HTR-TN
High Temperature Reactor Technology Network

The European HTR programme

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C-14

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The renewal of HTR development in Europe (1)

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- In 1998-1999 a small project (~ 150k$) funded by the European Commission (EC) in its 4th Research and Technological Development Framework Programme (RTDFP), INNOHTR:
  - ➢ State of the art and assessment of HTR technology
  - ➢ Recommendations for further developments
- \+ participation of many European research and industry organisations in the projects of industrial prototypes GT-MHR and PBMR
- Intensive work of information and explanation at the European level

⇒Creation of the HTR-Technology Network (HTR-TN), 04/2000

The renewal of HTR development in Europe (2)

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⇒5th Euratom Framework Programme (FP5), 2000-2003:

- 1st call for proposals (10/00): 4 contracts obtained from EC started ~ 10/00, ~ 8 M$ (50% funded by EC)
  - *HTR-N: reactor physics and fuel cycle study*
  - *HTR-F: fuel technology*
  - *HTR-M: material development*
  - *HTR-C: co-ordination and integration*
- 2nd call for proposals (01/01): 2 contracts opening new fields of HTR R&D + 3 contracts for complementary actions on the existing projects for ~ 9 M$ (50% funded by EC), starting in 2001 fall
  - *HTR-E: reactor components*
  - *HTR-L: safety approach and licensing main issues*

- The projects of FP5 cover the period 2001-2005
  New projects and continuation of the present developments are possible from 2004, in the next Framework Programme (FP6)

HTR-Technology Network
HTR-TN (1)

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- The Network is based on a club-type Agreement signed by all its members:
  - ➢ Voluntary association of partners for a common R&D objective,
  - ➢ Operated by JRC
  - ➢ No exchange of money, only free sharing of the results of a co-ordinated R&D programme
  - ➢ Possibility of association of non-European partners

HTR-Technology Network
HTR-TN (2)

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- The objectives
  - To create the technological basis for an industrial development of HTRs in Europe by the end of the present decade
  - To prepare longer term evolutions of HTRs
    - ☞ *optimisation for improved competitiveness*
    - ☞ *broadening of the scope of applications (heat applications including hydrogen production)*
    - ☞ *increase of the operating temperature*
    - ☞ *minimisation of wastes and sparing of the fissile resources*
  - To build a stable and consistent European partnership for these long term objectives
  - To create a strong European pole of expertise on HTR technology, which can play a key role in the international co-operation for the development of HTR technology

Long term strategy, a key tool for directing the action of HTR-TN

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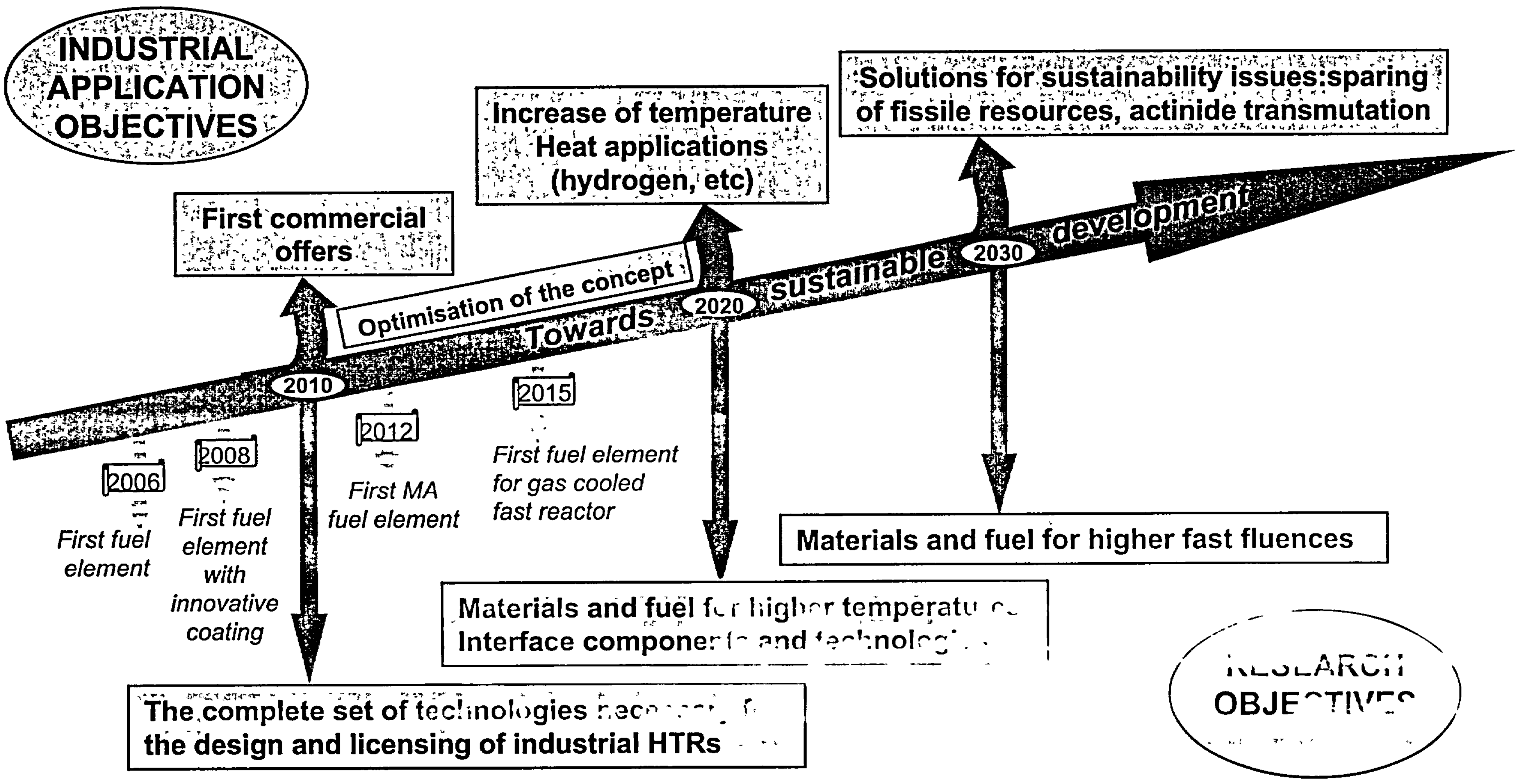

HTR-Technology Network
HTR-TN (3)

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- The partnership:
  - 18 organisations (9 industrial companies and 9 research and educational organisations):

Ansaldo	*Empressarios Agrupados*	*IRI University of Delft*
Balke Dürr	*Forschungszentrum Jülich*	*Joint Research Centre (EC)*
Belgatom	*Forschungszentrum Rossendorf*	*NNC*
BNFL	*Framatome ANP SAS*	*NRG*
CEA	*Framatome ANP GmbH*	*IPM Zittau*
Cogema	*IKE - University of Stuttgart*	*VTT*

  - 3 new observers (transitory status): *EDF, CIEMAT, Vüje*

HTR-Technology Network
HTR-TN (4)

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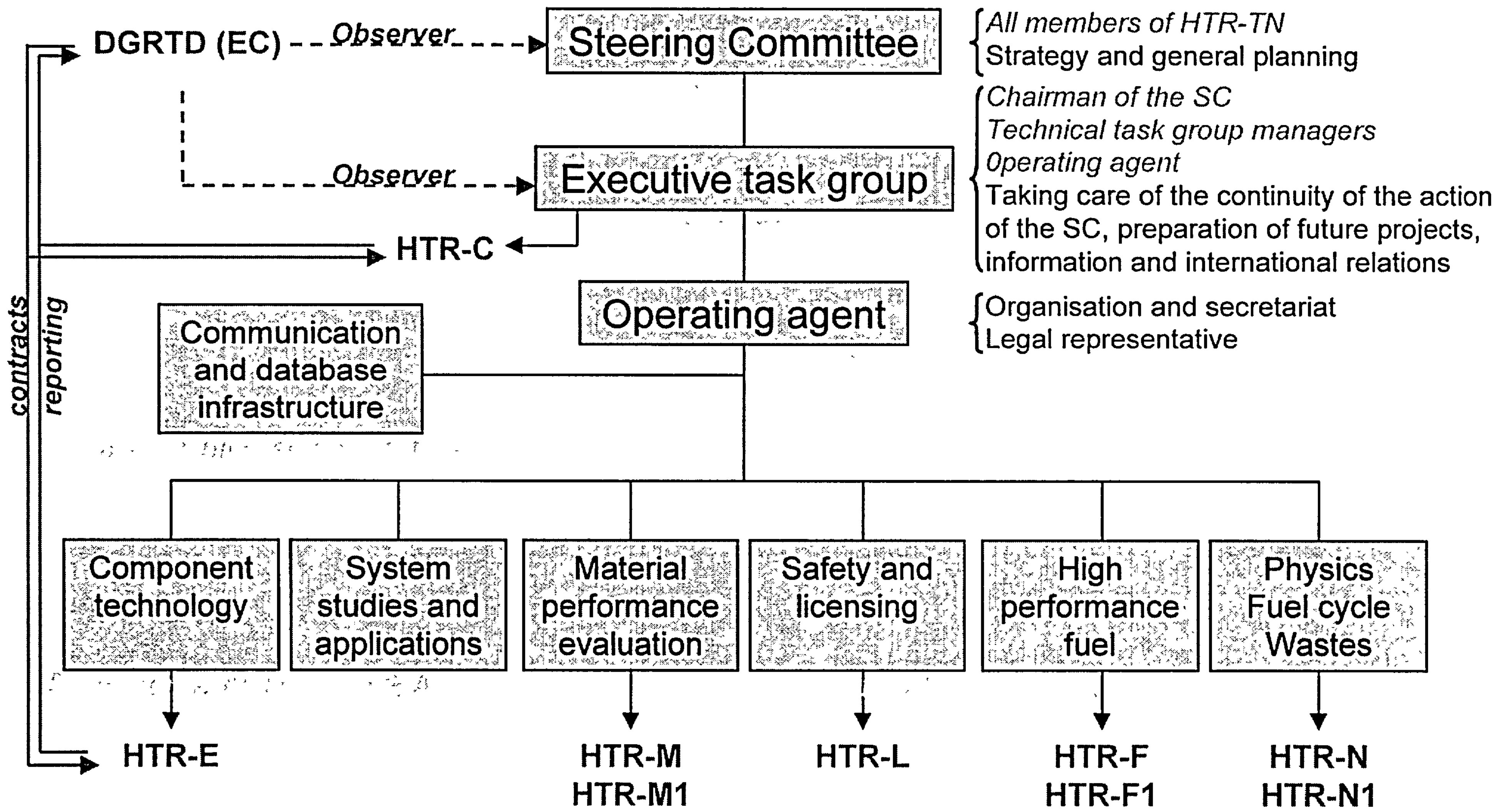

Process of selection and funding of projects by EC

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FP6 milestones

Step	Responsible	FP6 milestones
Definition of the specific programme	DGRTD	*mid 2002*
Call for proposals	DGRTD	*early 2003* + *further calls*
Classification of proposals / Recommendations	panel of independent experts	*second quarter 2003*
Selection	DGRTD	
Negotiation	DGRTD - HTR-TN	
Contract	DGRTD - HTR-TN	*last quarter 2003*

→ HTR-TN

Proposals * HTR-TN, etc → Classification of proposals

* *For FP6, one single integrated HTR project*
+ possibly a few specific targeted projects

HTR-Technology Network
HTR-TN (5)

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- First actions
  - Obtaining a funding of ~ 8.5 M€ from EC
  - Starting of the work for the contracts
  - Launching of a programme of irradiation and PIE of HTR fuel (pebbles and compacts) partly directly supported by JRC
  - Elaboration of a long-term R&D strategy of HTR-TN
  - Developing international co-operation
    - *agreement with GA and US DOE for an American participation to the fuel irradiation programme with GA compacts, and preparation of the irradiation with GA*
    - *MOU with JAERI*
    - *Agreement with INET, including the irradiation of 1 or 2 Chinese pebbles*
  - Organisation of an international fuel seminar in Brussels (1-2/2/01) and (with ENS + IAEA) of HTR 2002 in Petten (24-26/4/02)

HTR-N: Reactor physics and fuel cycle studies (1)

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- Objectives:
  - To validate codes for calculating HTR core physics
  - To assess the feasibility of different types of core and fuel cycle concepts
  - To assess the potential of HTR for solving the main waste issues
- Validation of reactor physics codes:
  - Comparison of calculations with experimental data from HTTR and HTR-10, analysis of the discrepancies and improvements of the method of calculation.
  - First results: the origin of the main discrepancies of the IAEA HTTR benchmark are understood
    - *modelling of the heterogeneity of the fuel and the burnable poisons*
    - *streaming effect*
    - *impurities in graphite*

HTR-N: Reactor physics and fuel cycle studies (2)

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- Identification of needs for improved nuclear data through sensitivity studies and uncertainty analysis
- Analysis of different HTR core and fuel cycle concepts
  - Objectives:
    - *assessment of burnup increase and waste minimisation capabilities*
    - *assessment of parameters relevant to economics and safety*
  - Concepts to be considered
    - *different types of fuel technology: block type or pebbles*
    - *for pebble bed, different reload schemes:*
      - ✓ continuous reload and multiple recycling
      - ✓ peu-à-peu (PAP)
      - ✓ once-through-then-out (OTTO)
    - *different fuels:*
      - ✓ U fuel,
      - ✓ Pu based fuels with civil Pu (1^{st} or 2^{nd} generation) + burnable poison, + Th

HTR-N: Reactor physics and fuel cycle studies (3)

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- Waste issues (1)
  - Analysis of operating and decommissioning wastes
    - + comparison with LWR wastes
    - + assessment of the possibilities of minimisation of the wastes
  - Treatment and conditioning of HTR-specific wastes
    - ☞ *review of existing methods and procedures*
    - ☞ *development of a heat up method for decontamination of graphite*
  - Long-term behaviour of disposed spent HTR fuel
    - ☞ *assessment of mechanical stability of spent HTR fuel elements*
    - ☞ *corrosion of graphite and coating layers in geological conditions (experiments with non-irradiated and irradiated material)*
    - ☞ *Leaching of fuel kernels in anaerobic conditions (experiments with non-irradiated and irradiated particles)*
    - ☞ *geochemical modelling of the radionuclide release (validated with data from past projects and from the the experiments of the present project*

HTR-N: Reactor physics and fuel cycle studies (4)

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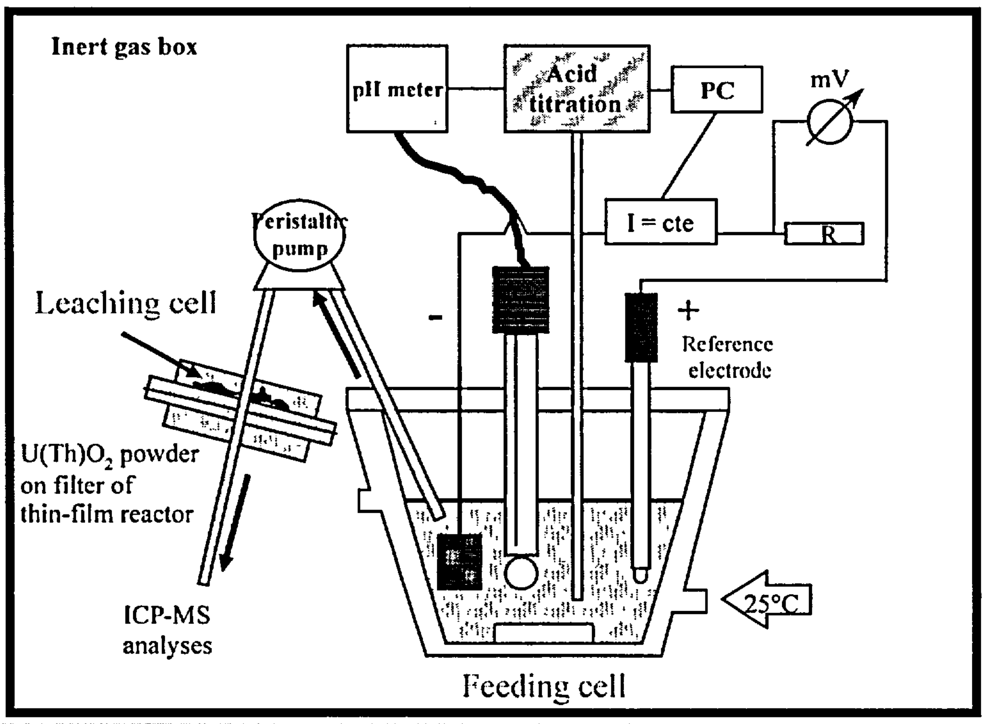
- Waste issues (2)
  - First results on the long-term behaviour of disposed spent HTR fuel :
    - *A leaching facility has been built up in a glove box*
    - *Lifetime of the (non-irradiated) SiC coating ≥ 10 000 years*



HTR-F: fuel technology (1)

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- Objectives:
  - To retrieve the know-how from past HTR programmes (design and fabrication)
  - To assess the HTR-fuel potential for ultra high burnups
  - To develop a European code for modelling the HTR fuel behaviour under irradiation
- Retrieval and evaluation of data from past irradiation experiments and construction of a fuel database

HTR-F: fuel technology (2)

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- Irradiation experiments
  - Objective: exploration of very high burnup (15-20% FIMA) performance of LEU TRISO fuel in normal and accident conditions
  - 2 irradiation experiments of about 2 years in 2 separate test rigs in the JRC reactor HFR in Petten (Netherlands):
    - *Pebbles of German origin (NUKEM latest fabrication), 17% enriched*
    - *compacts fabricated by GA with a renewed procedure, 10% enriched*

    Starting of the irradiation ~ 10/2002.
  - Non destructive and destructive PIE at NRG (Petten)
  - Temperature heat-up experiment in KÜFA facility at ITU (JRC Karlsruhe): measurement of fission products release in accident conditions. Only preliminary qualification tests of KÜFA, with already irradiated pebbles are planned.

HTR-F: fuel technology (3)

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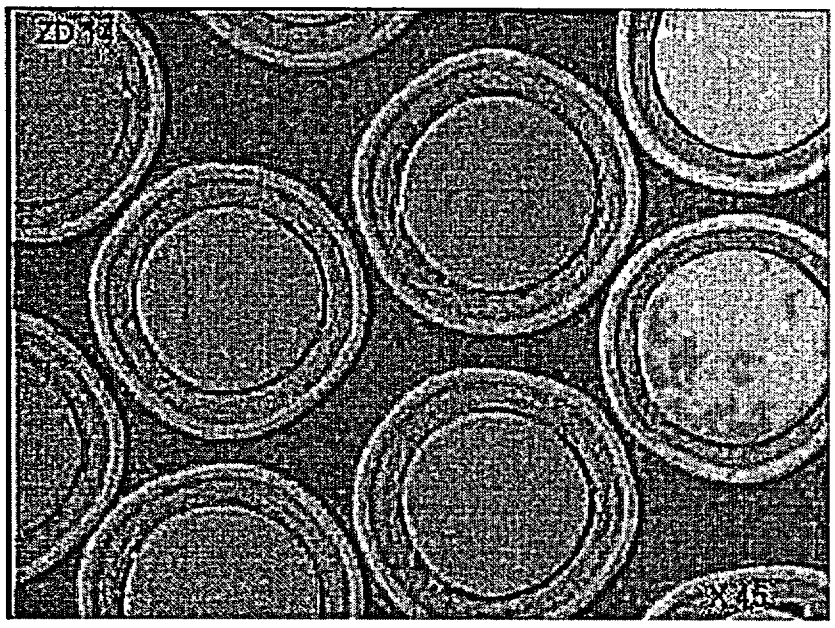
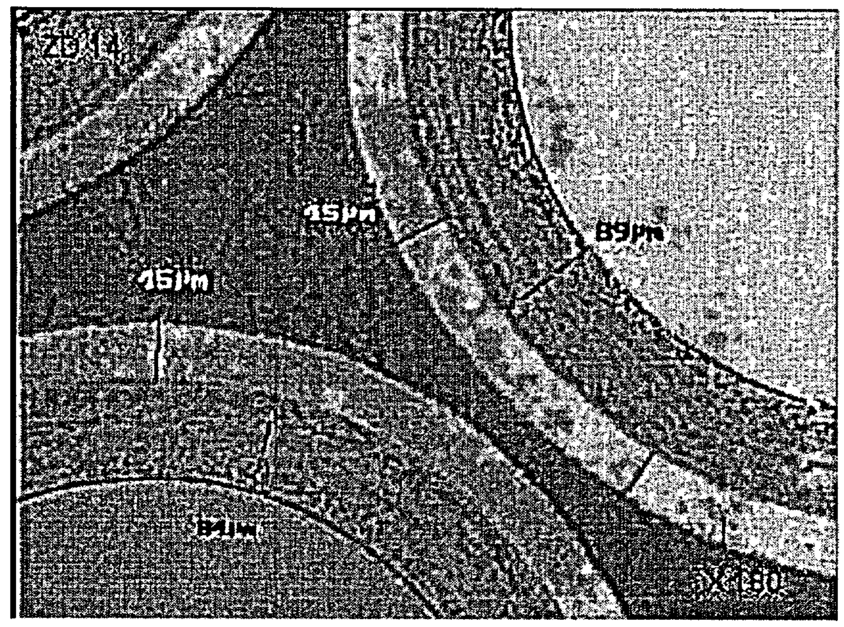
- Fuel modelisation
  - ➢Objective: deterministic calculation of particle behaviour under irradiation, up to very high burnup
  - ➢Choice of physical models for the description of phenomena, code development and qualification
- Fuel fabrication
  - ➢Objective: to restore the European know-how on coated particle fabrication
  - ➢Kernel fabrication:
    - ☞*development of 2 variants of sol-gel process (ITU and CEA)*
    - ☞*fabrication of Pu kernels*
  - ➢Coating:
    - ☞*restoration of the know-how on coating, using 2 fluidised bed CVD reactors existing at CEA Grenoble. Simulant kernels will be used.*
    - ☞*development of methods for quality control*
    - ☞*analysis of existing results on innovative coatings*

HTR-F: fuel technology (4)





Material development (1)

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- Objective: to select and qualify the key materials
  - ➢ Vessel material
  - ➢ Turbine blades and discs
  - ➢ Internal structures (graphite, carbon fibre composites...)

  In the first phase (→ 2010), no development of innovative materials
- Vessel material:
  - ➢ For the design option of the cooled vessel, the use of LWR vessel materials is acceptable
  - ➢ For the hot vessel option, there is a large experience of industrial use of the selected material, Mod. 9 Cr 1Mo, but very few record of irradiation behaviour, in particular with large thickness

  ⇒An irradiation test of a thick welded joint of is under preparation (starting end 2002)

Material development (2)

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- Turbine:
  - Key issues: the concomitant satisfaction the requirements on the following parameters is beyond the existing industrial experience:
    - ☞ *temperature (~ 850°C)*
    - ☞ *stresses*
    - ☞ *size of components*
    - ☞ *chemical environment*
    - ☞ *required long term endurance (~ 6 x 10^4 hrs without maintenance)*
  - Programme of work
    - ☞ *Selection of the most promising candidates*
    - ☞ *Mechanical tests at high temperature (≤ 1300°C)*
    - ☞ *Medium term (10^4 hrs) creep tests at 850°C on the chosen alloys*

Material development (3)

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- Graphite and advanced C-based materials
  - Graphite irradiation:
    - *key issue: the grades used in the past are no longer available, and data on the irradiation behaviour of present industrial grades are very limited*
    - *programme of work:*
      - ✓ elaboration of specifications of graphite grades satisfying HTR needs
      - ✓ selection of promising graphite grades
      - ✓ preliminary medium dose irradiation tests on the most promising grades (starting end of 2002)
  - Oxidation
    - *measurement of kinetic data at high temperature (up to ~ 1000°C)*
    - *test of the resistance to oxidation at high temperature of several C-based materials (new graphite grades, CFC, doped materials (in particular with Si))*
    - *evaluation of the potential of corrosion resistant coating of graphite and fuel matrix material*

HTR-E: Reactor components and systems (1)

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- Objective: to assess the feasibility of the key design issues and make recommendations for further developments
- Helium turbine
  - Key issues
    - *850°C without internal blade cooling*
    - *helium*
    - *high efficiency*
  - Programme of work
    - *functional specifications (including ISIR requirements)*
    - *state of the art (including lessons from EVO and HHV tests)*
    - *feasibility study (integrating material aspects from HTR-M)*
    - *design study (aerodynamic, thermal & thermo-mechanical analysis)*
    - *experimental test programme definition*
- Hot gas duct feasibility study

HTR-E: Reactor components and systems (2)

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- Recuperator
  - key issues
    - *compactness*
    - *high differential pressure (~50 bars)*
    - *high thermal efficiency*
  - Programme of work
    - *functional specifications*
    - *state of the art*
    - *design study (CFD and thermo-mechanical analysis) on 2 or 3 basic concepts*
    - *selection of a reference concept*
    - *steady state and transient validation test*

HTR-E: Reactor components and systems (3)

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- Magnetic & catcher bearings
  - key issues
    - *mechanical and thermal loads*
  - Programme of work
    - *functional specifications*
    - *load analysis (with the adaptation of a real time simulation tool of the whole rotating machine with its bearings and their regulation)*
    - *design of a prototype of active magnetic bearing and catcher bearing*
    - *experimental validation on IPM (Dresden) test bench*
    - *feasibility study of permanent magnetic bearings*

- Helium leak-tight rotating seal
  - Objective: to get an alternative solution (alternator outside the vessel, with classical mechanical bearings) in order to release the loads on magnetic bearings
  - After defining the functional specification, different available concepts will be assessed:
    - *dry system*
    - *use of a liquid film (cinematic effect)*
    - *controlled leak rate*
    - *liquid film with electromagnetic confinement*
    - *magnetic transmission or canned bearings*
  - The most promising concept will be identified and a programme of tests on a representative mock-up will be prepared

HTR-E: Reactor components and systems (5)

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- Tribology in helium conditions
  - Objective: to retrieve the existing know-how and to complement it with experiments for providing missing data related to specific conditions of direct cycle modular HTRs
  - Programme of work
    - *state of the art (review of tribological issues in HTRs, identification of typical tribological conditions, review the tribological performances of existing materials and coatings)*
    - *tests with representative tribological and environmental conditions*
- Helium purification system
  - State of the art
  - Specifications and recommendations for the control of impurities in modern HTRs

HTR-L: safety approach and licensing main issues (1)

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- Objective: to establish a common European safety approach for modular direct cycle HTRs
- Definition of a safety approach taking into account the specific safety features of modular HTRs, the IAEA and other international guidelines and the approach used in present HTR projects
  + evaluation of the impact of the different applications considered for HTRs (apart from electricity generation, Pu burning, heat utilisations)
- Determination and classification of the design basis operating conditions to be considered in the safety analysis

HTR-L: safety approach and licensing main issues (2)

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- Confinement requirements for the different confinements barriers in function of the radiological release limits defined from the HTR safety approach
- System, structure and component classification
- Instrumentation required in HTRs for a defence-in-depth strategy incorporating the level of prevention (control and monitoring of plant parameters), protection and safeguards
- Identification of the key licensing issues with the help of safety authorities or of their experts, to whom the approach will be presented

Accident analysis and fission product transport

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→ No project funded by the EC in FP5, but HTR-TN has created a task group based on the voluntary participation of partners

- Objective: assessment of the validity of available existing codes for global system thermal-hydraulics and contamination analysis of a direct cycle plant or for detailed study of phenomena (CFD, combustion...)
- Actions:
  - ➢ Experimental validation of codes (data from past experiments (AVR, EVO...), from HTR-10 and HTTR)
  - ➢ Thermal-hydraulic system code-to-code benchmark

Perspectives for the 6th Framework Programme (1)

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- Continuation of the present projects
- Starting a new project on safety analysis
- Starting activities on the interface between HTRs and non-electricity production applications
- Starting a conceptual study on the potential of HTRs for transmuting actinides

Perspectives for the 6th Framework Programme (2)

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- Continuation of the present projects (1)
  - Fuel
    - ☞ *heat-up experiment with the irradiated fuel in HFR EU1 and EU2*
    - ☞ *irradiation of the first fuel resulting from the new European fabrication programme (CEA)*
    - ☞ *acquisition of data on the physical properties of fuel materials*
  - Fuel cycle
    - ☞ *continuation of the FP5 separate effect leaching tests*
    - ☞ *starting of an integral leaching test on complete fuel elements*
  - Materials
    - ☞ *vessel material: large scale tests on representative elements*
    - ☞ *turbine materials:*
      - ✓ fabrication of a full scale disc of the turbine and mechanical tests on it
      - ✓ search of appropriate coatings for the blades
    - ☞ *Graphite: optimisation of graphite grades for HTR operating conditions*

Perspectives for the 6th Framework Programme (3)

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- Continuation of the present projects (2)
  - PCS components
    - ☞ *construction of a turbine mock-up for validation tests of the turbine performance*
    - ☞ *magnetic bearings: design and fabrication of a mock-up for the dynamic rotor tests*
    - ☞ *leak tight rotating seal: design, fabrication and helium test of a seal mock-up*
    - ☞ *tribology: representative qualification tests*

Perspectives for the 6th Framework Programme (3)

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- Safety analysis
  - Air ingress
    - ☞ *continuation of analytical tests on graphite oxidation*
    - ☞ *integral test (NACOK test loop)*
  - Co-operation with INET and JAERI for taking the maximum benefit of the HTR-10 and HTTR safety tests (qualification of thermal-hydraulic codes, plate-out experiments, etc)
  - Continuation of the benchmark of codes (system thermal hydraulics and fission product transport) available with the partners
  - Safety approach:
    - ☞ *feed-back from the interaction with safety authorities*
    - ☞ *accident analysis of existing designs and feed back on the safety approach*

Perspectives for the 6th Framework Programme (4)

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- Interface with non-electricity production applications
  - Preliminary development of an intermediate heat exchanger and of the related fast isolation valve
  - Safety aspects of the non-electricity production applications (hydrogen production, etc)
  - Tritium permeation

Perspectives for the 6th Framework Programme (5)

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- Deep burn transmuter
  - Reactor physics
    - *burnup calculation scheme: development and identification of the experimental needs for its qualification*
    - *analysis of the feed back and local effects, identification of needs for improved data and acquisition of the data*
    - *preliminary design study of a deep burn transmuter core.*
  - Fuel: fabrication of 100% Pu kernels
  - Fuel cycle
    - *exploratory feasibility study of the HTR fuel reprocessing*
    - *study of fuel cycle scenarios with the introduction of deep burner transmuters*

Deep burn transmutation of nuclear wastes

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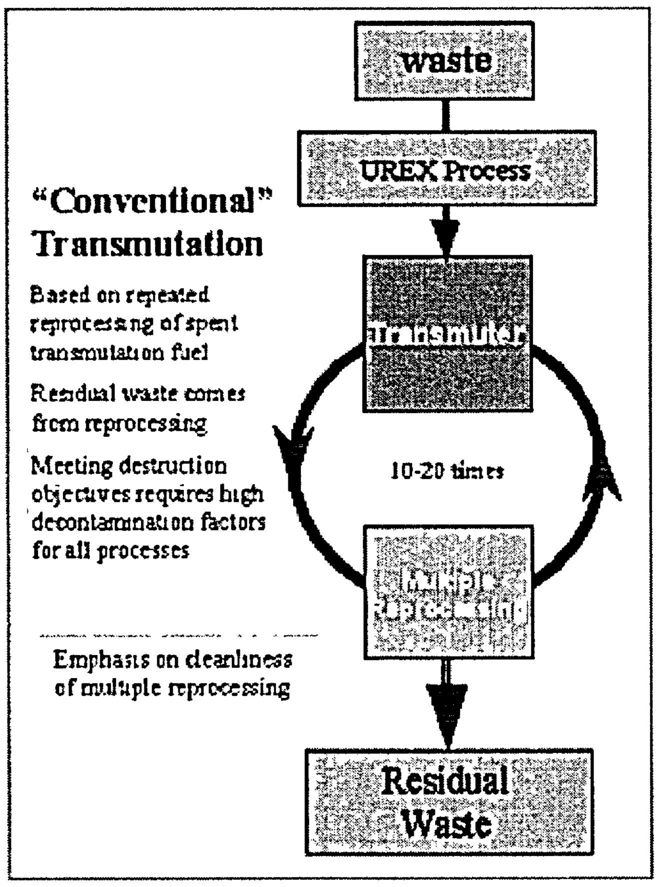

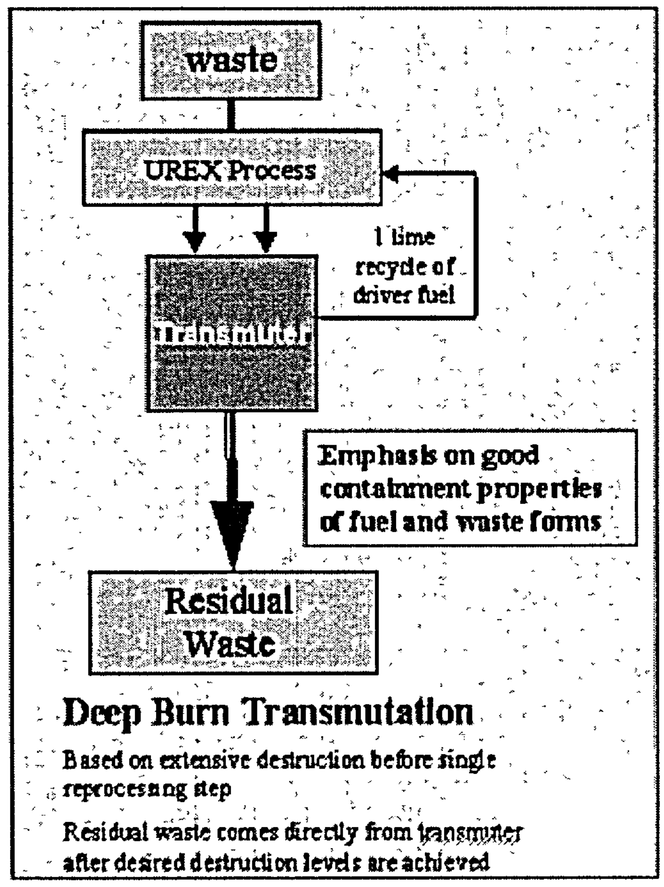

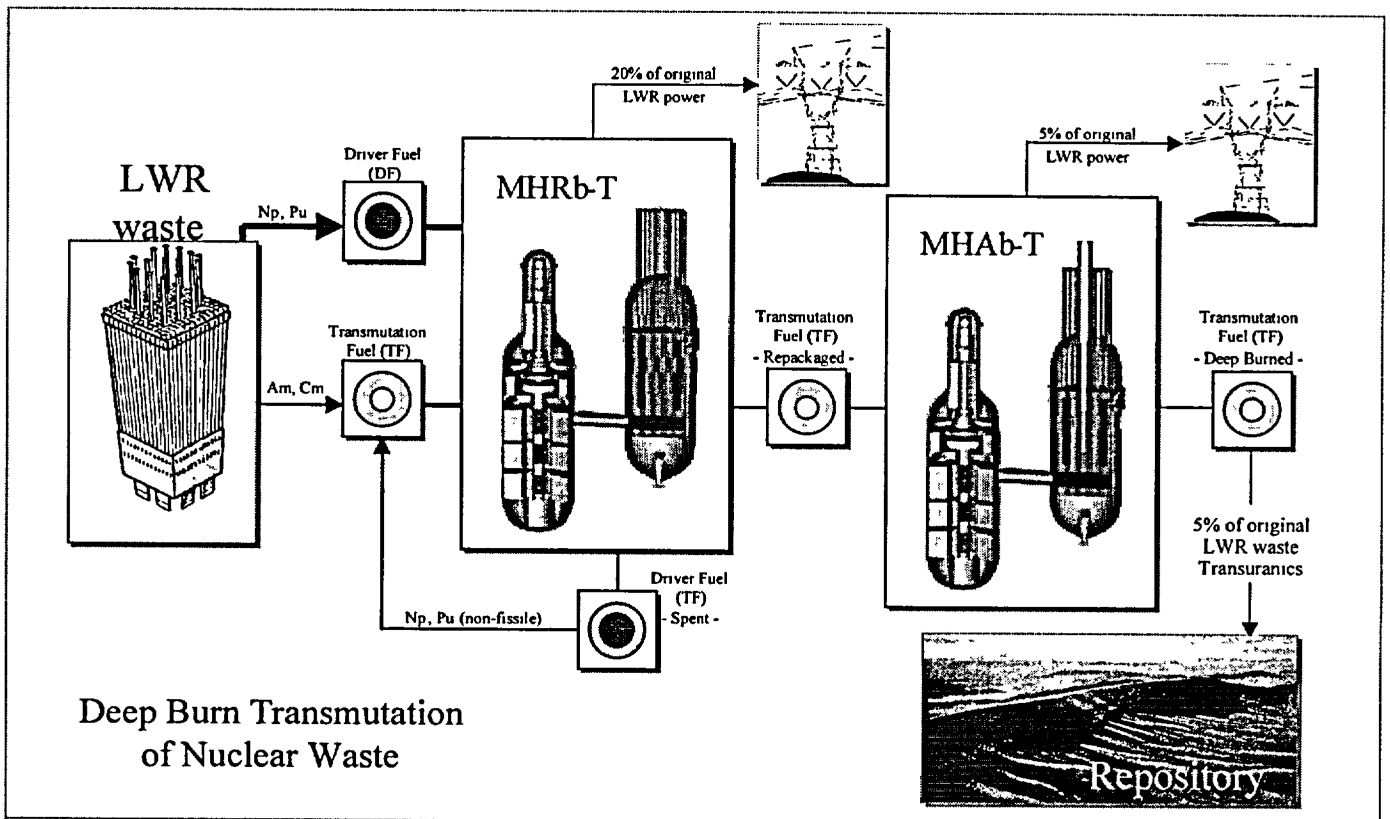

Fig. 2.1 Deep Burn Transmutation is based on the use of thermalized neutrons and high burnup fuel forms in Modular Helium Reactor systems (MHRs). Deep Burn Transmutation addresses the destruction of plutonium and the other transuranic actinides in spent fuel. An essential feature of Deep Burn Transmutation is the use of ceramic-coated fuel (TRISO) particles that are strong and highly resistant to irradiation, with very extensive destruction levels in one pass ("Deep Burn") TRISO fuel also provide a robust and attractive residual waste form The destruction of waste transuranics is carried through one burn-up cycle, achieving virtually complete destruction of weapons-usable materials, and roughly 95% destruction of all transuranics. Passively safe up to 600Mw per module, The MHR on which the concept is based can operate safely at high temperatures resulting in electric power produced at close to 50% efficiency.