it will simplify the licensing of this type of reactors in different countries and limit the number of specific adaptations of the designs needed for each country, which often adds a heavy burden on the cost of reactors.

The consortium, for the HTR-M1 work comes from 4 different countries of this network within the European Union, with the additional participation of JRC. Co-ordination through HTR-C and HTR-TN allows co-operation through international projects (i.e. JAERI in Japan). Most of the partners are experienced in performing complex multi-partner projects on research and/or industrial levels. They have all been involved in European Commission funded projects as co-ordinators or partners and are acquainted with the funding and reporting regulations. Many of the partners have already worked together during the 4th Framework Programme both on HTRs (INNOHTR) and, in a more general project, on the research needs of European nuclear industry (MICA).

Most of the partners have worked in the past, to varying extents, on the development of HTR technology. They are also actively participating in the HTR-M project hence co-ordination with outputs from HTR-M will be readily accommodated. Some have worked as leaders in this field and some for specific projects (like NNC), whilst others were associated to specific developments (this was the case for companies which later joined Framatome Group). For the maximum benefit to be obtained from the feedback of the past industrial development of HTRs, no redundancy of the partners is to be feared. Activities have been stopped in all countries for such a long time that many pieces of the HTR technology are missing and that several parallel experiences can help to recover a complete scheme.

The key objectives of the HTR-M1 project are to collate and obtain material data and information necessary for the development of the HTR concentrating on the following areas:

High temperature materials
Graphite irradiation and oxidation

A key element to the success of the project is communication and transfer of information. The topics are highly specialised and use specialised language.

The successful outcome of the work will require the close collaboration of experts that have a wide range of skills and experience on a range of technical disciplines. These include:

- materials and material behaviour covering both steel and graphite,
- experience in testing of steels under irradiated and non irradiated conditions,
- metallurgy (particularly of welds) and the influence of environment,
- knowledge of fabrication and design of the major HTR nuclear components and loads thereon,
- stress analysis and fracture mechanics techniques, flaw evaluation
- Interpretation for analysis and design and construction codes and their application to high temperature gas reactor situations.

This proposal brings together a technical team with all these capabilities. The members of the team are given below:

Organisation name	Postcode + city/town	Country
NNC Ltd.	WA16 8QZ Knutsford	United Kingdom
NRG	NL-1755 LE Petten	Netherlands
CEA	38054 Grenoble	France
Framatome	69456 Lyon cedex 6	France
JRC-IAM	NL-1755 LE Petten	Netherlands
Forschungszentrum Juelich GmbH	D-52425 Juelich	Germany
Empresarios Agrupados	28015 Madrid	Spain

Note: In addition graphite manufacturers will work as a Sub-contractor to NRG in the area of graphite materials development in order to supply graphite for the test specimens.

Aubert & Duval is currently participating within the HTR-M project as a subcontractor to CEA who are leaders of the work package on turbine materials and also within HTR-E on the development of the Turbine. Their participation in these projects will provide the necessary materials selection information for the intermediate creep tests scheduled within WP 1 of HTR-M1.

The contributions to the organisational and technical aspects of the proposal are summarised for each partner as follows:

NNC Contribution

NNC Ltd. is an international project management, engineering, and Consultancy Company and NNC together with their predecessors were responsible for the design, construction and commissioning of 34 commercial reactors in the UK and abroad. All of these units were gas cooled and graphite moderated. NNC Ltd. will be responsible for the overall co-ordination of the proposal and will be the lead contractor of Work Package 2 on "Graphite irradiation and oxidation". NNC will perform the materials database updates for Work Packages 1 and 2 and technical support for the graphite selection and tests.

NRG Contribution

NRG is a research organisation that has built up a considerable experience in HTR core physics analyses and Materials in the past 5 years. A code system for steady state and transient analyses of pebble-bed HTRs has been developed. NRG will provide the expertise for the graphite irradiation and PIE examination in WP2.

CEA Contribution

CEA will be the focus point for restarting the developments on HTR fuel fabrication within the overall consortium, with its facilities for coating, still in activity in Grenoble, which are the only ones left in Europe. CEA activities in the HTR-M1 project will be on intermediate creep testing and evaluation of high temperature materials for the turbine in WP1.

Framatome Contribution

Framatome will bring the feedback from their involvement with industrial prototype projects, with GT-MHR. From this experience, unique information will be obtained on the industrial and economic viability of direct cycle. The existence of pre-industrial models will enable Framatome to define relevant specifications for experiments and designs. Framatome will perform specific support for the high temperature turbine material tests in WP1 and graphite in WP 2.

JRC Contribution

JRC will have a central role in the organisation of the partnership, by managing of the European HTR Technology Network (HTR-TN) and in the implementation of the technical programme of the Project, by opening its experimental facilities to the European Project for some key tests (irradiation of pebbles, PIE). JRC will perform supportive testing in HTR-M1 WP1 for the intermediate creep tests and development of understanding of steels behaviour and data.

FZJ Contribution

FZJ will bring to the Project their past experience of development of HTRs from the research point of view. FZJ will contribute to the development work for the specialist turbine materials and graphite data and oxidation behaviour.

Empresarios Agrupados Contribution

Will bring their experience in advanced materials and structural aspects for the development of materials for the turbine.

Graphite Manufacturer Contributions

Graphite Manufacturers will be brought into the project as a Subcontractor to NRG to provide graphite samples for test specimens and expertise in graphite development as required.

Aubert & Duval Contributions

Aubert & Duval are participating within the HTR-M and HTR-E projects and will provide indirect support and expertise through interaction with these projects.

6. Other Information

6.1 References

Final report of INNOHTR Concerted Action

Recommendations for the development of high temperature reactors (HTRs) - *IAEA TCM - Beijing (INET), 2-4 November 1999*

The renewal of HTR development in Europe - *1st Information Exchange Meeting on Survey on Basic Studies in the Field of High Temperature Engineering - OECD / NEA - Paris, 27-29 September 1999.*

6.2 Related Projects and clustering with other projects

HTR-M1 is part of the European Project for the Development of HTR Technology, and will be clustered with the materials project HTR-M to optimise the common management. Other projects investigating aspects of HTR technology are:

- HTR-C "HTR Co-ordination",
- HTR-N / N1 "HTR Reactor Physics and Fuel Cycle Studies"
- HTR-F /F1 "HTR Fuel Technology
- HTR-E "HTR components"
- HTR-L "HTR-Licensing"

Projects HTR-C, HTR-F & HTR-M were selected for the 5th RDT Framework Programme as part of the second call for proposals and projects HTR-E, HTR-L, HTR-M1, HTR-N1, HTR-F1 are being considered for the third call for proposals. The above projects and proposals are for RT actions under the specific programme for research and training (Euratom) in the field of nuclear energy (1998 to 2002) (Key Action 2: Nuclear Fission).

Appendix A

Obligations and Schedule for Meetings and Reporting

A1 Meetings

Meetings will fall into one or other of the following four categories.

Progress meetings These meetings will be held at the discretion of the project coordinator or those assigned responsibility for progressing individual work packages. The meetings may concern the whole project or particular work packages and their scheduling and the level of participation will be determined by the needs of the project. Indicative scheduling of these meetings is set out in Annex I (Section 4).

Coordination meetings, workshops, conferences, etc, organised by the Commission The Commission will organise a number of coordination meetings, workshops or conferences, etc, under the auspices of the Nuclear Energy Programme. The main objectives of these coordination meetings, workshops, conferences, etc, are to report and disseminate, to a wider international audience, the progress and achievements made by the RTD in each of the main areas of the Programme (ie, operational safety of existing installations, safety of the fuel cycle, safety and efficiency of future systems and radiation protection) or in particular sub-areas. Participation in those meetings which are directly relevant to this project, is a contractual obligation; the costs of participation will be borne by the contractor/s and can be charged to the project (ie, they are eligible costs) where the meeting is held within the duration of the contract. This obligation will be strictly limited to participation in not more than two such coordination meetings, workshops, conferences, etc. **The level of participation will reflect the needs of the project, the nature of the meeting and what is to be reported** (eg, in some cases it may be sufficient for a project to be represented by the coordinator or other participant).

Other conferences, workshops, meetings, etc. Participation in other conferences, workshops, meetings, etc, should be strictly limited to that **essential** for the proper and effective conduct of the project and/or the dissemination of its results. Where participation is essential, the costs that can be charged to the contract will, in general, be limited to those for one participant; where the costs of more than one participant is to be charged to the contract, the prior approval of the Commission is required. Prior approval is also required for participation in any conference, meeting, etc, held outside the territory of the Member States, Associated States or a third State where a contractor is established, unless such a destination is provided for in Annex I (see Article 23 (4) of Annex II).

A2 Reporting

The requirements for reporting are set out in Article 4 of this contract and amplified in Article 4 of Annex II. For convenience, a summary of these requirements, insofar as they apply to this contract, is set out in Table A1.

Table A1: Schedule and deadlines for reporting and cost statements

Reports/Cost Statements		Submission time[1] (time after contract start – months)
Reports[2]		
Minutes of progress meetings		Within 1 month of each meeting
Periodic progress reports	Six monthly management reports	*[6, 12,18,24,30,36]*
	Annual scientific/ technical reports	*[12,24,36,]*
Mid term report		*[21]*
Final report		*[42]*
Technology Implementation Plan[3]		*[2,24,42]*
Supplementary reports/deliverables		As indicated elsewhere in Annex I
List of all reports prepared within the project		*[42]*
Cost Statements[4]		
Periodic cost statements		*[12, 24, 36, 42]*

[1] The **deadlines** for submission are generally two months after the period being reported on
[2] Three copies required of each report, except minutes (one copy only)
[3] See Articles 16 and 17 of Annex II
[4] Two copies required per participant (including the co-ordinator's integrated and summary cost statements) – see Article 4 of the Contract and Article 4 of Annex II

Guidance on reporting

Minutes of progress meetings*: minutes* (summarising the main decisions taken and actions placed) should be prepared for **all** progress meetings between partners. This applies to meetings concerned with progressing the project as a whole and progressing particular work packages.

Management reports: these should be succinct and **strictly limited** to project management issues. Their content should be sufficient to enable the Commission to evaluate progress relative to the work-programme (ie, milestones, deliverables, resource utilisation, etc) and judge whether any remedial action is needed. Any problems foreseen or experienced in executing the project should be identified at an early stage. Significant revisions to the work programme, schedule or deliverables should be drawn to the Commission's attention for approval.

Scientific/technical reports: these should summarise the scientific/technical progress made in the reporting period in sufficient detail to enable the Commission to evaluate what has been achieved relative to the scientific/technical goals of the project. The report should describe/synthesise progress in the project as a whole (ie, properly integrating the contribution of all partners) and **not** comprise just a compilation of un-connected progress reports prepared by individual partners; the actual contribution of individual partners should, however, be indicated succinctly in material annexed to the report.

Mid-term report: this report will form the basis of a formal, mid-term, review and assessment of progress made. The assessment will be carried out by the Commission in a meeting with the co-ordinator and representative/s of each of the partners; the need for and, where necessary, the nature of changes to the work programme for the remainder of the project will be identified. This report should be more extensive than the periodic scientific/technical reports; its content should be sufficient to enable a proper technical evaluation of what has been achieved relative to expectations and to judge the adequacy of the remaining work programme in terms of achieving the overall project goals.

Final report: the format of the final report (including an executive summary) will be defined by the Commission Services at least six months before the end of the project. Publication and dissemination of the final reports will normally be the responsibility of the contractors; publication in the open literature (journals, institute/company report series, etc) is strongly encouraged with due acknowledgement to the support provided by the Community (see Article 18 of Annex II). The Commission, with the agreement of the contractors, reserves the right to publish selected final reports (or syntheses of several final reports), in particular where these may have broader strategic or political importance. A compilation of the executive summaries of all final reports will be published by the Commission.

List of reports/documents: The co-ordinator will keep a register of all substantive reports/documents produced within the project; each will be attributed a code (ie, PU (public), RE (restricted), CO (confidential)) denoting limitations on their distribution. The list of reports/documents will be provided to the Commission at the end of the project.