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技術報告

MONJU as an International Asset: International Assistance and Cooperation

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国際的施設としてのもんじゅ―国際的支援と協力

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The role of the fast breeder reactor prototype MONJU has expanded to meet the challenges of the 21st century. The potential for MONJU's role in the Generation IV nuclear energy systems development, and fast reactor research and development area is clear. Its incomparable fast neutron spectrum density will be a major interest not only for Sodium Fast Reactor but for all the Generation IV concepts. As MONJU's potential future role is laid out, plans for future tests can be made.

This paper describes the recent involvement of three international researchers from the USA, France and the UK who have been working at MONJU on various projects but on the same common denominator: Generation IV. MONJU is seen from this international perspective as an essential research facility, and represents a unique international R&D facility which will fulfill many roles. This paper aims to present some of them.

21世紀における課題に向け高速原型炉「もんじゅ」に与えられた役割は拡大している。第４世代原子力システム開発，高速炉の研究開発分野における「もんじゅ」の将来的役割は明確である。その極めて大きい高速中性子スペクトルはナトリウム高速炉だけでなく，全ての第４世代原子炉システム概念にとっても大変重要である。

本報では，米国，仏国，英国からの３名の国際特別研究員及び駐在員が第４世代原子炉システムを目指して「もんじゅ」に係る様々な分野で研究している状況を報告する。「もんじゅ」は国際的観点から見て貴重な研究施設であり，多くの役割を成就する特有の国際研究開発施設である。現在,「もんじゅ」における国際協力は既に多様な成果を生み出しつつある。そのいくつかについて報告する。（本報告は，ANS Symposium- Building Bridges to Greater Cooperation, Miami Beach (2004)に報告されたものである。）

Key Word

Generation IV, Sodium Fast Reactor, International Collaboration, MONJU, International Fellowship, Post Irradiation Examination

第４世代原子力システム，ナトリウム高速炉，国際共同研究,「もんじゅ」，国際特別研究員，照射後試験

1. Introduction

Since the advent of civilian nuclear energy in the latter half of the 20th century in the west, the need for breeder reactors, such as the experimental ones built in the U.S. (EBR I, and EBR II), France (Phenix, Super Phenix), United Kingdom (PFR, DFR) and Germany (KNK)was well accepted. As the breeder designs were built and

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proven over the course of decades of reliable operation, research and development project funding was cut back, resulting in the shutting down of all plants still operating successfully, with the exception of France's Phenix. Today in the context of fossil fuel emissions, green house effects, unstable fossil fuel supplies, potential disruptions of fuels supplies, etc., the U.S. and other leading energy generators and consumers have come together to engage the worldwide community in discussions on the development of the next generation nuclear plant concepts, known as Generation IV. [1]

The United States along with nine other countries including France, the United Kingdom, and Japan have joined in the Generation IV program. Japan also brings a wide range of nuclear experience particularly in Fast Breeder Reactor technology. Of the six candidate Generation IV systems four are breeder reactors, or fast breeders. So the experience of France's Phenix, and the Japanese JOYO and the new much larger MONJU will contribute to the advancement of the Generation IV reactor concepts.

This paper discusses the cooperative efforts of the U.S., France, the United Kingdom and Japan, in furthering the program of the nuclear technology, MONJU and the Generation IV concept, and the Japan Nuclear Cycle Development Institute's International Exchange and Fellowship Program.

2. MONJU presentation

The development of Fast Breeder Reactor in Japan was initiated by the erection of JOYO reactor, which reached its first criticality in 1978 and still is operating. In 2003, JOYO core was successfully upgraded from 100 MWt (MK-II core) up to 140 MWt (MK-III core).

Then the design of MONJU reactor as a prototype reactor started. MONJU is on the strategic path to FBR deployment policy to develop Fast Breeder reactor technology and to achieve commercialization FBR in mid term of the 21st century [2]. MONJU is Japan's prototype fast breeder reactor : 280 MWe (714 MWt), fueled with mixed oxides of plutonium and uranium, cooled by liquid sodium. It is located in Tsuruga peninsula along with several other nuclear reactors in this area (Fig. 1).

Construction was started in 1985 - and initial criticality was attained in April 1994. In August 1995 there was the first connection to the grid. MONJU reactor is a loop type sodium reactor design with three secondary sodium loops connecting with three Steam Generators (Helical coil) (Fig. 2). Principal data are given in Table 1.

On the 8th of December 1995, sodium leakage from a secondary circuit occurred in a piping room of the auxiliary building. The secondary sodium leaked from the C Loop through a temperature sensor (Fig. 3), due to the breakaway of the tip of the thermocouple well tube installed close to the secondary circuit outlet of the Intermediate Heat Exchanger (IHX). Cooling of the reactor was never jeopardized, due to the redundancy of the three loop cooling circuits, and thus, the safety of the reactor was secured. There was no release of radioactive material. There were no adverse effects of personnel and the surrounding environment. The thermocouple well tube failure resulted from high cycle fatigue due to flow induced vibration. It was found that this flow induced vibration was not caused by the flow-crossing vibration with the well-known Von Karman vortex shedding, but by the flow-along vibration with a symmetric vortex shedding. The new more robust thermocouple well design, based roughly on the earlier design

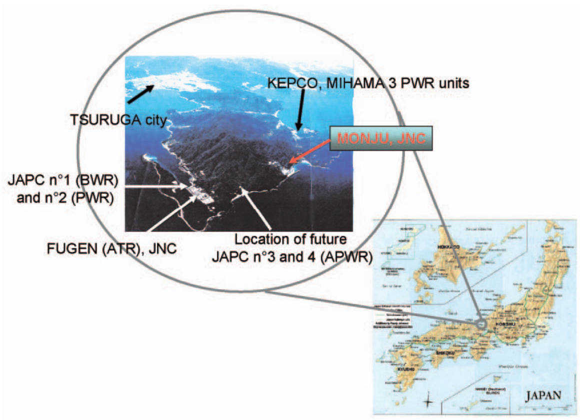

Fig. 1 : Aerial view of Tsuruga peninsula and location of different reactors

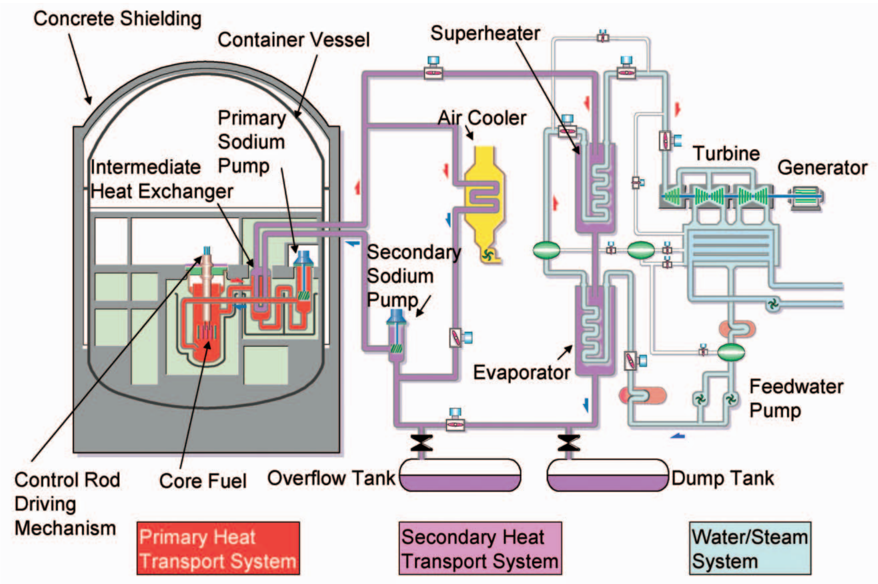

Fig.2 : Cut-away view of Monju plant

Table 1 : Monju main data

Reactor type	Sodium Fast Reactor, loop-type
Thermal output	714 MW
Electrical output	280 MW
Fuel type	Plutonium-uranium mixed oxide
Core Dimensions	
Equivalent diameter	Approx. 1,800 mm
Height	930 mm
Volume	2,340 liters
Plutonium enrichment (Pu fiss. %) Inner/outer core	16/21
Fuel mass loaded (equilibrium)	
Core (U+Pu metal)	5.9 tons
Blanket (U metal)	17.5 tons
Average burnup	Approx 80,000 MWd/t
Cladding tube Outer diam./thickness	6.5/0.47 mm
Cladding tube material	SUS 316
Power density	275 kW/l
Blanket thickness (Upper/lower/radial)	300/350/300 mm
Breeding ratio	Approx 1.2
Primary sodium temperature (Reactor inlet/outlet)	397/529 ° C
Secondary sodium temperature (IHX inlet/outlet)	325/505 ° C
Number of loops	3
Dimensions of reactor vessels (height/diameter)	18/7 m
Steam pressure before main stop valve	127 kg/cm^2
Steam temperature at turbine inlet	483 ° C

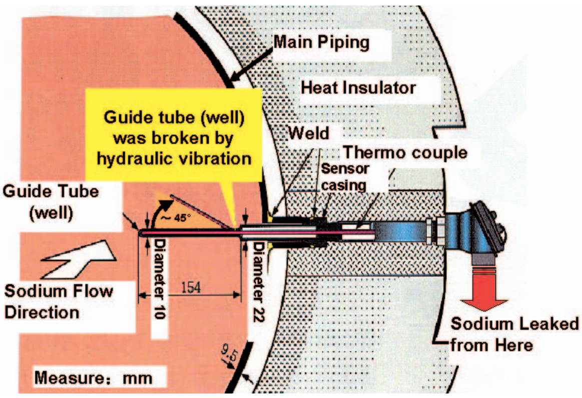

Fig. 3 : Drawing of the broken thermocouple phenomenon

which was modified to avoid this phenomenon, was analyzed, reviewed and found acceptable [3]. These new thermocouples will replace the original thermocouples upon approval of the plant improvements.

Additionally, comprehensive design review activities were started for the purpose of checking the safety and reliability of the plant including to prevent a recurrence of the secondary sodium leakage incident. As a result, several aspects to be improved were identified. The other main improvements and countermeasures are as follows:

- To enable the operators to understand and react to incidents quickly, new sodium leakage detectors (TV monitors, smoke sensors, thermo-detectors) and a new surveillance system will be installed,
- To reduce the amount of sodium leakage and damage by spilt sodium, drain system will be remodeled to shorten the drain time [4], (Fig. 4)
- To extinguish a sodium fire in the secondary circuit, a nitrogen gas injection system will be installed,
- To limit the spread of aerosols, each secondary circuit area will be divided into three smaller zones.

After a one-and-a-half year long Safety Licensing Examination, the Permission for the MONJU plant modification relative to measures against sodium leak was granted in 2002. After modifications and repairs still to be done, two main programs will be applied: Function Confirmation Tests (KKS) and System Start-up Tests (SST) [5], [6]. KKS tests aim to qualify the countermeasures taken mainly against sodium leak. SST: System Start up Tests are carrying out after nuclear starting to continue the program interrupted in 1995 by the sodium leakage. The detailed designed and construction procedure for the plant modification was approved in January 2004. The modification works should last 18 months.

3. Review of the MONJU future program

After repair and modification, the MONJU operating program is based on several phases. First a stable running operation will be done for the demonstration of the mastering of sodium handling and all maintenance operations. This duration should be around 5 years. The objective is then to go from low to high burn up. The primary goal is to demonstrate operational reliability up to 80 GWd/t burn up. Subsequent to that it with upgraded cores to achieve up to 100 GWd/t then 150 GWd/t burnups. At the same time it is intended to increase maximum linear rate from 360 W/cm up to 480 W/cm and to define several irradiation space (6 to 30 assemblies) for demonstration of burning of Minor Actinides and Fission Products transmutation [7]. Therefore the MONJU core evolution and future program of MONJU is going towards several requirements given to Generation IV program and projects:

i) High potential to operate with a high conver-

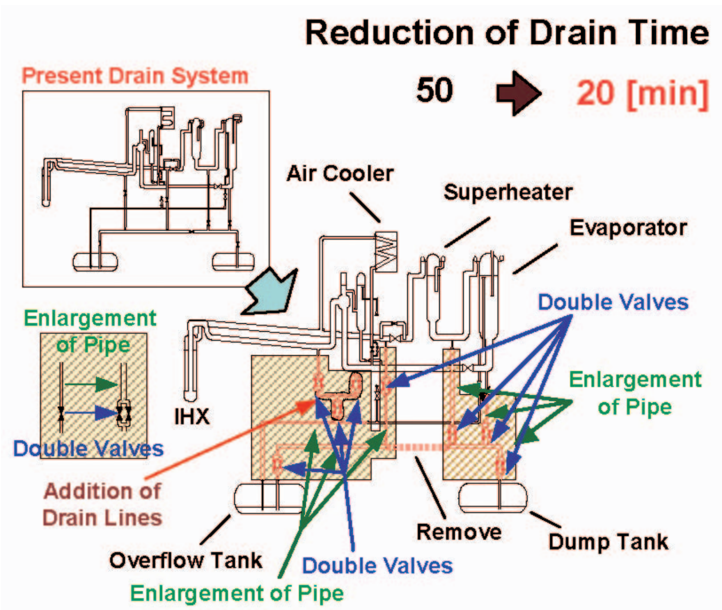

Fig.4 : Monju Drain Line Modifications

sion fast spectrum core with the resulting benefits of increasing the utilization of fuel resources.

ⅱ) Capability of efficient and nearly complete consumption of transuranics as fuel, thus reducing the actinide loadings in the high level waste with benefits in disposal requirements and potentially nonproliferation.

ⅲ) Enhanced economics achieved with the use of high burn-up fuels, fuel cycle (e.g., disposal) benefits, and lower operating costs achieved with improved operations and maintenance.

Since the very beginning international involvement at MONJU has always been a reality with many foreign technical exchanges. International agreements have been made with different nuclear power generating countries involved in Sodium Fast Reactor technology such as France, UK, USA, China, and Korea. And the International Research Fellowship program to facilitate this international effort. On October 1st, 1998, the JNC founded the International Cooperation and Technology Development Center (ICTDC). This center is located close to MONJU site (Fig. 5). The Center exists specifically to formulate and perform projects ensuring the maximum technical benefit from MONJU. The staff at the ICTDC includes physicists, engineers and nuclear industry leaders from around the world. Research Fellowships are focused on several specific areas such as advanced instrumentation, inspection techniques, plant reliability and safety, nucleonics, sodium handling technologies, irradiation and experiment management and coordination and advanced post-irradiation examination capabilities and techniques.

Fig. 5 : Aerial view of Monju plant and ITCDC buildings

4. The international involvement of MONJU reactor

MONJU and the JNC are definitely open towards foreign participation and international cooperation. With support from the ICTDC, MONJU is projected to play a key role in the international Generation IV program. Already this international cooperation is operational and efficiently working. Several recent international co-operations are described below.

4.1 The International Panel's Commissioning Test Review of MONJU

In early 2003, JNC decided to conduct an International Readiness Review. The international review for the MONJU preoperational test program was carried out by inviting four senior engineers with long FBR development experience from US (EBR II reactor), UK (PFR reactor), France (Phenix and Super Phenix reactors) and Germany (KNK II reactor) (Fig. 6). The purpose of this review was to utilize and apply the knowledge and

Fig 6. The international reviewer team at ICTDC office.
(from left to right : D.C. CUTFORTH (USA), K. BROCKMANN (Germany), R. A. STUART (UK) and B. MESNAGE (France))

experience of the overseas advanced fast reactor scientists and engineers to draft the MONJU pre-operational test program and thus to enhance the international cooperation at MONJU. They reviewed the program of KKS as well as SST from the following view points:

ⅰ) Comparison of test items and contents with overseas advanced reactors

ⅱ) Comparison of preparation and prior confirmation items for restart after long-term shutdown with overseas advanced reactors experience (due to the accidents and remodeling)

ⅲ) Proposal for new test items, etc.

The review lasted from January 6th, 2003 to March 31st, 2003. In this three month time an intensive review was conducted with the collaboration of all MONJU and ICTDC members. Statistically speaking, during this period, the total meeting times have been estimated to be 40 hours (9 weekly meetings and 4 individual meetings). There were 160 questions officially produced by the reviewers that lead to the assembly of 73 prepared documents for explanation and documentation. At the end, every reviewer produced a personal written report and a common synthesis has been given to JNC. This synthesis was including a summary table with all recommendations and comments. As a final result, 38 recommendations and 9 comments were addressed to MONJU. The matters pointed out by this review were not only focused on the contents and procedures of MONJU preoperational tests, but also considered of the improvement of the ability for operation and maintenance of MONJU in the future as well as future expectations for MONJU as an irradiation core. JNC has taken into consideration these comments and recommendations and has adapted its future tests consequently.

4.2 The plant modification program, and its review by an international fellow (UK)

As a follow-on to this international review, one reviewer, (Mr. Roger A. STUART) joined MONJU plant as a JNC international fellow, assigned to the MONJU Operation and Maintenance Engineering sections. The role of this fellowship is to give a global view and provide international expertise to all maintenance operations done or prepared at MONJU. Concurrently, it will measure actions recommended by the international review team and assess how recommendations have been taken into consideration by MONJU team. This expert work is also provides opportunity to provide technology transfer in several fields including safety, maintenance technology, work control, and conduct of operations. As an example of this technology transfer, a HAZOP review (Hazard and Operability) has been conducted with JNC maintenance team. HAZOP is one of a number of techniques which may be used to undertake safety reviews. It is now widely used in UK nuclear safety standard and required for every new and/or novel technology. The explanation of the HAZOP principle and its demonstration on the basis of a simple effective example taken from MONJU plant was the opportunity to exchange nuclear safety approaches and cultures from respective countries. This HAZOP review was chaired by UK fellow with the participation of the French CEA representative.

4.3 The role of the CEA (French Atomic Energy Commission) representative as a link between Phenix and MONJU plants, and between CEA and JNC companies

MONJU and Phenix have always had strong links of exchanges and relationships. These links are concretized by collaborative exchanges on technical subjects within the yearly Phenix/MONJU meetings. Moreover since 1991, agreement between the JNC and CEA allows reciprocal personnel exchanges from both reactors. Therefore since this date, 10 attaches from MONJU have been sent to the Phenix plant for missions lasting from 1 to 2 years. For its part, the CEA provides a mission to the French international representative on MONJU site that can be summarized by the following actions :

ⅰ) A link between MONJU and Phenix plants.

It will ease the exchange of technical information of both reactors and can give a quick answer on technical demand. To assume this work, the French representative can use particular CEA Fast Reactor databases, and provide a strong on-site link with the Phenix's assistant in charge of international relationships.

ⅱ) The CEA representative on several national or local events and conferences.

This activity is complementary to those done by CEA representative cabinet held in Tokyo. The MONJU CEA representative is providing news and technical data not only on MONJU situation but also on other JNC Fast Breeder Reactor programs : JOYO reactor, JNC Feasibility study on commercialized Fast Reactors held in O-arai Engineering Center, Generation IV programs.

iii) The support and help to JNC research and development program.

CEA representative is contributing by giving its own experience or by connecting to CEA French experts to improve the relationships between both companies and to try to solve or answer to technical questions. CEA's representative relies on the support of CEA senior expert's to provide quick and complete answers or technical expertise. Moreover, he is also involved as expert to do complementary reviews in support of the UK's fellow located at MONJU.

Defined at the beginning of the 90's as a collaborative technical exchange between Phenix and MONJU reactors, the role of the CEA representative has gained a larger responsibility. Its action within MONJU is completely integrated in the involvement of France into Generation IV Sodium Fast Reactor program whose leadership has been accepted by Japan. The CEA representative's position is renewed every year.

In parallel with this role, CEA representative is a link between French and Japanese sodium school to enhance international formation in FBR field. Indeed, in 2001, JNC and CEA finalized a specific agreement to strengthen links between both sodium schools: from Cadarache center and from MONJU site. It was therefore decided that CEA lecturers - experts in the field of sodium technology - will present a large and complete lecture program composed of 37 different courses. Since 2002, every year, an annual three day meeting is organized where 6 to 8 courses are presented in English language with simultaneous translation into Japanese (Fig.7). This collaboration should last until 2006. By that time, a major part of the French sodium school knowledge - an experience of more than 30 years (French sodium school opened in 1975) - will be transmitted to the JNC sodium school. It is expected from this thorough exchange, a common approach in teaching sodium technology. The JNC and CEA are already working on ways to pursue the strong links between the two sodium schools after 2006. The international involvement of both schools of sodium technology and their availability to all countries developing sodium fast reactors is a clear way of assuring future progresses.

4.4 The Post Irradiation Examination Facility project and the expertise of an international fellow (US)

The original mission of MONJU as a prototype fast breeder reactor was to demonstrate the economic and safety aspects of the liquid metal cooled fast breeder reactor. As such no post irradiation examination facility beyond readily available reactor or reactor auxiliary plant-resident systems would ever be needed. Now that MONJU is going to be the answer for the source of fast neu-

Fig.7 : A CEA lecture at ICTDC sodium school

trons for the research and development of Generation IV systems (see below), it will be necessary to have post-irradiation examination capabilities on site. These facilities will in no way supplant the excellent facilities already in existence at the JNC's O-arai Engineering Center [8], but will complement them. The complementary role of the MONJU semi-full scale post irradiation examination facility will support not only the experimental irradiations program with quick turn-around of experiments' non-destructive examinations and verifications, but it will also support the operational aspects of MONJU in its role as experimental irradiations test bed.

The role of the semi-full scale post irradiation examination facility at MONJU will be to provide quick turn-around of experiments to the reactor after projected change outs or rebuilds of subassembly hardware or capsules, to perform confirmatory measurements and examinations, and to provide non-destructive examination capabilities in support of surveillance programs, thus aiding in the establishment of exposure limits and thereby assuring operability of in-reactor components to and beyond projected life-times. Such programs aid in the development of materials and designs so necessary in the advancement of the technology. Thus the role of the MONJU Semi-full Scale Post Irradiation Facility will be to support the non-destructive examination needs of the reactor and the experimental irradiations program.

As a leader in the realm of Post-Irradiation Examination Examinations and nuclear energy systems' research and development, Argonne National Laboratory-West has provided engineering support to the scoping of MONJU's PIE facility. As such the proposed capabilities and systems of the MONJU PIE facility will bear a strong resemblance to the Argonne National Laboratory-West's Hot Fuel Examination Facility (Fig. 8) and the JNC's Fuels Monitoring Facility at O-arai, both of which are considered world-class, successful examples of facilities for the characterization and analysis of radioactive fuels and materials.

Fig. 8: Conceptual sketch of Semi-Full Scale Post-Irradiation Examination Facility for Monju

5. MONJU's future projects and the initiative in Generation IV programs: The industrial demonstration of burning of Minor Actinides

As it was written in a recent paper written by the President of American Nuclear Society [9] :

“*In order to realize a bright future for nuclear power, we must respond successfully to five challenges:*

- ⅰ) *Nuclear power must remain economically competitive.*
- ⅱ) *The public must remain confident in the safety of the plants and the fuel cycle.*
- ⅲ) *Nuclear wastes and spent fuel must be managed and the ultimate disposition pathways for nuclear wastes must be politically settled.*
- ⅳ) *The proliferation potential of the commercial nuclear spent fuel cycle must continue to be minimized.*
- ⅴ) *We must assure a sustained manpower supply for the future and preserve the critical nuclear technology infrastructure.*

The Generation IV program is conceived to focus the efforts of the international community on responding to these challenges.”

Amongst these five challenges, MONJU can play a key role in experimentation and irradiation under fast spectrum of new fuels and materials. This international collaboration has already started with the international project of demonstration of Minor Actinide burning in fast reactors. Indeed, in the framework of studies on radioactive waste minimization, one promising option is the transmutation of Minor Actinides (MA) and Long Life Fission Products (LLFP) in nuclear reactors. In the reduction of the quantity and the radio toxicity of waste, Fast Reactors can play a key role because of their advantageous fast neutron spectrum favorable for transmutation. Consequently, CEA has developed an irradiation program in Phenix reactor to demonstrate the technical feasibility of transmutation. The irradiation program at Phenix consists of several experimental tests that can be classified into five items [10] :

- ⅰ) General irradiation data acquisition
- ⅱ) Fuel irradiation for homogeneous transmutation mode (whole pin scale)
- ⅲ) Target irradiation for heterogeneous transmutation mode (sub-capsule scale)
- ⅳ) Irradiation of high Plutonium content fuel
- ⅴ) Fuel irradiation for future systems, e.g., higher burnups, advanced alloys, higher temperature.

Therefore, several experimental assemblies are already in the Phenix core for irradiation. An ambitious irradiation program is planned until 2008, at the final shutdown of Phenix. Post irradiation examination will provide major data and show possible ways to improve irradiation performances in 2009. In parallel, a trilateral project (Japan, France, USA) has been created in 2004 to continue and achieve this important program by realizing in MONJU plant, a commercial demonstration of the capability for Fast Reactor to burn minor actinides coming from fuel reprocessing and separation from LWRs. MONJU is intended to be used for transmutation testing in realistically high, fast flux conditions. This unique project is clearly a first step toward the goals and requirements of the Generation IV program, i.e., to reduce the burden of radioactive waste disposal. The design of new core configurations to meet these goals is already under development (Fig . 9).

6. Future objectives and the need for international collaboration

In the coming years, MONJU has the potential to have a major role in the international nuclear community. The selection of four fast reactor concepts among the six selected for Generation IV, highlights the near term urgency for a fast neutron source with which to demonstrate transmutation concepts and new fuel designs. The lack of fast reactors in the coming decades (Fig. 10) is a clear indicator that MONJU will be the center of many international collaborations.

This unique future role has been clearly expressed by international scientific panel during meeting held at Tsuruga [12]. Therefore, MONJU is projected to be an international irradiations test

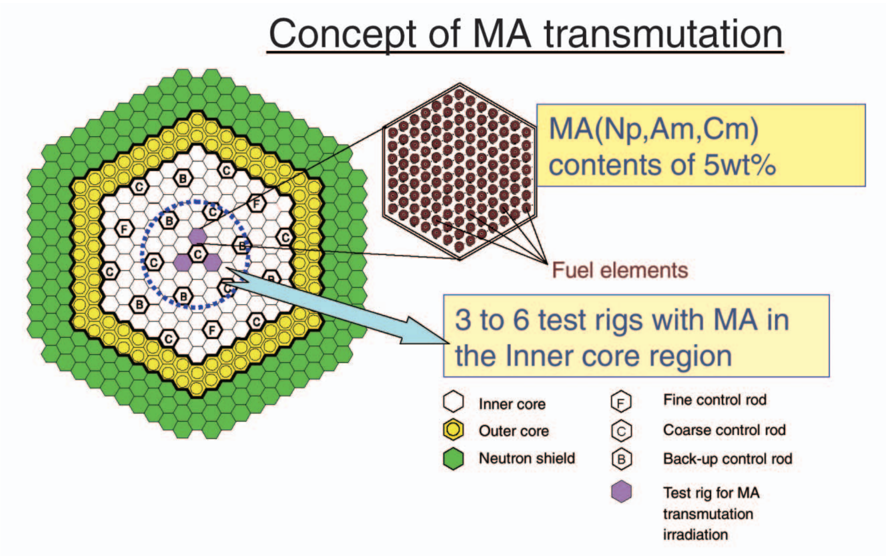

Fig. 9 : Development of new Monju core configuration of Minor Actinide transmutation

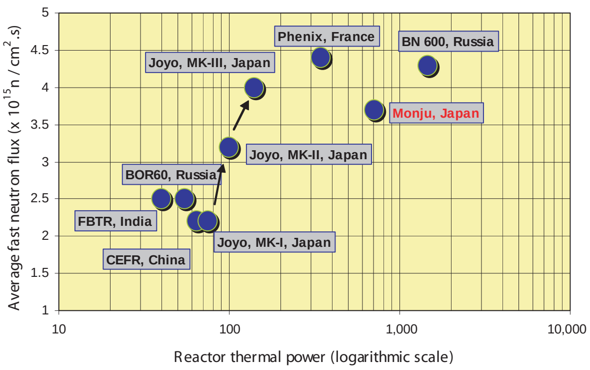

Fig 10. : The available Fast Neutron Flux in the world estimated at around 2006 (done upon data provided from Fast Neutron Database [12]).

bed and its technical support organizations are foreseen to be a future center of excellence for the international nuclear scientific community.

7. Conclusions

Since its early start, MONJU has always been strongly involved in international collaborations. This paper aimed to show how in fact this has developed. If we consider the future, there is no doubt that this international implication will go increasingly. Indeed, in 2008, MONJU associated with JOYO will remain the two only fast irradiation tools from the Organization for Economic Cooperation and Development countries or from Generation IV member countries. Therefore its future role is a prime importance and MONJU is not having only a national destiny but is fully implicated in an international context. It can be the car that will drive the nuclear community towards Generation IV reactors and advanced fuel cycle initiative.

8. Acknowledgments

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