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ADVANCED REACTORS WITH INNOVATIVE FUELS WORKSHOP ARWIF-2001

Summary

22-24 October 2001
Chester, United Kingdom

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English - Or. English

ADVANCED REACTORS WITH INNOVATIVE FUELS WORKSHOP
ARWIF-2001

October 22-24 2001
Chester, United Kingdom

SUMMARY

Motivation, scope and goals

This workshop was organised following recommendations from the OECD/NEA Nuclear Science Committee (NSC) that a follow-up to the first ARWIF Workshop, held at PSI in October 1998, would be valuable. The Workshop falls under the Working Group on the Physics of Plutonium Fuels and Innovative Systems (WPPR) that reports to the NSC.

A new generation of reactor designs are being developed that are intended to meet the requirements of the 21st Century. In the short term, the most important requirement is to overcome the relative non-competitiveness of current reactor designs in the deregulated market. For this purpose, evolutionary light water reactor (LWR) designs have been maturing and are being actively promoted. These are specifically designed to be less expensive to build and operate than the previous generation of LWRs, genuinely competitive with alternative forms of generation and at the same time establish higher levels of safety. A new generation of modular, small-to-medium (100-300 MWe/module), integral design water cooled reactors are under development. These are designed to be competitive with nuclear and non-nuclear power plants, to have significantly enhanced safety, to be proliferation resistant and to reduce the amount of radioactive waste produced. A different approach to improve competitiveness is the re-emergence of high temperature reactors (HTR) using gas turbine technology to give higher thermal efficiencies, low construction and operating costs, inherent safety characteristics, and low proliferation risk.

In the longer term, assuming that the current stagnation in the market is successfully overcome, other requirements related to long term sustainability will emerge. Important amongst these will be the need to minimise the environmental burden passed on to future generations (or at least to ensure that the cost to future generations is in balance with the benefits to the current generation), the need to establish sustainability of fuel and the need to minimise stocks of separated plutonium at the minimum possible working level and to minimise accessibility to plutonium.

In this context, topics of interest to the Workshop were: reactors consuming excess plutonium, advanced LWRs, HTRs, fast spectrum reactors, sub-critical systems, minor actinide systems, radical innovative systems.

The scope of the Workshop comprised reactor physics, fuel performance and fuel material technology, thermal-hydraulics, core behaviour and fuel cycle of advanced reactors with different types of fuels or fuel lattices. Reactor types considered were water-cooled, high temperature gas-cooled and fast spectrum reactors as well as hybrid reactors with fast and thermal neutron spectra. The emphasis was on innovative concepts and issues related to the reactor and fuel.

The Workshop concluded with a wide-ranging panel discussion which considered some difficult questions from which it is hoped that some recommendations for future priorities can be derived. A record of the discussion is included at the end of this summary.

Workshop organisation

General chairman	***Scientific advisory committee***
K Hesketh	P Finck ANL-E
Local organising committee	J Gehin ORNL
A Worrall	Rudy Konings EC-ITU
D Every	R Chawla PSI
S Crossley	P D'hondt SCK-CEN
Scientific advisory committee	J Rouault CEA
C Brown BNFL	P Alekseev Kurchatov Institute
M Mignanelli AEA-T	J. Kuijper NRG-NL
M Carelli Westinghouse	J Kim U-Hanyang
W Krebs Framatome-ANP	A Stanculescu IAEA
L Walters ANL-W	E Sartori OECD/NEA

Participation

The workshop was attended by 64 participants from 13 countries and 3 international organisations. Research laboratories and universities made up approximately 70% of the participants, industry 14%, utilities 5% with the remainder representing international organisations (see Annex 1 for List of Participants)

Technical programme

The workshop was organised into seven plenary sessions (including two parallel sessions on the second day) in which 35 papers were presented. In addition, 8 papers were presented in a poster session. Unfortunately, some of the authors were unable to travel following the events of September 11. In two such cases the authors agreed to forward their presentation slides and their papers were presented by the local organisers. In two other cases the papers were not presented, but they have nevertheless been retained within the workshop proceedings and will be published. (See Annex 2 for Workshop Programme)

There was a good response to the call for papers and more abstracts were submitted than the programme would allow. It was therefore necessary for the Scientific Advisory Committee to reject a number of abstracts. The majority of the rejections were abstracts for papers which emphasised codes and methods rather than the advanced systems and it was felt that the workshop should emphasise the latter.

The final plenary discussion was devoted to a panel discussion which considered five questions that had been compiled previously. Five panel discussion leaders were appointed in advance and asked to lead the discussion on these questions. Following these prepared presentations the discussion was opened to the floor.

Session summaries and panel discussion

Opening session – Chair: K Hesketh

W Wilkinson opened the proceedings with an invited paper «Barriers and Incentives to Introducing New Reactors in the Deregulated Electricity Market». The presentation highlighted that from the perspective of a utility operating in a deregulated market, there is only one incentive for new or replacement nuclear build and that is to obtain a commercial rate of return on the investment. However, while new reactors designs currently available or under development promise to achieve significant improvements in total generating cost such that they can be competitive in deregulated markets, there are nevertheless some difficult obstacles to overcome. The presentation highlighted in particular the need for a stable regulatory environment where potential investors can be certain that the regulatory process will not change during the course of construction and also the need for the regulatory processes to be consistent in different countries. A further point was the need for the environmental discharge requirements to be driven by rational cost/benefit approaches and not by demanding near-zero discharges without justification. For sustainable advanced reactors and fuel cycle systems which are intended to stabilise the accumulation of plutonium and/or the minor actinides, getting the economics right will be a considerable barrier. It seems likely that any strategy which is primarily designed to achieve significant benefits in terms of waste reduction, reduced radiotoxicity per GWye etc. will be economically disadvantaged compared with minimum cost generation strategies. Deregulated markets are not presently set-up to deal with anything other than simple cost-minimisation as a driver and therefore a major barrier in deregulated markets will be the need to establish mechanisms whereby the non-tangible benefits of advanced fuel cycles can be fully recognised.

A paper by L Walters and J Graham "The Need to Preserve Nuclear Fuels and Materials Knowledge" considered the precarious state of knowledge preservation in the field of fast reactor fuel design. The authors focused on this area because it reflects their particular expertise, but the situation is similar in many other areas. The authors suggested holding seminars in specific areas such fast reactor fuel design to try and capture past knowledge. The approach would be to invite young scientists and engineers to conduct smart interviews with experienced and retired experts. The former would try to capture the knowledge in writing and the experts would be invited to correct and add to these records. Such exchanges would complement the existing activities of international organisations, such as NEA, to build up and maintain knowledge preservation databases.

High temperature gas reactors – Chair: H Beaumont, W Zwermann

Two sessions considered high temperature gas reactors (HTGRs). The papers presented included one which reviews the European 5^{th} Framework activities in the HTGR field. There are separate programmes covering fuel technology, neutron physics and fuel cycle technology and materials technology. These programmes are broad-ranging and include experimental and theoretical studies. There were also two papers describing theoretical fuel cycle studies for the pebble bed modular reactor (PBMR). The first of these develops a design of B_4C burnable poison particles that might be used in a batch refuelling scheme for PBMR and which explores the effects of self-shielding as a function of particle diameter and ^{10}B enrichment. The second paper demonstrates the flexibility of the PBMR for utilising different fuels, including U-Th, U-Pu and Th-Pu. Finally, a poster presentation described a fluidised bed reactor concept for which coupled neutronics/multi-phase fluid dynamics calculations have been performed.

Design and performance of innovative fuels – Chair: R Thetford, Y Lee, K Bakker

Ten papers were presented under design and performance of innovative fuels, including two posters. Inert matrix fuels featured in several of the papers, specifically zirconia –plutonia, zirconium nitride, cerium-plutonium oxide and rock-like fuels. One paper considered the design of (U-Pu)N fuel for the RBEC lead-bismuth fast reactor. A paper was presented which describes test irradiations of fast reactor uranium-plutonium oxide fuels manufactured using the Sphere-Pac and Vipac processes. Two poster presentations related to the design, fabrication and physical and chemical properties of minor actinide target fuels.

Evolutionary and modular water reactors – Chair: D Porsch, P D'Hondt, T Downar

Thirteen papers were included in the proceedings under this heading, including four poster presentations. New reactor concepts include small modular PWRs, an upgraded VVER-440, a simplified BWR, a simplified PWR, a PWR with supercritical coolant state and reduced moderation LWRs designed to increase the plutonium breeding ratio. Novel fuel concepts include a PWR using HTGR particle fuel, a PWR partially loaded with inert matrix fuel and four papers on thorium fuel utilisation in LWRs. The research emphasis is on enhanced safety and improved utilisation of plutonium.

Fast spectrum reactors – Chair: P Alekseev, H Sekimoto

Five papers were presented under this heading, which was intended to cover critical fast reactors. The papers included one on a simplified sodium cooled fast reactor which eliminates the intermediate circuit through the use of novel high integrity steam generators. Other papers described a Pb-Bi cooled fast reactor and a gas cooled fast reactor, while one considered the performance of minor actinide target fuels. A novel concept compatible with a very long life core was presented. This is the candle strategy where only a small axial section of the core undergoes fissions and the fissioning region automatically propagates axially at a rate of a few cm per year. The same concept could apply to a thermal system as well. The emphasis is on fast reactors that are economically competitive with the current generation of LWRs and the evolutionary LWRs derived from them.

Molten salt reactors – Chair: W Zwermann

Three papers on molten salt reactors were presented, two of which are designed for both having an attractive fissile fuel utilisation and incinerating minor actinides. A third paper, presented as a poster, investigates a thorium- fuelled molten salt subcritical system intended for primary energy generation with low radiotoxic burdens.

Accelerator driven systems – Chair: C DeRaedt

Five papers were presented on sub-critical accelerator driven systems (including one poster). One paper described some of the first experimental results for a sub-critical system, while another paper described plans for planned MYRRHA experimental facility. A cascade molten salt sub-critical system was described which uses a super-critical central core surrounded by a sub-critical region where the bulk of the minor actinide transmutation takes place. The super-critical central zone acts to amplify the source neutrons and reduces the current requirements of the accelerator beam. Another paper described a sub-critical molten salt system for minor actinide transmutation.

Miscellaneous themes – Chair: W Zwermann, K Hesketh

Two papers were presented that do not fit exactly with the main session headings. One paper reviews experimental critical mock-up facilities for various reactor systems. Finally, an interesting concept was presented that features a core which is only just sub-critical and which uses an accelerator beam to simulate the effect of delayed neutrons. This system has the advantage of being able to load a large fraction of minor actinides, using a coupling to the accelerator current to mimic the effect of an extra delayed neutron group. In this way, many of the difficulties of more «conventional» sub-critical systems (such as demanding beam requirements and rapid spatial variations of flux) are avoided.

Panel discussion – Chair: K Hesketh

A panel discussion was held at the end of the workshop. Six participants agreed to sit on the panel and lead the discussion on five questions that were notified in advance. The panel members were:

Pierre D'Hondt (CEN-SCK)
Richard Sunderland (NNC)
Hiroshi Sekimoto (Tokyo Institute of Technology)
Joseph Somers (ITU)
Henri Mouney (EDF)

The four questions discussed were:

1. Is there a gap between vendors' and utilities' fuel research programmes designed to support operation and the advanced concept research such as that presented at this conference ? If so, what can the research community do to narrow the gap ? In other words, does the field need to be made more relevant to the utilities ?

2. The benefits of advanced concepts are usually in areas such as safety, proliferation resistance, environmental impact/radiotoxic burden, strategic and so on. A major weakness is that these are "soft" issues for which there is no agreed measure of the benefit. Are there any actions the research community could take to promote agreed metrics in these areas ?

3. What should be our strategy for partitioning and transmutation given the intractability of processing and destroying curium ? Should there be a policy of encapsulating curium for eventual disposal ?

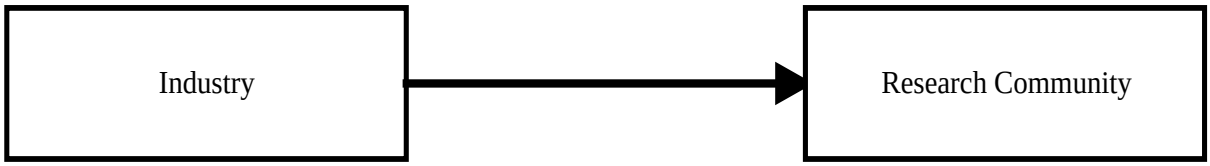
4. In the context of the objectives of initiatives such as Gen IV (particularly sustainability), how would once-though fuel cycles such as those HTGRs fit it ? What role would once-through fuel cycles play?

Question 1 discussion :

Is there a gap between vendors' and utilities' fuel research programmes designed to support operation and the advanced concept research such as that presented at this conference ? If so, what can the research community do to narrow the gap ? In other words, does the field need to be made more relevant to the utilities ?

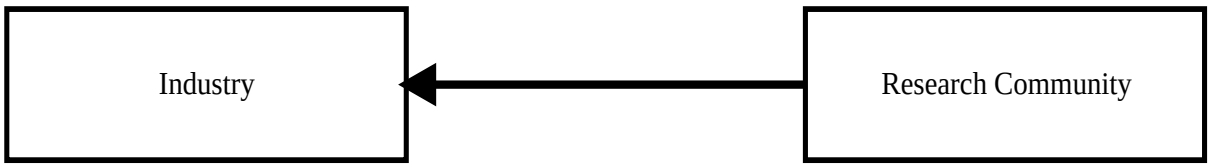
Pierre D'Hondt led the discussion for Question 1. He suggested that there are two perceptions or models to describe the development process. The first is driven by industry and is associated with «evolutionary» developments on a relatively short timescale. The diagram below illustrates the concept. The development is derived from an actual demand from industry

The second is driven by the research community and is associated with «revolutionary» developments on a



relatively long timescale. The diagram below illustrates the model. Here a perceived requirement or the study of innovative concepts drives developments. Research over a long timescales with or without a specific focus is normally funded through public agencies; it can be very difficult to interest industry in sponsoring research.

In summary, the link from industry to the research community, which is applicable to short term problem



solving and short term improvements with a direct economic benefit, works well. The link in the opposite direction, concerning long term development from the research community to industry, does not work as well as it should. Government funding is available to sponsor such research, but it would require the full involvement of industry to bring to fruition and at the moment industrial organisations, particularly the utilities, show very limited interest. (This is illustrated by the fact that the only utility represented at this workshop was EDF.) Other utilities find it difficult to be concerned with anything other than short term issues (maximum time horizon 5 to 10 years). Therefore the conclusion is that there is indeed a gap between industry and the researchers and that measures need to be taken to narrow the gap for the long term developments to be implemented industrially.

Points made from the floor during the discussion included :

- The key word is MONEY – the research community should highlight the economic gains of new systems.
- It would be useful to have representatives from the utilities at conferences such as this.
- The utilities have several options including P&T and underground disposal. Those working on underground disposal promote that option and there is a danger that if the experts say that this method is viable then the P&T studies will be sidelined/neglected.
- P&T may reduce the cost of underground disposal.
- A question that needs to be addressed is how an economic figure can be put on savings due to P&T.
- In Japan, issues that might imply that currently operating LWRs may not be safe are at risk of being suppressed.
- In terms of safety and economics, the vendor and the utilities have a conjunction of interest.
- In terms of P&T, the customer is the public/government; they should thus be funding it or at least making a contribution.

Question 2 discussion :

The benefits of advanced concepts are usually in areas such as safety, proliferation resistance, environmental impact/radiotoxic burden, strategic and so on. A major weakness is that these are "soft" issues for which there is no agreed measure of the benefit. Are there any actions the research community could take to promote agreed metrics in these areas ?

Richard Sunderland led the discussion by suggesting a few considerations:

On safety he suggested the need for:

- Enhanced safety
- Improved reliability
- Inherent safety (e.g. passive systems)
- Advanced control and monitoring systems
- Plant simplification
- Improved ISI and maintenance
- Reduced worker dose
- Reduced consequences of severe accidents

On proliferation resistance he noted the need for:

- Proliferation resistant fuel cycles
- Fissile material accounting
- Assured inspection processes (easy accountability and inspection)
- IAEA requirements

On environmental impact:

- Improved fuel utilisation
- Reduction in wastes
- No increase in natural environmental burden
- Decommissioning

He saw strategic concerns as being:

- Optimum use of resources
- Energy costs: capital, financial and fuel cycle
- Construction timescale
- Siting
- Security
- Profitability
- National strategies

In summary:

- What shall we do to develop metrics[1]?
- In what areas should metrics be developed?
- How can metrics be combined to assess reactor concepts on an equivalent basis?
- Who should be involved in metric development: researchers, manufactures, utilities, fuel manufacturers and reprocessors, the public?
- Lead institutions: IAEA, OECD, Governments?

This question is very wide ranging, many factors need to be considered.

[1] Metrics – what measures do we adopt to ensure that we meet utility requirements. For example, there is no easy measure to assess whether one system is more proliferation resistant than another. There is a need to develop scales to measure these issues.

Hiroshi Sekimoto also addressed this question.

- The measure of the benefit depends on the consideration of weight of value.
- The consideration of weight of value changes for different persons.
- Even for one person it changes with time for different circumstances and environments.
- It is almost impossible to set a measure of the benefit, which can be applied to everyone.
- Even if the measure is set by public, specialists can offer the *options* which will be evaluated by such a measure.

Points made from the floor during the discussion included:

- A precedent has been set by the US DOE to answer these questions in terms of the best route for disposal of weapons grade Pu (e.g. geological disposal or burning). This illustrates the possibility of applying metrics to this type of issue.
- It is difficult to quantify the values of different systems, and it may need an international working group to agree on values. The USA is trying to do this for the Generation IV reactors.
- In terms of risk categorisation it is relatively easy to converge on a value.
- If agreements on metrics could be reached it might be possible to then present these to the public and to shareholders.
- Public opinion is not likely to be favourable if the experts are in disagreement.

The discussion illustrates the difficulty of addressing this question. There is a clear agreement of the need to establish meaningful and useful metrics, but recognition that in most of the areas they are very difficult to define. The economics of different systems is the only area where clear quantitative metrics exist and utilities' decisions are understandably dominated by this aspect. In spite of the difficulties of making progress in this area, it is important enough that it should not be neglected. There may be benefits in attempting to generate suitable metrics even if they are not perfect, because the process may give rise to important new questions and generate new perspectives. There may be benefits to be gained from other fields, such as environmental protection, where there is a need for analogous metrics. Ultimately, it may be the general stakeholders (public, government, shareholders, regulatory bodies etc.) who decide which metrics will apply, and then it would be the research community's responsibility to provide the specialist inputs needed to apply the chosen metrics.

Question 3 discussion :

What should be our strategy for partitioning and transmutation given the intractability of processing and destroying curium ? Should there be a policy of encapsulating curium for eventual disposal ?

Joe Somers led the discussion of this question. He began by expanding the question further to ask:

- In the transmutation of Cm, is the radiotoxicity reduction sufficiently high?
- Are Am/Cm separation processes feasible?
- What should the design of the sub-assemblies be?
- How to manufacture Cm targets and sub-assemblies?
- What are the appropriate logistics (colocation of facilities)?

These in turn lead to further questions:

- Encapsulation of Cm - final or interim (the famous 100 years)?
- Simple encapsulation or immobilisation matrices?
- What type of immobilisation matrix (e.g. Pyrochlore (e.g.Gd1.8Cm0.2ZrO7))?

- Can the interim storage host become the target (e.g. $(ZrYCm)O_2$)?
- Management of He and heat damage to the matrix?

Hiroshi Sekimoto pointed out that ^{244}Cm is the curium isotope which initially has the highest concentration and which is a powerful neutron source, but which decays relatively quickly (18.1 year half-life). There would be clear advantages, therefore, in allowing ^{244}Cm to decay for a few half-lives before attempting to irradiate curium in targets.

The following additional questions and comments were made from the floor:

- What type of partitioning processes could be applied?
- What is the necessary investment for these partitioning processes?
- It is complicated, chemically, to separate Cm and Am and Am/Cm and the lanthanides. Some promising methods are under development but a lot of work remains before these processes could be applied on an industrial scale.
- In future it may be necessary to reach a compromise between physics and chemistry.
- It may be more reliable to develop systems that utilise incompletely separated fuels i.e. an Am/Cm mixture needs to be considered.
- There is a network in place with an OECD/NEA working party to look at these P&T issues.
- P&T may not be so important now but it is important for the far future (2050+); an integrated reactor and fuel cycle may be needed (e.g. molten salt) to avoid the transport of highly active waste.
- Geological disposal should not be ruled out. The USA has an operating geological disposal facility (WIP) for military waste; this demonstrates that geological disposal is viable/possible.

This discussion highlighted the present lack of knowledge in relation to curium and the best strategy for dealing with it. It is clear that the fabrication of Cm transmutation fuels/targets is technically difficult but not impossible. An interim storage period would alleviate these difficulties, but would still require Cm fabrication in a suitable form ensuring chemical durability and management of the considerable heat and He produced. Such an interim storage strategy would necessitate an active nuclear programme remaining long after this storage time. It is important to ensure that all possible scenarios are covered, including a scenario in which nuclear energy is no longer deployed at the end of such an interim storage period. Therefore, it will be necessary to develop strategies, which assume final disposal of curium after a possible interim storage period, alongside long term sustainable strategies where curium is brought into balance in a transmuter directly after its separation (or possible interim storage).

Question 4 discussion :

In the context of the objectives of initiatives such as Gen IV (particularly sustainability), how would once-though fuel cycles such as those HTGRs fit it ? What role would once-through fuel cycles play?

Henri Mouney led the discussion of this question, beginning by providing a reminder of the definition of sustainability: «Development that meets the needs of the present generation without compromising the ability of future generations to meet their needs» (WCED - 1987). He then listed the issues to be addressed, which are:

Sustainability of nuclear energy with the following main requirements :

1. Uranium resources need to be saved
   Known resources : 4.3 Mt (NEA - 1997) combined with consumption of 70 kt/year equates to 60 years of supply

2. Nuclear waste production should be minimised with an adequate Management of Spent Nuclear Fuel. But, until now no country has yet implemented a permanent solution such as Partitioning and Transmutation and/or geological disposal
3. Enhanced safety
4. Enhanced resistance to proliferation risks
5. Economic competitiveness which needs to be reinforced

- Assets and limits of LWR for sustainable development:

  ⇨ A mature technology with an irreplaceable experience
  ⇨ Convincing results on economy, safety and reliability
  ⇨ For immediate future - new generation of PWR (EPR)
  High burnup level (65 GWd/t)
  Plutonium control
  Waste volume reduction

  BUT

  A non-optimum use of resources - only 1 % of initial U is used (even with reprocessing) in LWR

- How can HTGRs fit the objectives of sustainability ?

  ⇨ The French approach (CEA-FRAMATOME/ANP) : the choice of coolant appears to be a major element of future nuclear system :

  - Water is unsuitable to fast neutron systems
  - Liquid metal leads to a complex fuel handling, and a difficult structure inspection
  - Gas coolants - their potential must be confirmed particularly in GCR

- Gas cooled reactors (GCR) their technological range potentials are the following :

  1. Economics
     - Simplicity of circuits : a single, direct-cycle circuit
     - High energy performance : gas goes directly to turbo-alternator
     - Modularity : small modules, standard, assembled in manufacture
     - Fast construction, less capital outlay
  2. Safety
     - Robust fuel in the case of accidental transients (passive safety)
     - Little interaction between fuel and coolant
     - Fuel characteristics that are likely to resist to the risk of proliferation
  3. Environment protection
  4. Optimum use of resources and minimisation of waste (fast spectrum)

- GCR : an evolutionary technological range for sustainability

  1. For the short term : first configuration is aimed at a direct cycle HTR that modern turbines enable (GT MHR or PBMR)
  2. For the medium term : specialised GCR allowing
     - Very high temperatures and high efficiency
     - Optimised configurations for waste transmutation

3. For the long term : long-lasting energetic development needs
   - Fast spectrum for breeding
   - Complete uranium consumption
   - Integrated cycle transmuting all the actinides

- Some features of GCRs
  - ⇨ Fuel cycle (short term HTR)
    - Very high burn-up : 120 GWd/t (TRISO particles)
    - 700 GWd/t (incineration - equivalent to several Pu recyclings in PWR)
  - ⇨ Once through fuel cycle» attractive from this objective (transmutation of Pu and Minor Actinides)

    BUT
  - ⇨ U consumption is 13 to 25 % higher than for a PWR

    GCR : The challenge for sustainability is to develop a fast spectrum reactor and an integrated fuel cycle system for effective utilisation of resources and waste production minimisation

- Key technology fields for a gas cooled fast neutron reactor fitting the objectives of sustainability
  1. Fuels have to
     - be confining and refractory
     - be able to obtain fast spectra and very high combustion levels
     - authorise different options in reprocessing matter
  2. Reprocessing of the spent fuel as integrated as possible with improvements of existing technologies
     - Implementation of dry processing, pyroprocessing
     - A good resistance to proliferation
  3. Materials resisting to high temperatures and to fast neutrons allowing passive safety
  4. Technology of high temperature helium circuits to be developed and improved

Hiroshi Sekimoto made some additional points on this question:

- Sustainability is an important item for the future of human being, such as the future equilibrium society. However, it will come after a certain period for transition.
- Once-through fuel cycles cannot be accepted for the future equilibrium system, but it should be acceptable in the interim. This depends on the burnup strategy & reprocessing R&D.
- For higher burnups such as Pu burner, the once-through option may be acceptable.
- For higher fissile content in the spent fuel, the reprocessing option may be better.
- Temporarily interim storage option may be attractive.
- The questions of safety and proliferation resistance are the most urgent
- The question of reducing the radiotoxic burden is less urgent.
- Urgent items should be solved soon and promoted with well supported R&D.
- However, other items should also be addressed, and supported with enough R&D.

In summary, the research programmes are not yet at the stage where a definite answer can be made to this question. The research programmes are currently at the stage where feasibility of the various technical options are being assessed. The role of HTGRs may be as in interim step towards a fully sustainable fuel cycle or they may find a role as one component of a fuel cycle with a number of different component reactors. There may be synergistic benefits of HTGRs such as establishing gas cooled technologies that might later find application in long term sustainable fuel cycles.

Specific actions

It is recommended that a summary of ARWIF-2001 should be presented to the next Nuclear Science Committee Meeting in June 2002. This presentation should specifically include a discussion of the four questions considered in the panel discussion and the responses to those questions. It is recommended that the Nuclear Science Committee also debate whether it considers that a third ARWIF workshop, to be held in 2004 would be useful.

Annex 1

List of Participants

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14 countries, 3 international organisations, 40 establishments or institutes, 84 registered participants (64 actually attended, 10 had their paper presented, and 10 others could not attend because of travel restrictions at that time).

Annex 2

Advanced Reactors with Innovative Fuels (ARWIF-2001)

Chester, UK, 22-24 October 2001

Programme

Monday, 22 October - Plenary Sessions

Opening Session - (Osbourne Suite)
Chairman: Kevin Hesketh

09:00 Opening Address
A. Worrall, K. Hesketh

09:30 (1.1) W.L. Wilkinson: Barriers and Incentives to Introducing New Reactors in the Deregulated Market

10:00 (1.2) Leon C. Walters (ANL-W-Idaho, USA), John Graham (ETCetera Assessments LLP, USA) (presented by K. Hesketh) The Need to Preserve Nuclear Fuels and Materials Knowledge

10:30 COFFEE

High Temperature Gas Reactors
Chairman: Derek Buckthorpe

11:00 (1.3) T. J. Abram (BNFL, UK), D. Hittner (Framatome ANP, France), W. von Lensa (FZ-Jülich, Germany), A. Languille (CEA, France), D. Buckthorpe (NNC, UK), J. Guidez (EC-JRC), J. Martin-Bermejo (EC DG-Research) European Collaboration on Research into High Temperature Reactor Technology

11:30 (1.5) V. Berthou, J.L. Kloosterman, H. Van Dam, T.H.J.J. Van der Hagen (IRI-Delft, The Netherlands) Design of B4C Burnable Particles Mixed in LEU Fuel for HTRs

12:15 LUNCH

Design and Performance of Innovative Fuels I (Osbourne Suite)
Chairman: Roger Thetford

13:30 (2.1) C. Degueldre, F. Ingold, C. Hellwig, P. Heimgartner (PSI-Villigen, Switzerland) , S. Conradson (LANL, USA), M. Döbeli (PSI-ETH-Zurich, Switzerland), Y. W. Lee (KAERI, R.O. Korea) Extensive Characterisation of a Material for understanding its Behaviour as a Nuclear Fuel: the Case of a Zirconia - Plutonia Inert Matrix Fuel.

14:00 (2.2.) M. Streit, F. Ingold (PSI-Villigen, Switzerland), L.J. Gauckler (ETH-Zürich, Switzerland), J-P. Ottaviani (CEA-Cadarache, France) Annular Plutonium Zirconium Nitride Fuel Pellets

14:30 (2.3) Toshiyuki Yamashita, Ken-ichi Kuramoto, Hiroshi Akie, Yoshihiro Nakano, Noriko Nitani, Takehiko Nakamura, Kazuyuki Kusagaya (JAERI-Tokai-mura, Japan) and Toshihiko Ohmichi (RIST-Tokai-mura, Japan) Rock-Like Oxide Fuels for Burning Excess Plutonium in LWRS

15:00 COFFEE

Evolutionary and Modular Water Reactors I (Osbourne Suite)
Chairman: Dieter Porsch

15:30 (2.4) Bojan Petrovic, Mario Carelli (WEC-STD, USA), Ehud Greenspan, Hiroshi Matsumoto (UC-Berkeley, USA), Enrico Padovani, Francesco Ganda (Politecnico-Mi, Italy) Innovative Features and Fuel Design Approach in the IRIS Reactor

16:00 (2.5) Kouji Hiraiwa, Noriyuki Yoshida, Mikihide Nakamaru, Hideaki Heki, (Toshiba-Corp., Japan), Masanori Aritomi (TIT, Japan) (not presented orally) Core Concepts for Long Operating

Cycle Simplified BWR (LSBWR)

16:30 (2.6) H. Akie, Y. Nakano, T. Shirakawa, T. Okubo and T. Iwamura (JAERI, Japan) Core Design Study on Reduced-Moderation Water Reactors (RMWRs)

Tuesday, 23 October - Parallel Sessions

Design and Performance of Innovative Fuels II - (Victoria Room)

Chairman: Young Woo Lee

09:00 (3.1) Young –Woo Lee (KAERI, R.O. Korea) Application of Ceramic Nuclear Fuel Materials for Innovative Fuels and Fuel Cycles

09:30 (3.2) K. Bakker and H. Thesingh (NRG-Petten, Netherlands), T. Ozawa, Y. Shigetome, S. Kono and H. Endo (JNC, Japan), Ch. Hellwig, P. Heimgartner, F. Ingold and H. Wallin (PSI-Villigen, Switzerland) Innovative MOX Fuel for Fast Reactor Applications

10:00 (3.3) K. Kusagaya, T. Nakamura, M. Yoshinaga, H. Akie, T. Yamashita and H. Uetsuka (JAERI, Japan) Behaviour of Rock-like Oxide Fuels Under Reactivity Initiated Accident Conditions

10:30 COFFEE

Design and Performance of Innovative Fuels III - (Victoria Room)

Chairman: Klas Bakker

11:00 (3.4) A. Vasiliev, P. Alekseev, K. Mikityuk, P. Fomitchenko, A. Shestopalov (RRC-KI, Russian Federation) Theoretical Requirements to Tolerances to be Imposed on Fuel Rod Design Parameters for RBEC Lead-bismuth Fast Reactor

11:30 (3.5) Jacques Porta, Bernard Gastaldi, Cécile Krakowiak-Aillaud, Laurence Buffe (CEA-Cadarache,France) Advanced Plutonium Assembly (APA) : Evolution of the concept, neutron, and thermal-mechanic constraints

Evolutionary and Modular Water Reactors II - (Osbourne Suite)

Chairman: Pierre D'hondt

09:00 (4.1) Thomas J. Downar, Yunlin Xu (Purdue-University-W.Lafayette, USA) The Utilization of Thorium Fuel in a Generation IV Light Water Reactor Design

09:30 (4.2) Dieter Porsch (Framatome-ANP- Erlangen, Germany), Dieter Sommer (KKW-Obrigheim, Germany) Thorium Fuel in LWRs - An Option for an Effective Reduction of Plutonium Stock Piles

10:00 (4.3) Y. Shimazu (Hokkaido Univ., Japan), H. Tochihara (EDC, Japan), Y. Akiyama(MHI, Japan), K. Itoh (NDC, Japan) PWRs using HTGR Fuel Concept with Cladding for Ultimate Safety

10:30 COFFEE

Fast Spectrum Reactors I - (Osbourne Suite)

Chairman: Pavel Alekseev

11:00 (4.4) D.V. Sherwood, T.A. Lennox (NNCL-Knutsford, UK) A Simplified LMFBR Concept (SFR)

11:30 (4.6A&B) H.M. Beaumont, A. Cheyne, J. Gilroy, G. Hulme, T. A. Lennox, J. T. Murgatroyd, R. E. Sunderland, E. K. Whyman (NNC) and S. J. Crossley, D. P. Every (BNFL) The Design and Flexibility of the Enhanced Gas Cooled Reactor (EGCR)

12:00 LUNCH

Molten Salt Reactors / HTGR II - (Victoria Room)

Chairman: Winfried Zwermann

13:30 (5.1) P.N.Alekseev, A.A. Dudnikov, V.V. Ignatiev, N.N. Ponomarev-Stepnoy, V.N. Prusakov, S.A. Subbotin, A.V. Vasiliev, R.Ya. Zakirov (RRC-KI-Moscow, Russian F.) Molten Salt

Reactor for Burning of Transuranium Nuclides Forming in Closed Nuclear Fuel Cycle

14:00 (5.2) D. Lecarpentier, C. Garzenne, J. Vergnes, H. Mouney (EDF, France), M. Delpech (CEA-Cadarache, France) AMSTER : A Molten-Salt Reactor Concept Generating its own 233-U and Incinerating Transuranium Elements

14:30 (5.3) U. E. Sikik, H. Dikmen, Y. Çeçen, Ü. Çolak, O.K. Kadiroglu (Hacettepe-University, Turkey) (presented by K. Hesketh) Thorium and Plutonium Utilization in Pebble Bed Modular Reactor

15:00 (5.4) Bruno Bernardin (CEA-Cadarache, France) (presented by P. Dumaz) A New Approach for the Systems Dedicated to the Transmutation: the Reactor with Compensated Beta

15:30 COFFEE

Evolutionary and Modular Water Reactors III - (Victoria Room)

Chairman: Thomas Downar

16:00 (5.5) U. Kasemeyer, C. Hellwig, R. Chawla (PSI-Villigen, Switzerland), D.W. Dean (Studsvik-Scandpower, USA), G. Meier (KKW-Gösgen-Däniken, Switzerland), T. Williams (EG-Laufenburg, Switzerland) Feasibility of Partial LWR Core Loadings with Inert Matrix Fuel

16:30 (5.6) P. Dumaz, A. Bergeron, G.M. Gautier, J.F. Pignatel, G. Rimpault, G. Youinou (CEA-Cadarache) CEA Studies About Innovative Water-cooled Reactor Concepts

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Accelerator Driven Systems - (Osbourne Suite)

Chairman: Charles DeRaedt

13:30 (6.1) Sergei E. Chigrinov, Hanna I. Kiyavitskaya, Ivan G. Serafimovich, Christina K. Rutkovskaia, Yurij Fokov, Anatolij M. Khilmanovich, Boris A. Marstinkevich, Victor V. Bournos, Sergei V. Korneev, Sergei E. Mazanik, Alla V. Kulikovskaya, Tamara P. Korbut, Natali K. Voropaj, Igor V. Zhouk, Mikhail K. Kievec, Igor L. Rakhno (RPh&ChPI-Minsk, Belarus), Experimental Investigations of the Accelerator Driven Transmutation Technologies at the Subcritical Facility "YALINA"

14:00 (6.2) H. Ait Abderrahim, P. Kupschus, Ph. Benoit, E. Malambu, K. Van Tichelen, B. Arien, F. Vermeersch, Th. Aoust, Ch. De Raedt, S. Bodart, P. D'hondt (SCK-CEN, Belgium) MYRRHA, A Multi-purpose ADS for R&D - Pre-design Phase Completion

14:30 (6.3) A. Vasiliev, P. Alekseev, A. Dudnikov, K. Mikityuk, S. Subbotin (RRC-KI, Russian Federation) Optimization of Conceptual Design of Cascade Subcritical Molten Salt Reactor

15:00 COFFEE

Fast Spectrum Reactors II - (Osbourne Suite)

Chairman: Hiroshi Sekimoto

15:30 (6.4) P. Alekseev, P. Fomichenko, K. Mikityuk, V. Nevinitsa, T. Shchepetina, S. Subbotin, A. Vasiliev (RRC-KI-Moscow, Russian F.) RBEC Lead-Bismuth Cooled Fast Reactor: Review of Conceptual Decisions

16:00 (6.5) T.D. Newton and P.J. Smith (AEAT-Winfrith, UK) Design and Performance Studies for Minor Actinide Target Fuels

16:30 (6.6) Hiroshi Sekimoto (TIT, Japan) Applications of "CANDLE" Burnup Strategy to Several Reactors

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18:30 **POSTER SESSION** (Albert Room)

(8.1) J. Somers, A. Fernandez, R.J.M. Konings (JRC-ITU-Karlsruhe, Germany), G. Ledergerber (KKW-Leibstadt, Switzerland) Some Views on the Design and Fabrication of Targets or Fuels Containing Curium

(8.2) M.A. Mignanelli, R. Thetford (Serco Assurance. UK) Thermophysical and Chemical Properties of Minor Actinide Fuels

(8.3) F. Tovesson, F.-J. Hambsch, S. Oberstedt (JRC-IRMM-Geel, Belgium), A. Oberstedt (Örebro-

University, Sweden), B. Fogelberg, E. Ramström (Studsvik-Nyköping, Sweden) Determination of the 233-Pa(n,f) Reaction Cross Section for Thorium Fueled Reactors
(8.4) A. Polismakov, V. Tsibulsky, A. Chibinyaev, P. Alekseev (RRC-KI, Russian Federation) Advanced Fuel Cycle for Long-lived Core of Small-size Light Water Reactor of ABV Type
(8.6) V. Berthou (IRI-Delft, The Netherlands), I. Slessarev, M. Salvatores (CEA-Cadarache, France) Proposal of a Molten Salt System for Long Term Energy Production
(8.7) C.C. Pain, J.L.M.A. Gomes, C.R.E. de Oliveira, M.D. Eaton, A.J.H. Goddard (Imperial College, UK), H. van Dam, T.H.J.J. van der Hagen and D. Lathouwers (IRI-Delft, The Netherlands) A Conceptual Fluidised Particle Bed Reactor - Application of Space-dependent Kinetics
(8.9) Ch. De Raedt, B. Verboomen, Th. Aoust, H. Aït Abderrahim, E. Malambu, L.H. Baetslé (SCK-CEN-Mol, Belgium) Transmutation and Incineration of MAs in LWRs, MTRs and ADSs
(8.10) Kouji Hiraiwa, Yasushi Yamamoto, Ken-ichi Yoshioka, Mitsuaki Yamaoka (Toshiba-Corp., Japan), Akira Inoue , Junji Mimatu (Gifu-University, Japan) BARS : BWR With Advanced Recycle System

Wednesday, 24 October - Plenary Sessions

Miscellaneous Themes

Chairman: Kevin Hesketh

09:00 (7.1) G. Bignan, D. Rippert, P. Fougeras (CEA-Cadarache, France) The Key Role of Critical Mock-Up Facilities for Neutronic Physics Assessment of Advanced Reactors: An Overview of CEA/Cadarache Tools.

09:30 (7.2) M. Hron, J. Uhlir (NRI-Rez, Czech Rep.) and J. Vanicek (CPC, Czech Rep.) The SPHINX Project (Experimental Verification of Design Inputs for a Transmuter with Liquid Fuel Based on Molten Fluorides)

10:00 (7.3) M. Hugon, V. P. Bhatnagar and J. Martin Bermejo (EC-Brussels) (presented by J. Somers) Advanced Concepts for Waste Management and Nuclear Energy Production in the EURATOM Fifth Framework Programme

10:30 COFFEE

Panel Discussion 11:00-12:30

Chairman: Kevin Hesketh

Panelists: P. D'hondt, H. Mouney, H. Sekimoto, J. Somers, R. Sunderland, E. Sartori

Questions for Panel Discussion:

1. Is there a gap between vendors' and utilities' fuel research programmes designed to support operation and the advanced concept research such as that presented at this conference ? If so, what can the research community do to narrow the gap ? In other words, does the field need to be made more relevant to the utilities ?
2. The benefits of advanced concepts are usually in areas such as safety, proliferation resistance, environmental impact/radiotoxic burden, strategic and so on. A major weakness is that these are "soft" issues for which there is no agreed measure of the benefit. Are there any actions the research community could take to promote agreed metrics in these areas ?
3. What should be our strategy for partitioning and transmutation given the intractability of processing and destroying curium ? Should there be a policy of encapsulating curium for eventual disposal ?
4. In the context of the objectives of initiatives such as Gen IV (particularly sustainability), how would once-though fuel cycles such as those HTGRs fit it ? What role would once-through fuel cycles fit in?

12:15 Close of Meeting