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The First Studsvik AB-JAEA Meeting for Cooperation in Nuclear Energy Research and Development July 18, 2008, JAEA-Oarai

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The First Studsvik AB - JAEA Meeting for Cooperation in Nuclear Energy Research and Development
July 18, 2008, JAEA-Oarai

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Based on the implemental agreement between the Studsvik AB and the Japan Atomic Energy Agency (JAEA) for cooperation in nuclear energy research and development, the first annual meeting was held at Oarai Research and Development Center, Japan Atomic Energy Agency. In this meeting, information exchange on two cooperation areas, “Radioactive waste treatment technology including recycling of materials” and “Technical developments for the neutron irradiation experiments in materials testing reactors”, was carried out, and future plan in cooperation was discussed. This report describes contents of information exchange and discussions in two cooperation areas.

Keywords: Radioactive Waste Treatment Technology, Recycling of Materials, Irradiation Technology

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スタズビックグループと日本原子力研究開発機構との
原子力開発分野における協力のための第１回会合

日本原子力研究開発機構　大洗研究開発センター
照射試験炉センター

（編）石原　正博、柳原　敏[+]、
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（2008 年 10 月 10 日　受理）

スタズビックグループと日本原子力研究開発機構との間の原子力開発分野における協力のための実施取決めに基づき、情報交換と今後の進め方に関して議論するための第１回定例会合を行った。本会議では、研究協力テーマである「リサイクルを含む放射性廃棄物処理技術」及び「照射試験炉における中性子照射試験に関する技術開発」に関し、双方から現状と課題等について報告した後、今後の研究協力の進め方等についての議論を行った。本報告書は、情報交換の内容等についてまとめたものである。

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1. Introduction

The Studsvik AB (its former organization AB Atomenergi was formed in 1947 for the purpose of developing building and operating nuclear power stations in Sweden) has wide fields of experience/technology with the R2 reactor's operation; e.g. materials irradiation technology, post irradiation technology, RI production technology as well as radioactive waste treatment technology aiming at the clearance treatment. On the other hand, the Japan Atomic Energy Agency (JAEA) has devoted efforts to produce prominent achievement in research and development activities concerning long-term energy security, countermeasures for environmental problems and certain advanced science and technology with competitive advantage. Within the research and development activities, several projects have been promoted for sustainable nuclear energy utilization. These include the projects of the refurbishment/re-operation of the Japan Materials Testing Reactor (JMTR), and operation of the advanced volume reduction facility (AVRF) to treat radioactive wastes for producing final disposal form.

In these situations, the Studsvik AB and the JAEA decided to push on effectively with the cooperation research and development on projects with both organizations, and the Memorandum of Understanding between both organizations for the future cooperation in nuclear energy research and development was signed May 23, 2006. Moreover, noting the Memorandum of Understanding, and wishing to cooperate in nuclear energy research and development, implemental agreement was signed December 12, 2007.

Under the implemental agreement on cooperation in nuclear energy research and development, first annual meeting was prepared by the JAEA, and held at Oarai Research and Development Center, JAEA on July 18, 2008. In this meeting, information exchange was carried out on two cooperation areas, "Radioactive waste treatment technology including recycling of materials" and "Technical developments for the neutron irradiation experiments in materials testing reactors". Moreover, the future cooperation plan under this agreement was discussed, and the action plan for both parties was proposed in two cooperation areas. Contents of information exchange and discussions in the meeting are prescribed in this report.

2. Cooperative program between JAEA and Studsvik AB

The implemental Agreement between the Studsvik AB and the Japan Atomic Energy Agency was signed December 12, 2007 for cooperation in nuclear energy research and development. The objectives of this Implementation Agreement is to establish a general framework of cooperation in the field of research and development of nuclear energy and to define terms and conditions under which the parties will cooperative on a balanced basis. (The Implemental Agreement is attached in the appendix.)

The specific areas are defined in the agreement as follows:

- Radioactive waste treatment technology including recycling of materials,
- Technical development for the neutron-irradiation experiments in materials testing reactors.

The first area covers the radioactive waste treatment, recycling of nuclear materials, and measurement of radioactivity. The second area covers international standard in neutron-irradiation experiments, industrial application of materials testing reactor, and advanced irradiation technology.

Activities of cooperation are also defined in the agreement as follows:

- Exchange of general information,
- Exchange of scientific and technical information on specific topics,
- Short visits by specialists to the facilities of the other Party relevant to the area of cooperation,
- Joint research and development studies on specific topics,
- Exchange or attachment of staff.

3. Technical exchange meeting

3.1 Outline of information exchange meeting

On the basis of the agreement, the first annual meeting was held for information exchange at Oarai Research and Development Center, Japan Atomic Energy Agency on July 18th, 2008. In this meeting, there were seven presentations, four by JAEA and three by Studsvik AB, on the two cooperation areas; radioactive waste treatment technology including recycling of materials and technical developments for the neutron irradiation experiments in materials testing reactors. The agenda is attached in the appendix A1.

The subjects are as follows:

Radioactive waste treatment technology

(1) Study on waste treatment for effective recycling (JAEA)
(2) Assurance for radioactive metal clearance and recycling (Studsvik Nuclear AB)
(3) Present status of waste treatment for volume reduction (JAEA)
(4) Treatment and volume reduction of radioactive metal (Studsvik Nuclear AB)

Irradiation technique in materials testing reactor

(1) JMTR strategy on re-operation (JAEA)
(2) Status and assignment of post irradiation examinations (JAEA)
(3) Irradiation technique and industrial utilization (Studsvik Nuclear AB)

After the presentation, discussions were followed to strengthen the mutual understanding and remarks in further development of the studies in each party. As for the radioactive waste treatment technology including recycling of materials, discussion was focused on treatment of large components such as spent nuclear fuel casks sent by JAEA to Studsvik AB facilities for effective material recycling. Major issues are the cost of transportation of large components and the reasonability of treatment in foreign facilities.

3.2 Summary of presentation

Radioactive waste treatment technology

(1) Study on waste treatment for effective recycling

Radioactive wastes generated from research activities are collected in the waste treatment and storage facilities in the Nuclear Science Research Institute of Tokai Research and Development Center. It is planned to treat the wastes for producing final disposal form by the Advanced Volume Reduction Facility (AVRF). However, various kinds of wastes have been stored so far, and some of the wastes are difficult to be treated effectively or troublesome by the AVRF. It should be, therefore, considered to treat the waste by using other facilities and also to take account of clearance for free releasing.

Under the background described above, feasibility on waste treatment in foreign facilities was studied to treat effectively the waste for recycling. Major subjects to be studied are as follows;

- Regulatory frame on import/export of radioactive wastes
- Transportation of radioactive materials or large components
- Waste treatment in foreign facilities
- Transaction of returned radioactive materials in regulatory frame
- Advantage/disadvantage of radioactive waste treatment in foreign facilities

Two kinds of waste were assumed as the objects to treat in foreign facilities; very low-level radioactive metal waste stored in storage facility of JAEA and the slightly radioactively-contaminated metal components (Spent fuel transfer casks). The casks have been categorized into non-radioactive material group. However, cautious transaction will be necessary to them in taken out of the nuclear site. There is a possibility that these materials will be released as a non-radioactive material if these are treated by melting and confirmed of complying the release criteria on the clearance procedures. The major results obtained so far in the preliminary feasibility studies are as follows: It is basically possible under the present legal frame to export radioactive waste for treatment in foreign facilities. However, since there is no precedent, it may be required by the government to explain the detail plan. Costs were evaluated in terms of transportation and treatment in Europe.

In the preliminary studies, it might be possible to treat some waste in foreign facilities. However it is important to reinforce the reasonability of treatment in foreign facilities from financial point of view. There are some cost figures evaluated on waste disposal in Japan; 130,000 yen/drum of trench disposal, 700,000 yen/drum of pit disposal, where both not including treatment costs. In addition, we need further consideration about possibility of clearance materials being brought back to Japan for recycling or reusing in regulatory frame.

(S. Yanagihara)

(2) Assurance for radioactive metal clearance and recycling

The nuclear industry is today facing the fact that repository space is limited and cost for waste disposal is constantly increasing. With fossil fuel contributing to global warming a renaissance of nuclear power puts the question of radioactive waste treatment in the spotlight.

A large volume of waste from NPP's is generated as the segment defined as LLW (Low Level Waste) and the rate of waste generation is quickly reducing repository space. This puts focus on waste volume reduction as an important mean to save cost and capacity.

Several categories of waste can be identified from the nuclear industry, and these are:

- Metal waste (LLW - surface contaminated, not induced contamination)
    - Can come in large variety of shapes and forms but is generally very heavy.
    - Very large and heavy objects are difficult to move and bulky to put into a repository as they are.
- Combustible waste (LLW)
    - Large volumes are generated and create a form of LLW that is not suited to put into a repository as is due to its unstable form.

Both forms of waste mentioned above can be reduced down the volume to a residual volume of between 3-10 % and thus save a proportional cost in repository. Metal treatment as well as volume reduction of combustibles is performed by both the NPP's and specialised service suppliers but vary from one country to another.

- Surface contaminated metal can, in most cases, be decontaminated, clearanced and free released through recycling back into the market. Residual material containing the radioactive nuclides is classified as a secondary waste and returned to owner as country of origin for final repository requiring significant less volume and cost.
- Combustible waste can be incinerated, and the energy can be recirculated. Residual ashes containing the radioactive nuclides are classified as a secondary waste and returned to owner as country of origin for final repository requiring significant less volume and cost.

To perform waste volume reduction of LLW it is important to assure a good control during the decontamination and to ensure the radioactive nuclides collected and conditioned in a safe way for final repository. Personnel exposure should always be minimized (ALARA) as well as good measures taken to contain all activity during waste volume reduction processing. The obvious principle is that the radioactive nuclides always should be returned to the country of origin after the waste volume reduction service.

For metal treatment, the bulk of the material can be classified after assurance as a suitable material for clearance and ultimately free released and recirculated metal market.

Assurance to meet the regulatory demand on maximum residual activity in metal aimed at free release is an area of Studsvik spent large effort on. Over the last 20 years Studsvik has developed own unique tools and methods for decontamination of metallic LLW, and also best practical mean to verify results.

Wipe testing and scintillation measurements are time consuming, and even if sample volume is very large, it will be difficult to say it is representing the whole piece of material. Consequently it will be difficult to demonstrate reliably that regulatory values are met for the material aimed for free release. The problem is even more obvious if the item has complex geometries. The use of metal melting technique has been found to be a very reliable mean in the procedure of verifying residual activity since a representative sample of the whole batch easily can be taken.

Radiological analysis can be made to verify the whole batch from the small sample and the data and sample is archived for future reference. The data is considered reliable and is ground for transfer of ownership to Studsvik as long as the metal batch is meeting criteria for clearance and subsequently recycles through free release. Secondary waste containing the radioactive nuclides is radiologically analyzed to verify the activity. A final report is always written to summarize the work and returned to the owner together with the secondary waste from the volume reduction process.

(Anders Stenmark)

(3) Present status of waste treatment for volume reduction

As a result of a half century of persistent R&D for atomic energy in Japan, a large amount of low-level radioactive solid wastes (LLW) are stored in the Nuclear Science Research Institute (NSRI) of the Japan Atomic Energy Agency (JAEA). Most of these wastes aren't suitable for near-surface disposal criteria because they don't have enough chemical and physical stability and their detail radioactive inventory haven't been evaluated yet.

JAEA had therefore decided to construct the Advanced Volume Reduction Facilities (AVRF) at the NSRI to reduce volume of LLW, to make LLW into waste packages for near-surface disposal.

The AVRF consist of the Waste Size Reduction and Storage Facilities (WSRSF) and the Waste Volume Reduction Facilities (WVRF).

In the WSRSF, large size wastes such as tanks are cut to reduce the size, segregated by materials and undesirable materials such as liquid, heavy metals are removed. The size reduction is carried out by cutting installations such as a laser cutter, a plasma cutter, a shear cutter and so on according to the shapes and the materials of the wastes. From June 1999, total 880 m3 of LLW have been treated and volume of the large size wastes reduced to 1/3 by the size reduction.

In the WVRF, the wastes are segregated in pre-treatment system and the volume is reduced by super compactor, metal melting system or non-metal melting system. The cold tests started in February 2003.

Wastes are segregated by materials and undesirable materials are removed in the pre-treatment system. The hot operation has partly started in the system since September 2005. As a result, it was found that increasing the processing capacity is needed for future steady operation.

The super compactor consists of the horizontal direction unit with 500 ton force and the vertical direction unit with 2,000 ton force. Compacted drums are filled into new 200-liter drums as close as possible to the limit of the height. The volume reduction ratio was about 1/3 in cold tests. The hot operation is planed to start at second half in 2008.

The metal melting system has an induction furnace with 1.2MW of electric power. The non-metal melting system has an incinerator and a plasma furnace with 2.6MW of electrical power. During cold tests to find out the optimal conditions for homogenization of molten slag of non-metal melting system, the fire trouble happened in February 2006 because of wrong selection of repair materials inside the bellows of plasma furnace. After the trouble, preventative measures has developed and resumption of cold tests is in preparation.

The super compactor is used for treating reactor wastes mainly because of radioactive inventory aspect. The radioactive inventory of such wastes can be evaluated by detecting only γ-ray emitting nuclides such as Co-60 and Cs-137, so called key nuclides, if the correlation between the key nuclides and other nuclides had been known.

The melting system is used for treating non-reactor wastes and radioactive inventory of the melted wastes is evaluated from samples taken from the melted wastes. The melting system is also used for accumulating radioactive inventory data of LLW (reactor wastes mainly) in order to determine the correlation between key nuclides and other nuclides.

Considering needs of reducing the LLW volume, making waste packages for disposal and safety operation of the system, the operation plan of the AVRF is conducted as follows ;

- After increasing pre-treatment capacity, steady operation (4,000 drums/year) starts in 2010.
- Super compactor and Incinerator are used as main processes for a while.
- Melting systems increase the processing volume of wastes gradually with confirming safety.
- Radioactive inventory data of LLW is accumulated by operating melting systems.

(Toshiyuki MOMMA and Nnobuyuki Nakashio)

(4) Treatment and volume reduction of radioactive metal

The nuclear industry is generating a large volume of waste in the segment defined as LLW (Low Level Waste). NPP's are nowadays often life-time extended as society's energy needs increases and this is causing an issue with storage space for the spent equipment and parts. Historically there has not been a clear route for very large metal components and this has lead to local decay-storage at NPP-site. This exercise is demanding large areas for storage that may no longer be available and society is in general starting to raise questions if this can not be handled now instead of pushing it further out in the future.

Cost for final storage of large metal components is a major issue and since repository cost is closely linked with volume demand, any volume reduction of waste is beneficial.

Large metallic components can be handled in several ways.

i) Put into repository as they are

ii) Volume reduced by only super compaction or melting

iii) Volume reduced by decontamination and by that;

- separating the radioactive contamination from the bulk metal to form a small volume secondary waste,
- make sure the bulk metal is possible to clear for free release to the open market,
- enable alternative use of free releasable metal by making products for return back to nuclear industry.

It is clear that option number three is the most attractive one where the volume reduction of radioactive contaminated waste is most efficient and recycling of good valuable material back to the open market saves on the environment.

Waste volume reduction of containerized metal scrap by decontamination and free release has for decades been utilized by the industry and in some areas of the world treatment of large objects as heat exchangers, turbine shafts and steam generators today is common praxis.

Treatment of large components does however require significantly different technology since both transportation and radiation protection becomes more challenging.

- A 20' IP-2 container with metal scrap may be easy to transport under existing regulations compared with a 350 t Steam Generator or Turbine Shaft.
- Treatment of very large components is also from a radiation protection standpoint different. Segmentation and decontamination will require tailor made equipment to protect personnel working with very heavy material as well as radiation to meet the goal of ALARA. This is not tools found in the regular industrial environment but must be developed for the purpose. It is also very important to minimize secondary waste generated during segmentation and decontamination to save cost in repository space.

Some Waste Volume Reduction suppliers have over the last 20 years developed unique methods to meet this requirement. With this technology now available large quantities of LLW metal should be possible to volume reduce before waste disposal and by that save money and extend the lifetime of Low Level Repositories. Additional benefit is that free releasable metal can be recirculated into the raw material stream enabling society to lower strain on environment and save natural resources.

(Anders Stenmark)

Irradiation technique in materials testing reactor

(1) JMTR strategy on re-operation

Technical developments for the neutron-irradiation experiments in material testing reactors have been carried out in this implemental agreement. In the development, we go forward with standardization of neutron-irradiation tests in the world and efficiency of the facility management through the information exchange and exchange of staff. Thus, status and assignment of neutronic evaluations for materials test reactors are discussed in this meeting.

An evaluation procedure using continuous energy Monte Carlo code MCNP and nuclear data library of the JENDL3.2 with a calculation model of the whole 3-D JMTR core has been introduced to evaluate irradiation parameters. Detailed analyses of irradiation parameters were conducted before irradiation using this procedure and these results were verified by comparing with the measured values. Calculated neutron flux/fluence was verified against measurements of irradiated fluence monitors (Iron and Aluminum-Cobalt wires). With regard to gamma dose, calculated gamma heating rate were verified against measurements of the nuclear heating evaluation capsule which was developed in order to measure nuclear heating rate (generated from interaction between materials and neutrons or gamma-rays). It was confirmed that the calculated fast and thermal neutron flux/fluence agreed with measurements within ±10%, ±30%, respectively, and the calculated gamma dose agreed within -3~+21%.

Mutual exchange of dosimetry information for world standardization, is very desirable to raise the scientific and technical potential in the irradiation research and to get break-through of the study in the field of nuclear application.

(Yoshiharu NAGAO, Noriyuki TAKEMOTO, Hiroshi KAWAMURA)

(2) Status and assignment of post irradiation examinations

Technical developments for the neutron-irradiation experiments in material testing reactors have been carried out in this implemental agreement. In the development, we go forward with standardization of neutron-irradiation tests in the world and efficiency of the facility management through the information exchange and exchange of staff. Thus, status and assignment of post irradiation examinations of each hot laboratory are discussed in this meeting.

The Hot Laboratory (JMTR HL) associated with the Japan Materials Testing Reactor (JMTR) was put into service in 1971 to examine specimens irradiated mainly in the JMTR. A wide variety of PIEs for research and development of nuclear fuels and materials is available in three kinds of $\beta-\gamma$ hot cells in the JMTR HL. These examinations are on LWR high burn up fuels subjected to power ramping tests, NSRR test fuel, structural materials for LWRs, HTGRs and fusion reactors, shape memory alloys. In addition to PIEs, re-capsuling including re-instrumentation is currently conducted for the power ramping tests using the Boiling Water Capsule (BOCA) or for coupling irradiation tests. The developed techniques by the JMTR HL have provided us with the key information about the irradiation effects on mechanical and physical properties of the specimens in various environments as fission and fusion reactors.

Mutual exchange of PIE information among these facilities, interchange of researchers and mutual utilization of PIE facilities are very desirable to raise the scientific and technical potential in the irradiation research and to get break-through of the study in the field of nuclear application.

(Kunihiko TSUCHIYA, Masao OMI, Tetsuro NAKAGAWA
Masahiro ISHIHARA, Motoji NIIMI, Hiroshi KAWAMURA)

(3) Irradiation technique and industrial utilization

1) There are a number of different areas in which the MTR can be providing services

The MTRs (Multipurpose Test Reactors) are by definition multipurpose machines, delivering neutrons and irradiation conditions to a wide Varity of purposes:

- Basic research
- Fuel and Material irradiation
- Corrosion and Water Chemistry irradiation
- Silicon doping
- Medical and Industrial isotope production
- Medical treatment

Each one of the services is demanding, requiring resources, expertise and experience which make it very demanding when an MTR is to deliver all this at highest standard. Furthermore, MTRs are not the same; they have different pros and cons, some being high neutron flux facilities with many annual short operation cycles, while others are operating for longer cycles. The owner's intention with an MTR can also be very different and not always fully clear.

In addition the operation itself, with increased authority demands and increased operational cost is a demanding environment. Altogether it is a challenging experience when trying to operate an MTR in the best way, fulfilling the responsible authority's or owner's intention.

The MTR operator must define what areas shall be of importance. Shall the MTR focus on all areas? It is a highly demanding decision as the demands are high and the MTR have to perform within all the areas.

2) Different irradiation conditions, different clients and client demands

The irradiation conditions and requirements are very different when comparing the list of services above and so are the clients, some being commercial nuclear companies, some being non-nuclear companies and some authorities or universities.

Furthermore, the pure research services are acting in an environment different from the one working with services to the nuclear industry. Pure research requires a long-term view and patience, which mostly is granted when an MTR is working within he research area on Governmental funds. Nuclear technology on the other hand is today a mature technology and the R&D community is expecting as well as requiring the facilities to be able to deliver services and irradiations as standard services. Technology excellence is taken for granted, experience a necessity, specified conditions has to be maintained while fulfilling demanding and challenging time schedules as well as budgets.

The MTR has to understand all these clients and all the requirements in order to be an accepted supplier to their clients. Typically the MTR has its origin as a Governmental research facility, with a good understanding of that environment and the requirements going with it, while being more unusual to the expectations and demands when trying to be a supplier to the commercial industry. Studsvik is, and have for many years been, a world-wide supplier of examinations and tests of nuclear materials to the commercial nuclear industry and is today cooperating with JAEA, so both organizations can be even better suppliers.

3) Requirements – neutron dosimetry

Silicon doping and medical treatment are the services requiring the most detailed and the largest precision in the neutron dosimetry. The neutron dose must be better than 3% and it must be predictable.

It is fairly important to know the neutron distribution when an MTR is providing services within water chemistry and corrosion experiments, material irradiations, isotope production and long term fuel irradiations.

4) Accuracy – neutron flux distribution

The key is not to be able to calculate the neutron flux in the entire core or in all positions. It is of course important to be able to predict the neutron and other irradiation fields to a degree so it is possible to design experiments. However, it is of outermost importance to use the experience from measurements made and not just start to model. All models results must be compared with measured data and old measured data can often be used to plan experiments.

Believing that modeling is the key can be a real “cul-de-sac”. It can be better to make measurements and use them to calibrate modeling results and by using such a procedure reduce uncertainties. The optimal way is to be able to make dosimetry measurements during high power operation and use these for the calibration of needed modeling.

5) Requirements on physical properties

Extremely important with high demands on small uncertainties and even more difficult well controlled parameters when the MTR provide services such as ramp tests, water chemistry tests, corrosion tests and other instrumented tests (fuel or material). It is less important (typically the projects require “target” values) when services as long term fuel irradiations, material irradiations and isotope production are to be performed.

The key is to be able to measure these types of data as close to the irradiation position as possible, especially some chemistry reactions are very fast and such entities must be measured very fast.

6) Timely delivery

Correct performed irradiations are just a part of the client requirements! Delivery as agreed can be extremely important. Some medical isotopes can have demands to be delivered as agreed within a number of ours only, while there are other services, as basic research, which is quite insensitive, a delay of half a year or so is perfectly acceptable.

7) Client expectations

The industry regards the following to be of real importance:

- The facility must be in operation
- Must deliver promised test conditions
- Must deliver on time and according to budget
- Strict confidentiality
- Authorities – are they predictable?

(Authority impact must be taken into account as the MTR service and operation is under careful authority supervision)

- Reliability:
    - Will the facility still be there in the future
    - Will the facility develop its services for the future
    - Will the facility deliver as requested

The MTR community worldwide will be changing in the future. Some will close (like the Studsvik R2 that already closed), some will be replaces (like the French OSIRIS with JHR), and some will be refurbished (like the JAEA JMTR test reactor). The capacity, the competence and the capabilities at different locations and facilities will all be influenced of what is happening. It is difficult to be the expert within all fields of irradiations and the client demands are at the same time growing all the time. Studsvik, without a test reactor since 2005, is today cooperating with the IFE test reactor HBWR in Halden, the CEA test reactor OSIRIS today and JHR tomorrow and with JAEA´s JMTR to be able to be a provider for all services that a client can require. Cooperation is needed, not only to be able to a complete provider of client services but also to learn from each other and to specialize, utilizing the advantages a facility have, due to technique, experience, capabilities and the local authorities.

(Mikael Karlsson)

4. Future plan

Future plan on two cooperation areas, “Radioactive waste treatment technology including recycling of materials” and “Technical developments for the neutron irradiation experiments in materials testing reactors”, was discussed with both parties.

For the first cooperation area, proposed future plan of radioactive waste treatment technology is summarized in Table 4.1. It was confirmed that volume reduction treatment of spent fuel transfer casks will be targeted to discuss with both parties.

Table 4.1 Future plan of radioactive waste treatment technology.

Items	JAEA’s Proposal	Studsvik	Term
Project selection	Step by step approach for focused results -Start with 34 ton Mutsu Casks		
	-Metal material for treatment by Studsvik	Re-check cost figures for treatment and transport	~Sep.08
	Collect arguments; -Comparison of domestic and foreign treatment	Collect argument: -Environmental benefit of recirculation vs. new production -SKB/SSM statements supporting	~Sep.08
Procedure	-Send new information	-Send new information	~Sep.08
	-Review and agree on information and data	-Review and agree on information and data	~Mid Oct.08
Future activity and meeting	After review of information, new meeting will be scheduled. Preparation for presentation to authorities in Japan	After review of information, new meeting will be scheduled. Preparation for presentation to authorities in Japan	2008

For the second cooperation area, proposed future plan of irradiation technique in materials testing reactor is summarized in Table 4.2. It was confirmed that a definite technical cooperation will be important by step-by-step information exchange.

Table 4.2 Future plan of Irradiation technique in materials testing reactor

Items	JAEA's Proposal	Studsvik	Term
Dosimetry Test procedure	-Neutron flux/fluence -Neutron spectrum	-Studsvik comment with ideas and continue the discussion -Studsvik present ideas	~ 2009
Irradiation Technology	-Power rump test for fuels -SCC test for materials	Second step	2009~2011
RI Production	-^{99}Mo production technology -Other RI	Conceptual design Discussion & logistic	~ 2009
Si Production	-Si irradiation facility	Have been discussed a lot	-
Sensor	-ECP sensor -High temp. multi-paired T/C -FP gas pressure gauge -New sensor by light	-Ongoing discussion -Studsvik worked lately only to 600°C	~2011
PIE Technology	-SCC test for materials -Recycling technology of beryllium	-Second step -Studsvik support this if possible with test/discussion/ ideas /HCL work	2009~2011

5. Concluding remarks

Under the implemental agreement on cooperation in nuclear energy research and development between the Studsvik AB and the JAEA, the first annual meeting was held at Oarai Research and Development Center, JAEA on July 18, 2008. Very instructive information exchange for both parties was made on two cooperation areas, "Radioactive waste treatment technology including recycling of materials" and "Technical developments for the neutron irradiation experiments in materials testing reactors". Moreover, future cooperation plan was discussed through the information exchange, and the concrete aim and a method toward them were recognized by both parties. It was also confirmed that next annual meeting will be held in Sweden.

Appendix

A.1 Agenda of the meeting

1. Opening (13:30 - 13:50)
   Objective of this Meeting (H.Hiroi, JAEA)
   Self-introduction (All Participants)

2. Radioactive Waste Treatment Technology (13:50 - 15:10)
   (1) Study on Waste Treatment for Effective Recycling S.Yanagihara (JAEA)
   (2) Assurance for Radioactive Metal Clearance and Recycling A.Stenmark (Studsvik)
   (3) Present Status of Waste Treatment for Volume Reduction T.Monma (JAEA)
   (4) Treatment and Volume Reduction of Radioactive Metal A.Stenmark (Studsvik)
   (5) Discussion (All Participants)

Coffee Break (15:10 - 15:30)

3. Irradiation Technique in Materials Testing Reactor (15:30 - 16:50)
   (1) JMTR Strategy on Re-operation Y.Nagao (JAEA)
   -Dosimetry for Standardization of Irradiation Technology-
   (2) Status and Assignment of Post Irradiation Examinations K.Tsuchiya (JAEA)
   (3) Irradiation Technique and Industrial Utilization M.Karlsson (Studsvik)
   (4)Discussion (All Participants)

4. Total Discussion and Future Plan (16:50 - 17:20) (All Participants)

5. Closing (17:20 - 17:30) (President, Studsvik)

6. Adjourn(17:30)

A.2 Participants list

< Studsvik Nuclear AB >

Magnus ARBELL	President
Toshio YAMAZAKI	President, Studsvik Japan, Ltd.
Mikael KARLSSON	Marketing Manager, Sales and Business Development
Anders STENMARK	Sales and Business Development

< JAEA >

Satoshi YANAGIHARA	Deputy Director General, Nuclear Cycle Backend Directorate
Yoshihiro MEGURO	Principal Scientist, Nuclear Cycle Backend Directorate
Toshiyuki MONMA	General Manager, Dep. of Decommissioning& Waste Management
Nobuyuki NAKASHIO	Research Engineer, Dep. of Decommissioning& Waste Management
Hiroshi HIROI	Director General, Oarai Research and Development Center
Masuro OGAWA	Deputy Director General, Oarai Research & Development Center
Hiroshi KAWAMURA	Director, Neutron Irradiation and Testing Reactor Center
Motoji NIIMI	Director, Department of JMTR Operation
Etsuo ISHITSUKA	General Manager, Neutron Irradiation and Testing Reactor Center
Kunihiko TSUCHIYA	Principal Researcher, Neutron Irradiation and Testing Reactor Center
Yoshiharu NAGAO	Deputy General Manager, Neutron Irradiation and Testing Reactor Center
Naohiko HORI	Deputy General Manager, Department of JMTR Operation
Masao OMI	Deputy General Manager, Department of JMTR Operation

A.3 Implemental agreement between the Studsvik AB and the Japan Atomic Energy Agency for cooperation in nuclear energy research and development

IMPLEMENTAL AGREEMENT BETWEEN THE STUDSVIK AB AND THE JAPAN ATOMIC ENERGY AGENCY FOR COOPERATION IN NUCLEAR ENERGY RESEARCH AND DEVELOPMENT

The Japan Atomic Energy Agency (hereinafter referred to as "JAEA") and the Studsvik AB (hereinafter collectively called the "Party" or the "Parties");

Noting the Memorandum of Understanding between the Studsvik AB and the JAEA for the future cooperation in nuclear energy research and development signed May 23, 2006, and

Wishing to cooperate in nuclear energy research and development,

Hereby agree as follows:

ARTICLE 1
PURPOSE

The objective of this Implemental Agreement is to establish a general framework of cooperation in the field of research and development of nuclear energy and to define terms and conditions under which the Parties will cooperate on a balanced basis.

ARTICLE 2
AREAS OF COOPERATION

The specific areas of cooperation may include the following activities:

(1) Radioactive waste treatment technology including recycling of materials;
(2) Technical developments for the neutron-irradiation experiments in materials testing reactors;
(3) Other areas as may be mutually agreed upon by the Parties.

ARTICLE 3
SCOPE OF COOPERATION

Cooperation under this Implemental Agreement may include the following activities:

(1) Exchange of general information
(2) Exchange of scientific and technical information on specific topics mutually agreed
(3) Short visits by specialists to the facilities of the other Party relevant to the area of cooperation

(4) Joint research and development (R&D) studies on specific topics mutually agreed
(5) Exchange or attachment of staff

When a Party considers necessary, any specific detail to implement activities listed in (1) through (5) above may be determined through consultation and/or separate arrangements between the Parties.

ARTICLE 4
COORDINATION

Each Party shall designate a coordinator for the coordination, preparation, and implementation of the cooperation within the scope of this Implemental Agreement. All administrative contacts between the Parties shall be effected through the coordinators.

ARTICLE 5
FINANCE

Unless otherwise mutually agreed in writing by the Parties, each Party shall bear all costs of its activities under this Implemental Agreement.

ARTICLE 6
EXCHANGE OF STAFF

Each Party may assign its staff to the other Party. The following provisions shall apply to assignment or exchange of staff:

1. Each Party shall ensure that qualified staffs are selected for assignment to the other Party. The Parties shall enter into a separate Personnel Assignment Agreement for the purpose of putting this article into effect.
2. Each Party shall be responsible for the salaries, insurance and allowances to be paid to its staff.
3. The assigning Party shall be responsible for bearing the travel and living expenses of its staff while on assignment to the receiving Party unless otherwise agreed upon in writing.
4. The receiving Party shall arrange for adequate accommodations for the assigned staff and their families.
5. The receiving Party shall provide all necessary assistance to the assigned staff and their families regarding administrative formalities (travel arrangement, etc.).
6. The assigned staff of each Party shall conform to the general and special rules of work and safety regulations in force at the receiving Party.

ARTICLE 7
CONFIDENTIALITY-RIGHT OF USE

1. Except as provided for the contrary in the following, each Party shall keep data and other information communicated from the other Party strictly confidential, and shall not publish or otherwise communicate them to third parties without prior written arrangement of the providing Party unless the receiving Party can prove that they are already in the public domain. However, each Party shall have the right to communicate information received from the other Party to its National Safety Authorities on a need to know basis. Regarding information to National Safety Authorities each Party shall do its outmost to ensure that information to such authorities should be treated as strictly confidential to ensure that such information is not forwarded to any third party outside the Parties' control. The informing Party shall also inform the other Party about all information exchange to its National Authority.

2. Each Party shall use at least the same degree of care in protecting confidential information communicated from the other Party against disclosure to any third party as it exercises in protecting its own confidential information.
3. As a general rule, all data and other information which the Parties communicate mutually will be considered as "business-confidential". For the purpose of this Implemental Agreement "business-confidential information" means any know-how, technical data, or technical commercial, or financial information that meets all of the following conditions:
(1) It is of a type customarily held in confidence for commercial reasons;
(2) It is not generally known or publicly available from other sources;
(3) It has not been previously made available by the owner to others without an obligation concerning its confidentiality;
(4) It is not already in the possession of the recipient without an obligation concerning its confidentiality.
4. Without prejudice of pre-existing rights of use granted to third parties, each Party will have, as case by case to be mutually agreed, for its own research and development activities and applications under this Implemental Agreement, a free right of use of data and other information, whether protected or not, communicated by the other Party, provided the Parties have mutually agreed in writing before any such activities can start. Each Party will also have free rights of use of the results generated under this Implemental Agreement.
5. Without prejudice of rights of transmission and rights of use granted under this Implemental Agreement or Specific Contracts, each Party shall remain the owner of any information, patented or not, communicated to the other Party.

ARTICLE 8
INTELLECTUAL PROPERTY RIGHTS

1. For the purpose of this Implemental Agreement, "Invention" means any invention

made in the course of the cooperative activities under this Implemental Agreement which is or may be patentable or otherwise protected under the laws of Japan, Sweden or any third country.

2. As for an Invention, the Parties shall take appropriate steps, in accordance with the national laws and regulations of the respective countries, with a view to realizing the following arrangement of invention rights. In case of inconsistency, both parties shall meet and mutually solve the issue in good faith.
3. Unless agreed otherwise, if an Invention is made as a result of a cooperative activity under this Implemental Agreement that involves only the transfer or exchange of information between the Parties, such as by joint meeting, seminars, or the exchange of technical reports or papers:
(1) The Party whose personnel makes the Invention (hereinafter referred to as the "Inventing Party") or the personnel who make the Invention (hereinafter referred to as the "Inventor") have the right to obtain all rights and interests in the Invention in all countries;
(2) In any country where the Inventing Party or the Inventor decides not to obtain such rights and interests, the other Party has the right to do so.

4. If the Invention is made by an Inventor of a Party (the "Assigning Party") while assigned to work on a site owned by another Party (the "Receiving Party") in the course of programs of a cooperative activity that involve the visit or exchange of staff:
(1) The Receiving Party has the right to obtain all rights and interests in the Invention in its own country and in third countries;
(2) The Assigning Party or the Inventor has the right to obtain all rights and interests in the Invention in its own country;
(3) In any country where the Receiving Party decides not to obtain such rights and interests, the Assigning Party or Inventor has the right to do so.

5. The Inventing Party will disclose promptly the Invention to the other Party and furnish any documentation or information necessary to enable the other Party to establish rights to which it may be entitled.

6. The Inventing party has always the right to use its inventions for applications worldwide, at no cost and without timely restrictions whether or not it has obtained all rights above. This right survives the expiration of this Agreement.
7. The patent description and its implication must be mutually agreed between both Parties, whatever part plans to apply patent applications for this patent – in any country - to avoid the following risks - listed but not limited to – below:
(1) The patent under pending must not comprise any earlier intellectual rights of any Party;
(2) The patent must not be sold to a third party at any time later in order to allow interference by organizations;
(3) Any such action shall not block or restrict the other Party's actions.

ARTICLE 9
LIABILITY

1. Each Party shall alone be responsible for accidents to its staff or damages to its property, regardless of where the damages have been incurred during the term of this Implemental Agreement and shall not bring suit or lodge any other claims against the other Party for damages to its property or accidents to its staff, unless the claim is based on gross negligence or intentional misconduct of the other Party or its employees.

2. The foregoing provisions of this Article shall not apply to damages caused by a nuclear incident, as defined by the laws of the countries of Parties. Damages caused by such a nuclear incident shall be compensated in accordance with the laws of the countries of the Parties.

ARTICLE 10
DISPUTE

This Implemental Agreement shall be implemented in accordance with the laws of the respective countries and the regulations of the respective Parties:

(1) Any dispute arising out of the interpretation or implementation of this Implemental Agreement and any question relating to this Implemental Agreement shall be settled by amicable efforts of the Parties;
(2) An attempt to arrive at settlement shall be deemed to have failed as soon as one of the Parties so notifies the other Party in writing;
(3) If an attempt at settlement has failed, the disputes shall be finally settled by arbitration under the Rules of the Arbitration institute of the London Chamber of Commerce in accordance with the Rules;
(4) The place of arbitration shall be London, United Kingdom. The arbitration language shall be English;
(5) The arbitral award shall be substantiated in writing. The arbitral tribunal shall decide on the matter of costs of the arbitration;
(6) The arbitration result so reached shall be final and binding on the Parties.

ARTICLE 11
ADDITIONAL PROVISIONS

1. This Implemental Agreement shall enter into force upon signature of the Parties and shall remain in force for a period of five (5) years.

2. This Implemental Agreement may be terminated at any time at the discretion of either Party upon six (6) months advance notification in writing by the Party seeking to terminate this Implemental Agreement. Such termination shall be without prejudice to the rights which may have accrued under this Implemental Agreement to either Party up to the date of such termination.

3. This Implemental Agreement may be amended or extended through mutual written agreement of the Parties.

DONE at Nyköping this 12th day of December, 2007, in duplicate.

for THE STUDSVIK AB

Title President and CEO
Studsvik AB

for THE JAPAN ATOMIC ENERGY AGENCY

Title Executive Director
Japan Atomic Energy Agency

APPENDIX I

<table>
<tr><td colspan="3">Studsvik AB JAEA
COOPERATION IN NUCLEAR ENERGY RESEARCH AND DEVELOPMENT</td></tr>
<tr><td colspan="2">SPECIFIC TOPIC OF COOPERATION
STC SHEET No.1</td><td>Date: December 12, 2007</td></tr>
<tr><td colspan="3">TITLE OF THE SPECIFIC TOPIC OF COOPERATION:
Radioactive waste treatment technology including recycling of materials</td></tr>
<tr><td colspan="3">AREAS OF COOPERATION:
a) Radioactive waste treatment
b) Recycling of nuclear materials
c) Measurement of radioactivity</td></tr>
<tr><td colspan="3">CONTENT OF THE SPECIFIC TOPIC OF COOPERATION

1- Purpose: This Specific Topic of Cooperation covers mainly the following item:
- Exchange of information of JAEA and Studsvik AB.
- Exchange of samples for trial treatment of materials[1)]

2 - Specific Conditions:
A specialist meeting will be organized for the information exchange.
Attendees and place for meeting will be as mutually agreed.

3 - Duration/ Schedule:
The cooperation in this area will enter into force from December 12, 2007 until December 11, 2012.

1) Trial treatment is limited to:
- Amounts: small amounts as mutual agreed
- Material: materials which have not been treated by the Parties before or untested compositions (nuclides, geometry etc) as mutual agreed</td></tr>
<tr><td></td><td>Contact Person</td><td>Field Coordinator</td></tr>
</table>

APPENDIX II

Studsvik AB	JAEA
COOPERATION IN NUCLEAR ENERGY RESEARCH AND DEVELOPMENT	
SPECIFIC TOPIC OF COOPERATION STC SHEET No.2	Date: December 12, 2007
TITLE OF THE SPECIFIC TOPIC OF COOPERATION: Technical developments for the neutron-irradiation experiments in materials testing reactors	
AREAS OF COOPERATION: a) International standard in neutron-irradiation experiments b) Industrial application of materials testing reactor c) Advanced irradiation technology	
CONTENT OF THE SPECIFIC TOPIC OF COOPERATION 1- Purpose: This Specific Topic of Cooperation covers mainly the following item: Exchange of information of JAEA and Studsvik AB 2 - Specific Conditions: A specialist meeting will be organized for the information exchange. Attendees and place for meeting will be as mutually agreed. 3 - Duration/ Schedule: The cooperation in this area will enter into force from December 12, 2007 until December 11, 2012.	

	Contact Person	Field Coordinator

A.4 Presentation documents

The 1st Studsvik-JAEA Meeting on Nuclear Development

A Study on Waste Treatment for Effective Recycling

July 18, 2008

Satoshi Yanagihara
Nuclear Cycle Back-end Directorate
JAEA

Outline

- ✓ Background of the study on waste treatment for effective recycling
- ✓ Premise of waste treatment in foreign facilities for material recycling
- ✓ Regulatory consideration of export/import of radioactive waste
- ✓ Cost estimation of waste treatment in foreign facilities and transportation
- ✓ Concluding remarks

Background

- ✓Radioactive wastes generated from research activities are collected in the waste treatment and storage facilities located each nuclear site of JAEA.
- ✓In the Nuclear Science Research Institute of Tokai R&D Center, it is planned to treat the waste for volume reduction and final disposal in the Advanced Volume Reduction Facility.
- ✓However, various kinds of waste have been stored so far and some of the waste are expected to be troublesome or difficult in treatment for producing final disposal form effectively.
- ✓ It is important to consider treatment of wastes and/or materials for recycling after releasing in compliance with clearance procedures.

Radioactive Wastes in Need of Thorough Consideration of Their Treatment

Capability of treatment in Advanced Volume Reduction Facility

- ➢sorting by hands, incineration, compaction
- ➢melting by induction furnace, plasma torch

<u>Radioactive waste and materials possible for recycling</u>

- ✓ Very low level radioactive waste stored in the storage facility
- ✓ Slightly contaminated materials classified to non-radioactive group

<u>Radioactive wastes in need of thorough consideration of their treatment</u>

- ✓ Ion exchange resins(~420drums): incineration, plasma melting
- ✓ HEPA filter(~40drums: increase in future) : incineration, plasma melting
- ✓ Aluminium material (~420drums) : melting by induction furnace
- ✓ Multi-material-complex components such as pumps, lining pipes, motors (~420drums) : sorting by hands, compaction, incineration, melting

Feasibility Study on Waste Treatment in Foreign Facilities

There is no commercial base radioactive waste treatment facilities in Japan. It might be therefore important to consider treatment of the wastes in foreign facilities if it is difficult to treat them domestically in effective way.

Major subjects to be studied for treatment in foreign facilities

- ✓ Regulatory frame on import/ export of radioactive wastes
- ✓ Transportation of radioactive materials or large components
- ✓ Waste treatment in foreign facilities
- ✓ Transaction of returned radioactive materials in regulatory frame
- ✓ Advantage/disadvantage of radioactive waste treatment in foreign facilities

Waste and Materials Candidate for Treatment in Foreign Facility

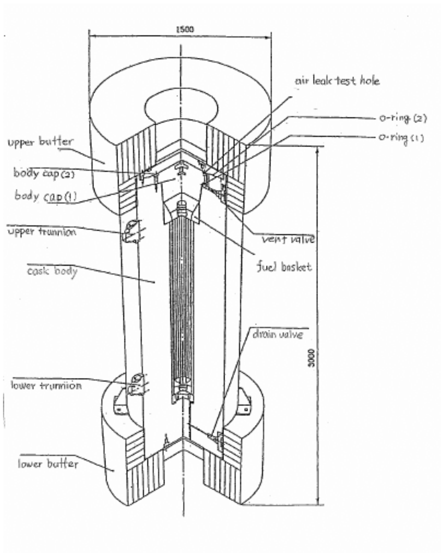
- ✓ Radioactive waste stored in JAEA
  - ● Very low-level radioactive metal waste
    There is a possibility of releasing as a non-radioactive material if these are treated by melting.
  - ● Ion exchange resins
    Extreme volume reduction will be expected. However secondary waste should be brought back to Japan for disposal or storage.
- ✓ Slightly radioactively-contaminated materials
  - ● Spent nuclear fuel casks
    A cautious transaction is necessary for the casks to be taken out of the nuclear site. Transporting and outside-treating of this kind of radioactive materials, even its contamination is negligible, is a sensitive matter.

Spent Fuel Casks

There are 34 retired casks temporary stored in JAEA Tokai site. They were used for transportation of spent fuels from a nuclear facility.

Contamination level: The casks (Stainless Steal) have been decontaminated. But some possibility of slightly contamination remained, while they are classified as non radioactive material.

Parts name	Dimension	Weight
Overall (Body+Lids)	O.D.1.5m Length:3m	14.6 ton
Body	O.D.:970mm,I.D. :280mm Length:2,290mm	13 ton
Primary lid	O.D.:648mm Thicknes:98-275mm	-
Secondary lid	O.D.:860mm Thicknes:50-70mm	-



Outline of Cask

Low level Radioactive Metal Waste

The radioactive metal wastes generated from the reactor dismantlement are identifiably stored in the storage facility. Some of the wastes are classified into relatively low level group(0.4 to 4 Bq/cm^2 or less than 0.4 Bq/cm^2).

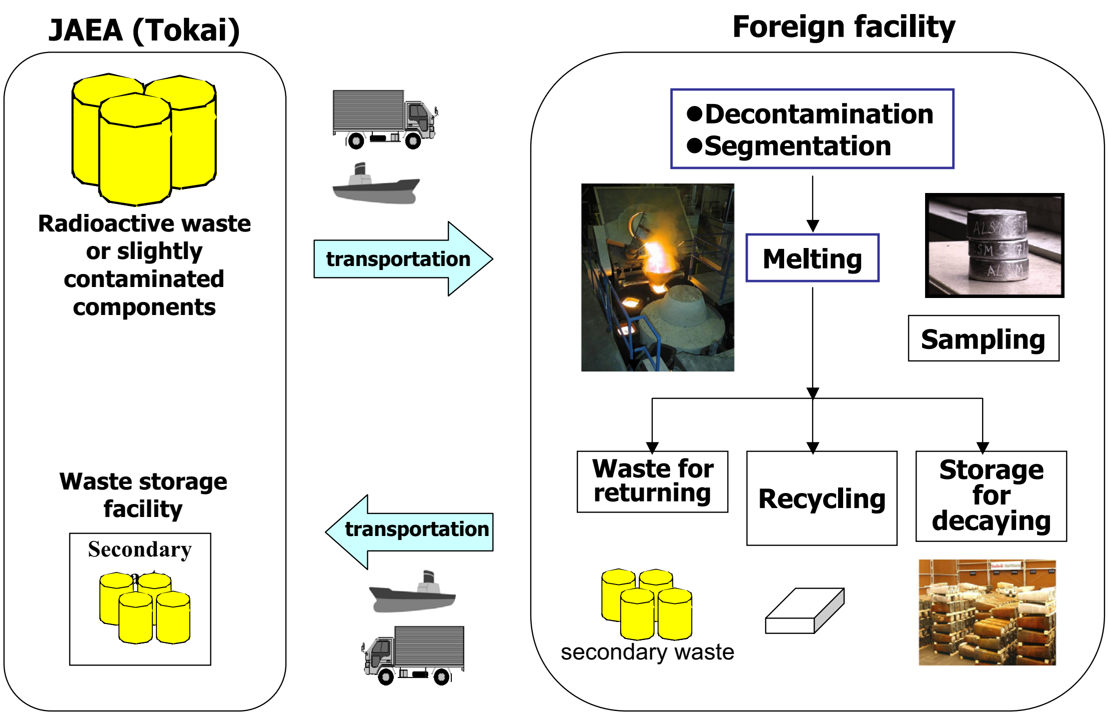
Radioactivity Level	Carbon Steel		Stainless Steel		Aluminum	
	Drums	Weight (kg)	Drums	Weight (kg)	Drums	Weight (kg)
0.4 to 4 Bq/cm^2	453	192,738	95	21,791	14	2,523
Less than 0.4 Bq/cm^2	1,797	508,136	119	27,456	40	8,422
Total	2,250	700,874	214	49,247	54	10,965

Regulatory Concerns for Export/ Import of Radioactive Materials

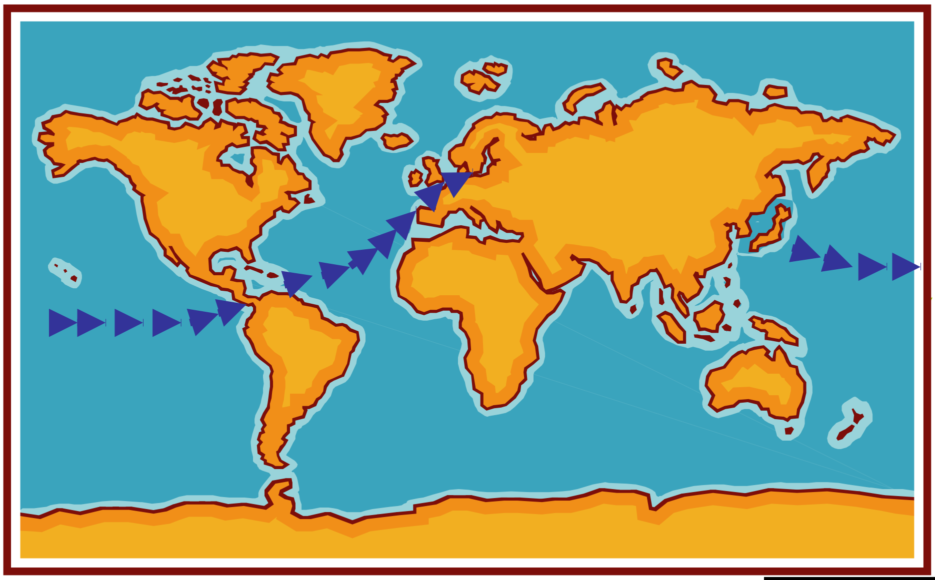
So far, there is no experience of transporting radioactive waste (or radioactive materials) to foreign facilities except spent nuclear fuels. It is needed to evaluate a possibility of transporting radioactive waste to foreign facilities for effective material recycling.

- ✓Is it possible to export radioactive waste to foreign facilities from a regulatory point of view?
- ✓Is it possible to import radioactive waste from foreign countries from a regulatory point of view?
- ✓How do we deal with the returned secondary radioactive wastes? Legal positioning of acceptance to a storage facility? Data enough for compliance with disposal verification?

An Example of Possible Scenarios for Waste Treatment in Foreign Facilities



Transportation (Example)



	From	To	Means
Route-1	Tokai	Tokyo Bay	Truck
Route-2	Tokyo Bay	EU Bay	Container Liner
Route-3	EU Bay	Studsvik	Small vessel

Regulatory Matters on Export/Import of Radioactive Waste

Laws related to export/import of radioactive materials

- The law for the regulation of nuclear source material, nuclear fuel material and reactors
- The joint convention on the safety of spent fuel management and on the safety of radioactive waste management
- Foreign exchange and foreign trade control law

✓ Basically it is possible to export (transport) radioactive materials to foreign facilities if exporting radioactive materials is permitted by the government with confirming the capability of importers by the counterpart country.

✓ Up to present time, there is no precedent of exporting radioactive materials except for spent nuclear fuels, it might be necessary to explain the detailed plan of treating radioactive materials in foreign facilities.

✓ In returning the products classified to radioactive waste, it is necessary to clear the legislative position in dealing with the radioactive wastes.

Concluding Remarks

- ✓ It is basically possible under the present legal frame to export radioactive waste for treatment in foreign facilities. However, since there is no precedent, it might be required by the government to explain the detailed plan.
- ✓ Costs were roughly evaluated in terms of transportation and treatment in Europe. These are the order of 100,000 yens/drum to wastes, for example.
- ✓ Are the evaluated costs comparable with those of the treatment and disposal domestically? (Trench disposal: 130,000 yens/drum, Pit disposal: 700,000 yens/drum, both not include treatment costs)
- ✓ Is it possible for the clearance materials to take back to Japan for recycling or reusing?

Studsvik

Assurance for Radioactive Metal Clearance and Recycling

Anders Stenmark, Studsvik Nuclear AB
July 18th - 2008

Assurance for Clearance and Recycling

Volume Reduction with Metal Recycling is the key objective of Studsvik concept to help industry save expensive repository space for Low Level Waste

- Assay of material/waste to be treated is required
  - Finger print (activity, dominating nuclide, etc)
  - Material composition (mix metal, alloys, etc)
- Verification of decontamination is essential
  - Metal ingot analysis
  - Secondary waste analysis
- Metal melting benefits
  - Homogeneity by induction furnace
  - Best practice for reliable activity analysis
  - Additional decontamination effects

Studsvik

Treatment at Studsvik – Metal Recycling

PREPARATION		TREATMENT		ASSURANCE		AFTER TREATMENT
Inspection Documentation Transport	➡	Segmentation Sorting Decontamination Melting Sampling Waste conditioning	➡	*Gamma-spectrometry* *Alpha spectrum* *Special nuclides* *Chemical assay*	➡	*Free release* *Secondary waste return* *Documentation* *(Decay storage)*

Studsvik

Assurance for Clearance and Free Release

3 samples representing each batch of metal ingots

Customer, Authorities, Studsvik

Radiological data from

spectroscopy measurements:

Alpha, Beta & Gamma

Metallurgical composition from spark

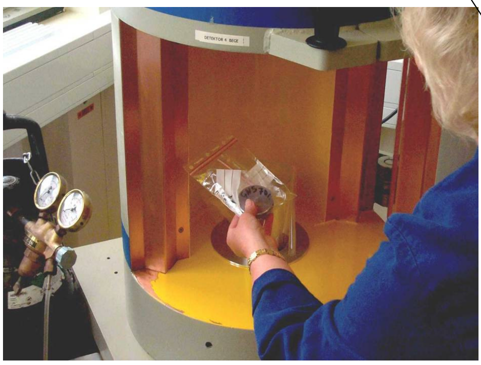
spectroscopy measurements:

Cr, Ni, Fe, Mo, etc..

Studsvik

Regulations for Free Release of Metal

Beta - emitters



Metal mass specific activity before and after re-melting in ratio >10:1 according to European Commission's Recommendation RP 89 table 3-1

Nuclides	Before open market Bq/g	In the open market Bq/g
H 3	<1 000	<100
C 14	<100	<10
Mn 54	<1	<0,1
Fe 55	<10 000	<1000
Ni 59, 63	<10 000	<1000
Co 58 & Co 60	<1	<0,1
Cs 137	<1	<0,1
Ra 226	<1	<0,1
U 235 & 238	<1	<0,1
Am 241	<1	<0,1
Pu 238, 239, 240	<1	<0,1

Studsvik

Secondary Waste Management

- Guarantee for secondary waste return to origin
  - Guarantee signed by customer and owners authority
- Always customer specific campaigns to minimize cross-contamination
- Secondary waste:
  - Segmentation residues
  - Dust from grit-blasting
  - Dust from ventilation
  - Slag from melting (will be crushed)
  - Ingots not free releasable
  - Out sorted material

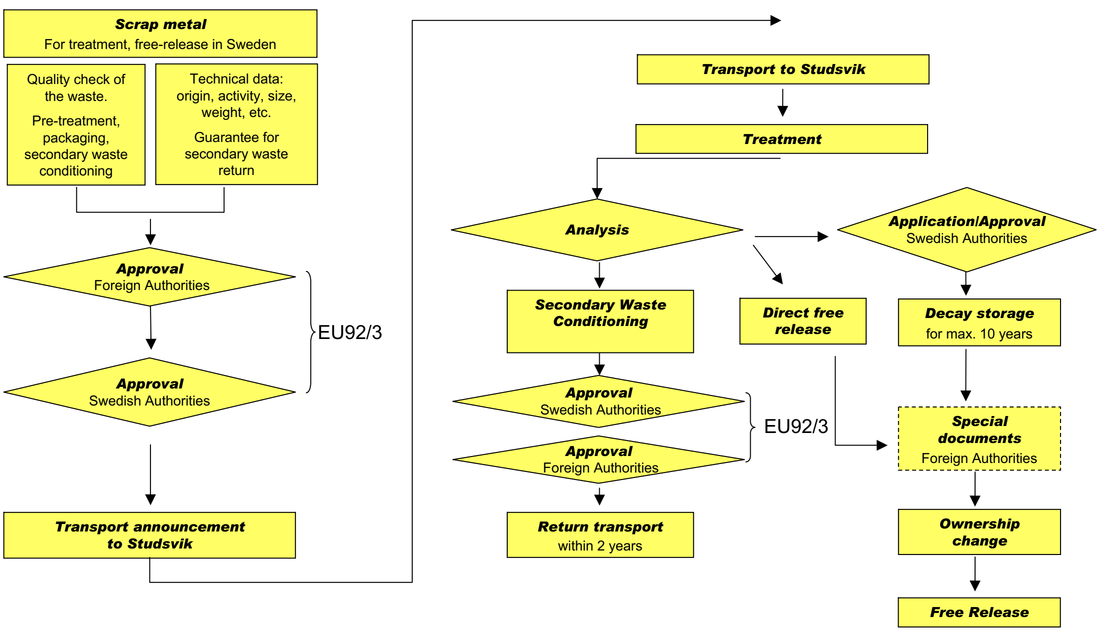
Studsvik

Secondary Waste Management

- Secondary waste is conditioned, packaged into drums and documented
- Radiological analysis
- All Secondary Waste generated is recorded in the waste tracking system "SVALA"
- Secondary Waste is always returned to customer (owner) for final disposal within two years

Studsvik

Procedure (simplified) for foreign waste



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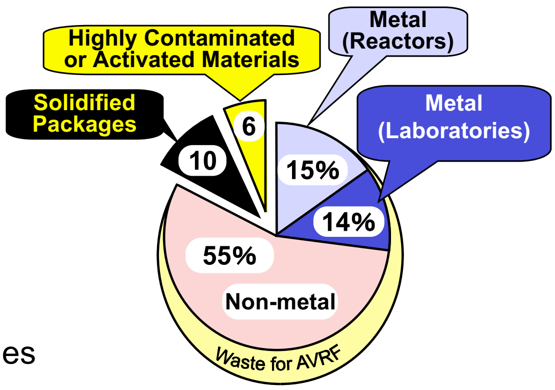
Advanced Volume Reduction Facilities (AVRF)

Objective:

- To make miscellaneous Low-level solid wastes (LLW) in NSRI into waste packages for disposal
- To reduce volume of LLW
- To accumulate data of radioactivity assessment of waste packages for disposal



Categorization of stored wastes in NSRI

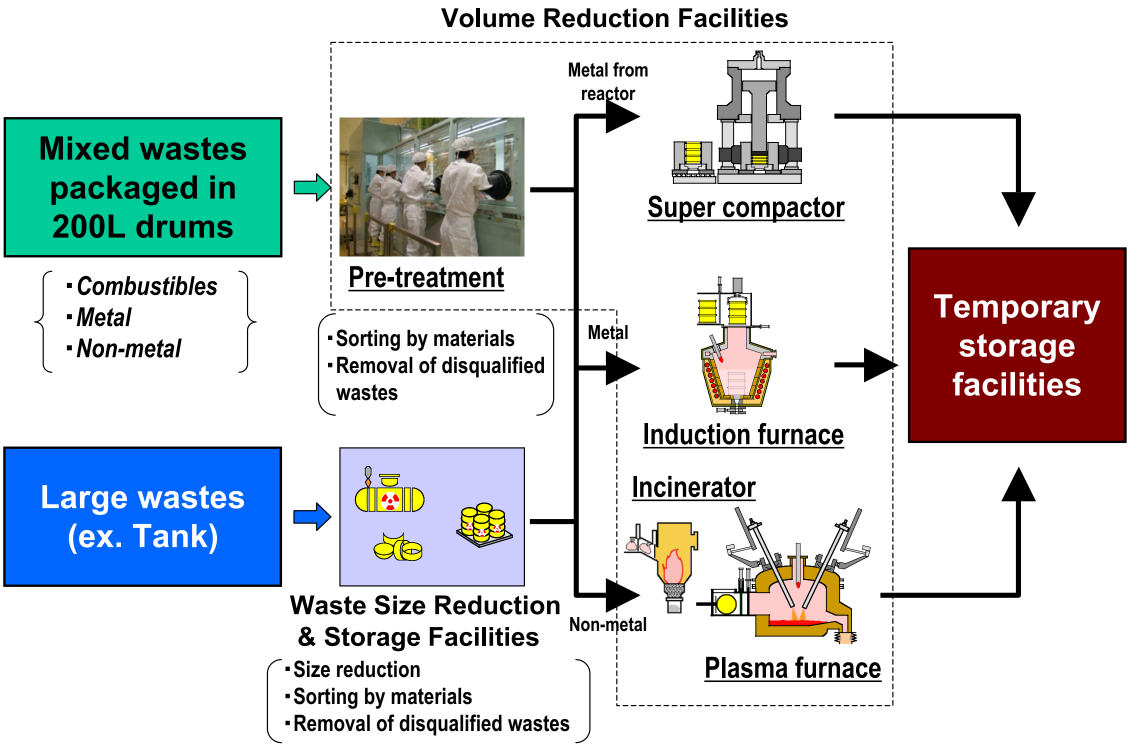
Facilities of AVRF:

①Waste Size Reduction &Storage Facilities
②Volume Reduction Facilities

①Waste Size Reduction & Storage Facilities

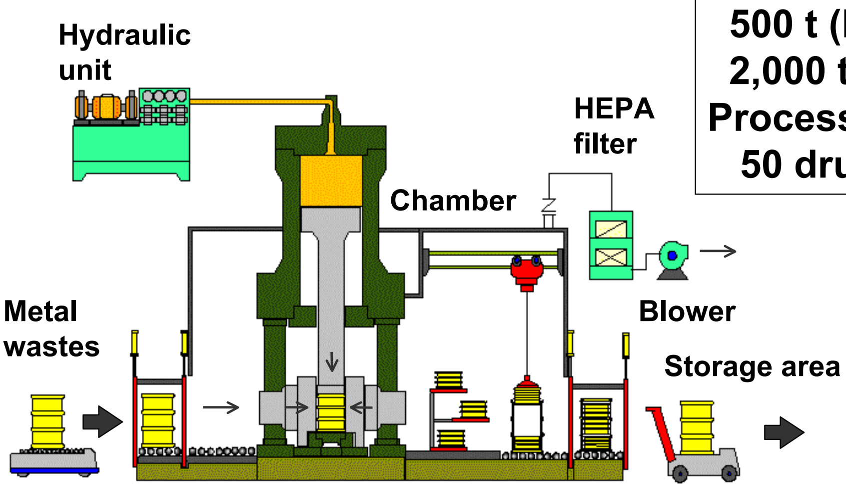
②Volume Reduction Facilities

Main process flow of waste treatment in AVRF



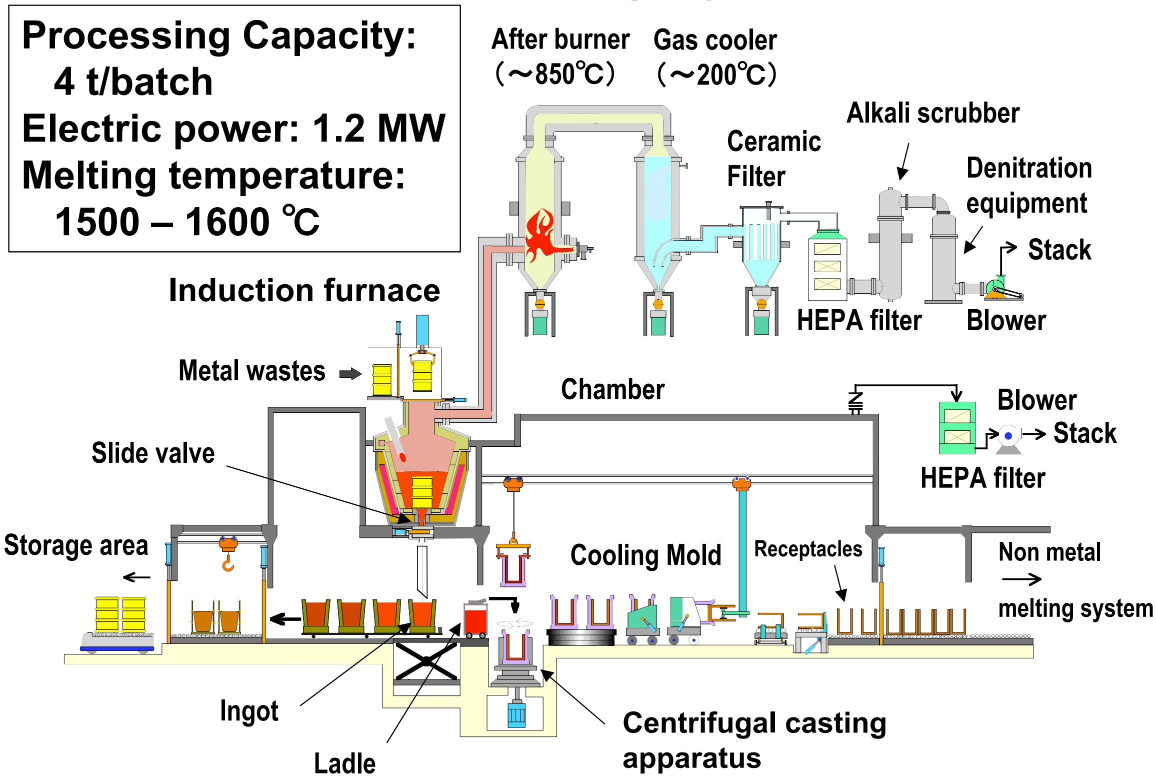
Super compactor

Compaction power:
500 t (horizontal)
2,000 t (vertical)
Processing capacity:
50 drums/day

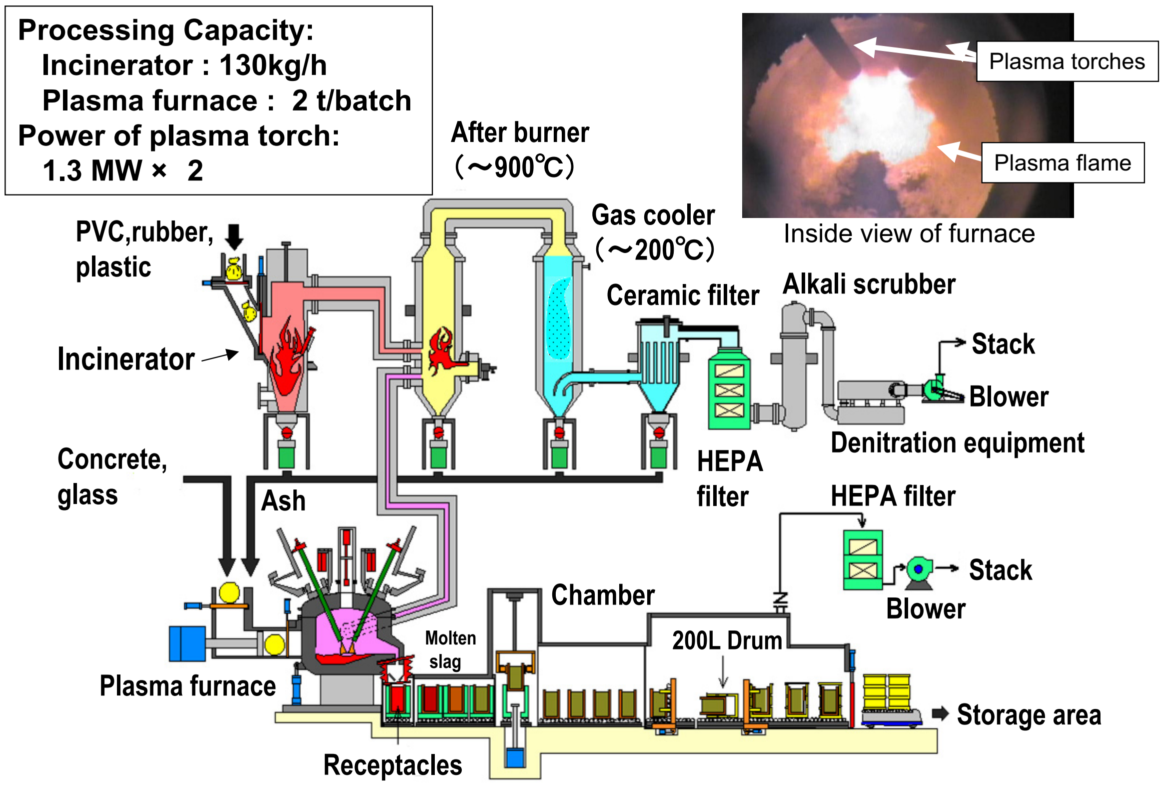


Comparison of compacted and non-processed drums

Metal melting system



Non-metal melting system



Current status

Waste Size Reduction & Storage Facilities (June 1999 -)

- Total 880m^3 of large size LLW has been treated.
- Averaged volume reduction ratio is about 1/3.

Volume Reduction Facilities (Feb. 2003 -)

- Pre-treatment system: Hot operation has partly started in Sep. 2005. As a result, processing capacity of the system is on upgrading.
- Super compactor: After cold tests, hot operation starts at second half in 2008.
- Melting system: To find out the optimal operational condition for homogenization, cold tests has conducted. After fire trouble of the plasma furnace (Feb. 2006), preventative measures has developed and resume of cold tests is in preparation.

Operation plan of AVRF

- Under safety operation of AVRF, the effective volume reduction of LLW will be conducted as follows;
  - Steady Operation (4,000drums/year) starts from 2010.
  - Compaction and Incineration are the main processes for a while.
  - Melting systems increase the processing volume of waste gradually with confirming safety.

- For future disposal of waste, the data of radioactivity inventory of waste will be accumulated by operating of melting systems

Studsvik

Treatment and Volume Reduction of Radioactive Metal

Anders Stenmark, Studsvik Nuclear AB
July 18th, 2008

Volume Reduction of LLW Metal

- Studsvik treatment concept is based on recycling the treated metal
- Secondary waste containing the radioactive nuclides is returned to the customer with emphasis on volume reduction
- Typically >95% of the incoming material to Studsvik is recycled
- To date Studsvik has processed in excess of 18’000t of material

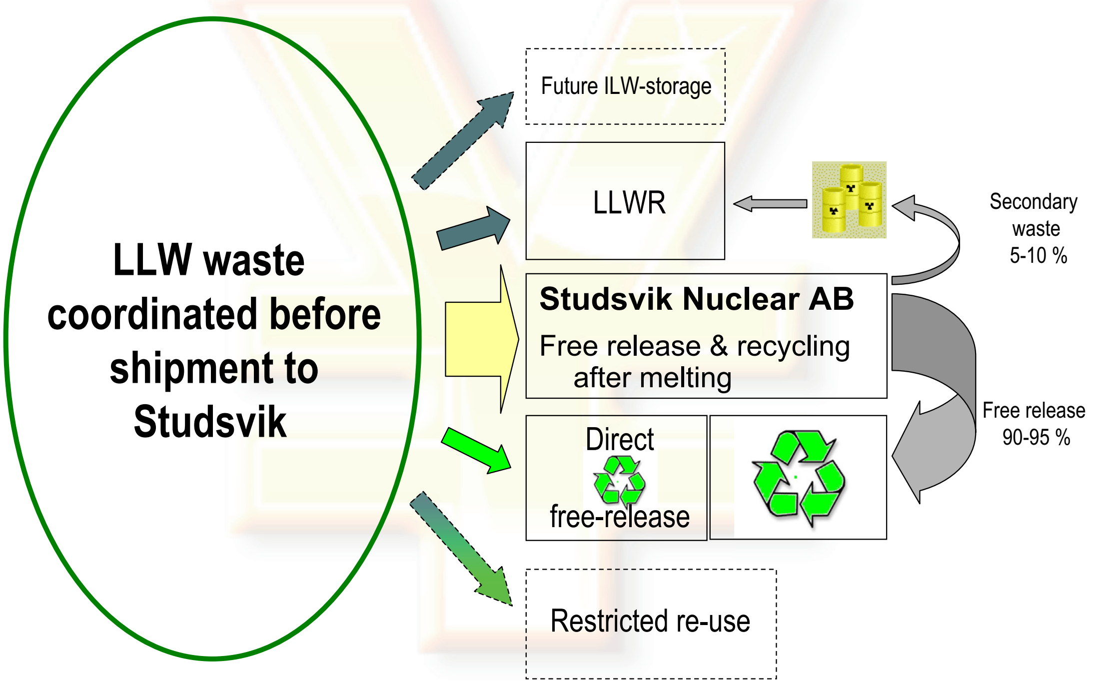
- Some environmental benefits

! Recycling 1 ton of steel saves:

! 1.5ton iron ore	60% less Water
! 0.5ton coal	86% less Emissions
! 1.3ton solid waste	75% less Energy

Anders Stenmark Studsvik

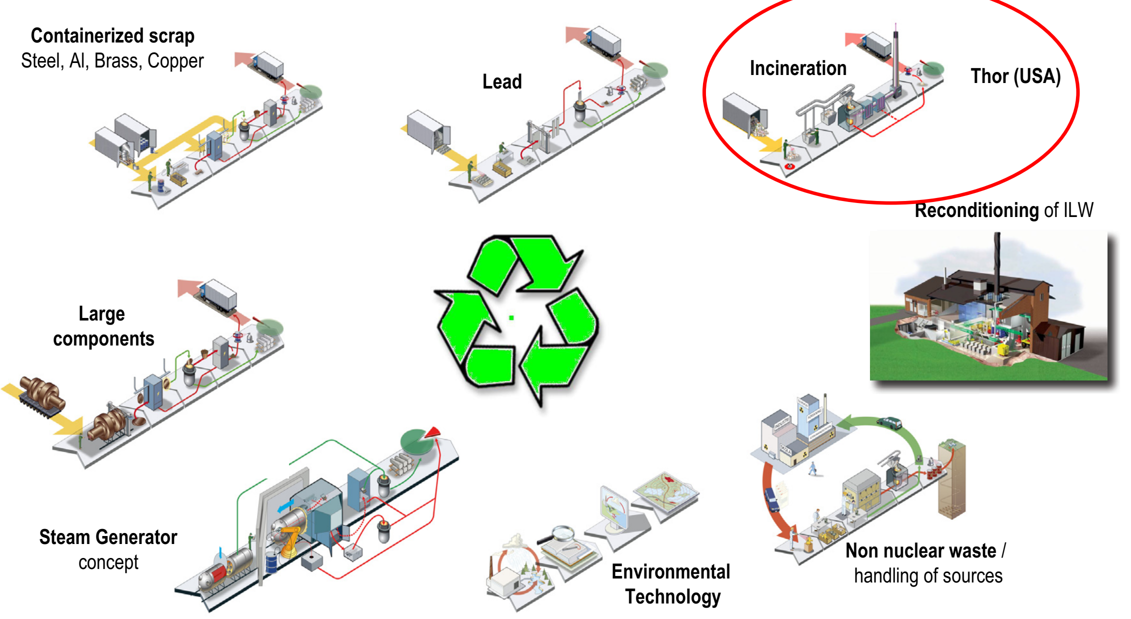
Metallic Waste Streams



Anders Stenmark
Studsvik

Waste Volume Reduction Services

by Studsvik



Anders Stenmark
Studsvik

THOR References

- ***Studsvik*** processing facility in Erwin. Volume reduction and stabilization of ion exchange resins. Technical capacity 1,300 m^3 (46,000 ft^3) per year
- ***Uranium separation/conversion customer:*** Demonstration project for treatment of low activity, high nitrate liquid waste in ponds. Nitrate amount ~100 000 tonnes. Suggested plant design availability >85%, with mineral-bound output.
- ***USA DOE Idaho:*** Processing plant for transuranic waste with high activity levels. Start of operation scheduled for 2012. Design and build by Studsvik/URS joint venture. Mineral-bound output, could be qualified for disposal as High Level Waste.
- ***USA DOE Hanford:*** Ongoing demonstration project for treatment of tank waste and vitrifier recycle stream. To be completed in July 2009. Mineral-bound output intended.
- ***USA DOE Savannah River:*** Treatment of benzene-bearing transuranic waste. In final negotiations. Output to be used as input to a vitrifier.

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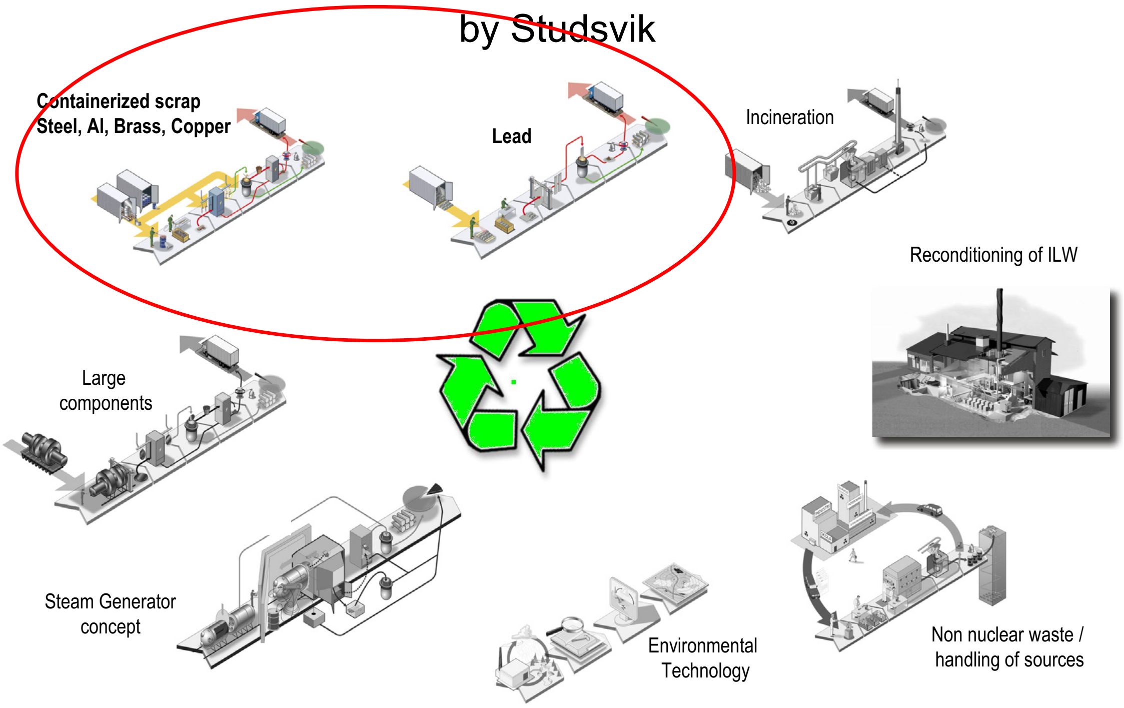
Waste Volume Reduction Services

by Studsvik



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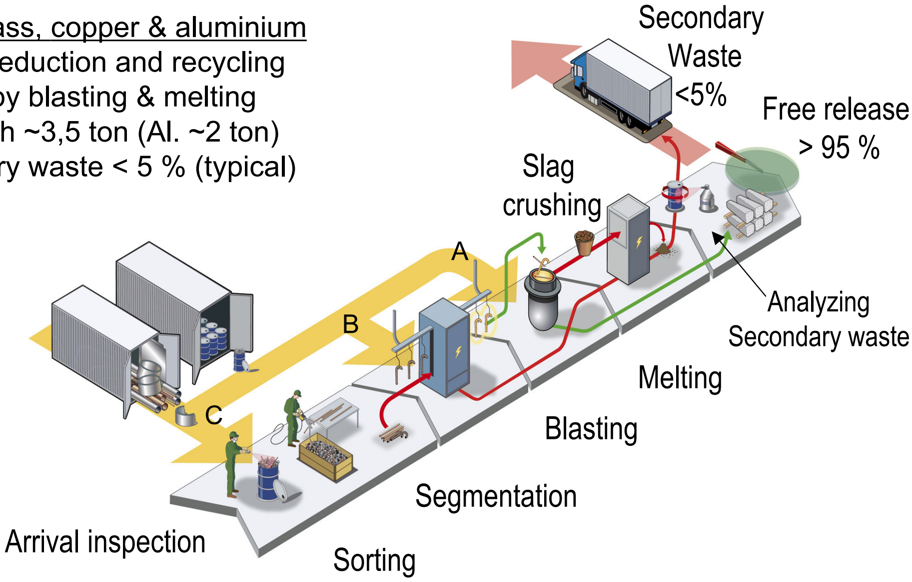
Containerized scrap

- Steel, brass, copper & aluminium
- Volume reduction and recycling
- Decont. by blasting & melting
- Melt batch ~3,5 ton (Al. ~2 ton)
- Secondary waste < 5 % (typical)



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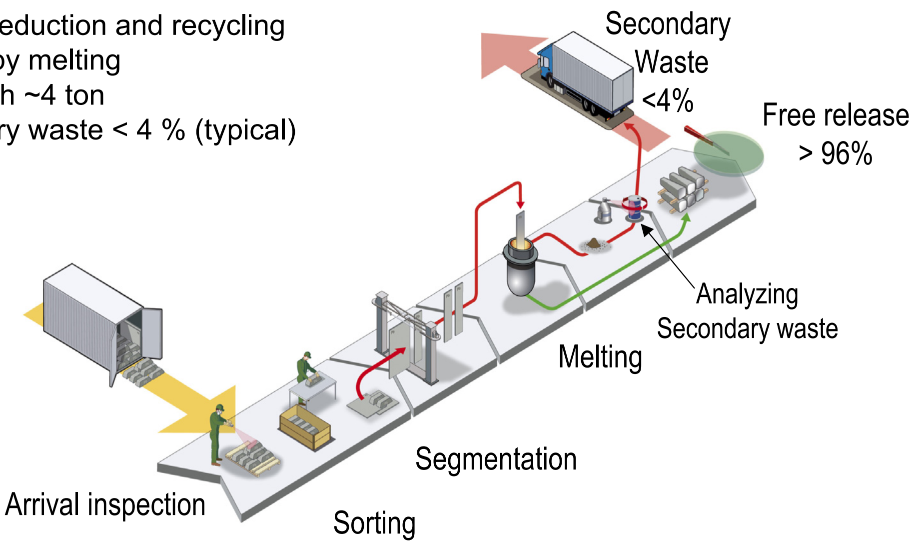
Containerized scrap

- LEAD
- Volume reduction and recycling
- Decont. by melting
- Melt batch ~4 ton
- Secondary waste < 4 % (typical)



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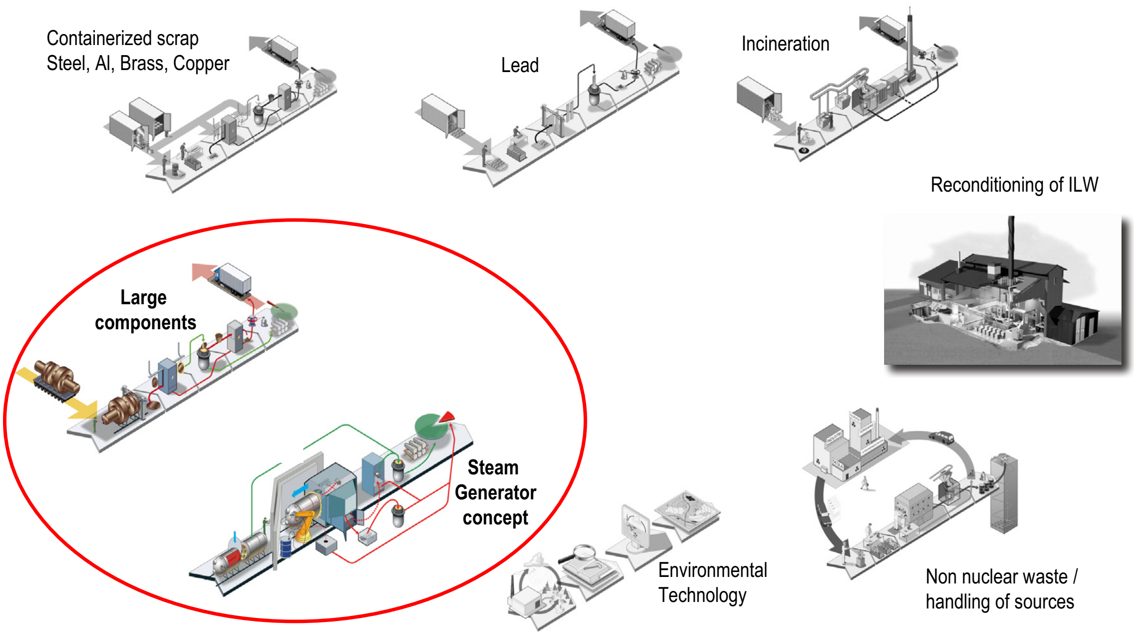
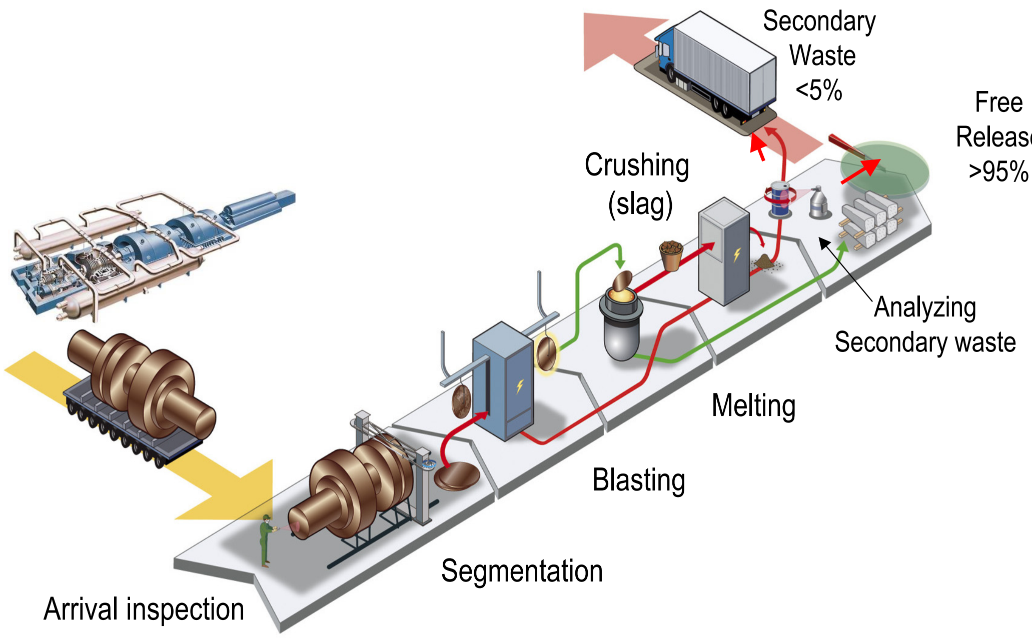
Waste Treatment Services



Anders Stenmark Studsvik

Treatment in Studsvik

Turbines etc.



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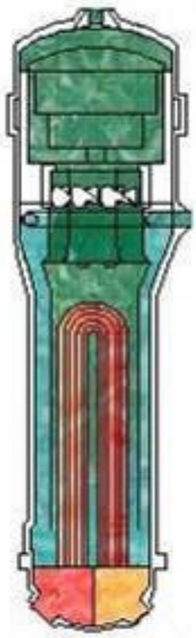
Ringhals SG - Project Objectives

- Complete waste conditioning
- Free release & recycling of relevant parts
- Minimize secondary waste for disposal to < 10 % of original volume
- Tube bundle pre-defined as waste
  - minimize volume by melting or
  - minimize volume by super compaction
  - explore future options for possible free-release
- Minimize dose to personnel – ALARA



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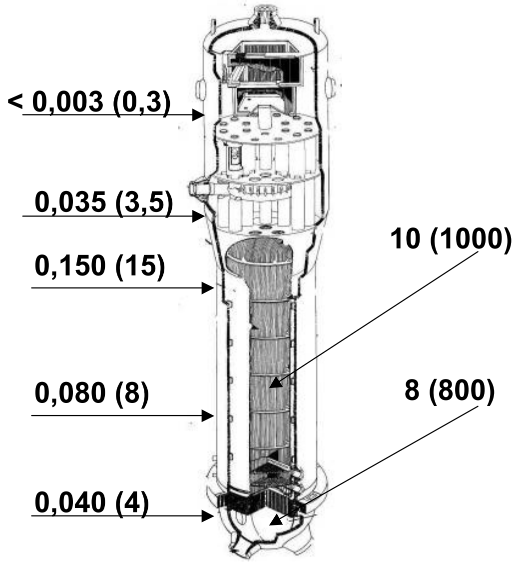
Radiological info.

Radioactivity inventory	TBq	Ci
Total:	~1.7	~5.7
Co-60:	0.65	2

95 % in tube bundle
5 % in the primary chamber



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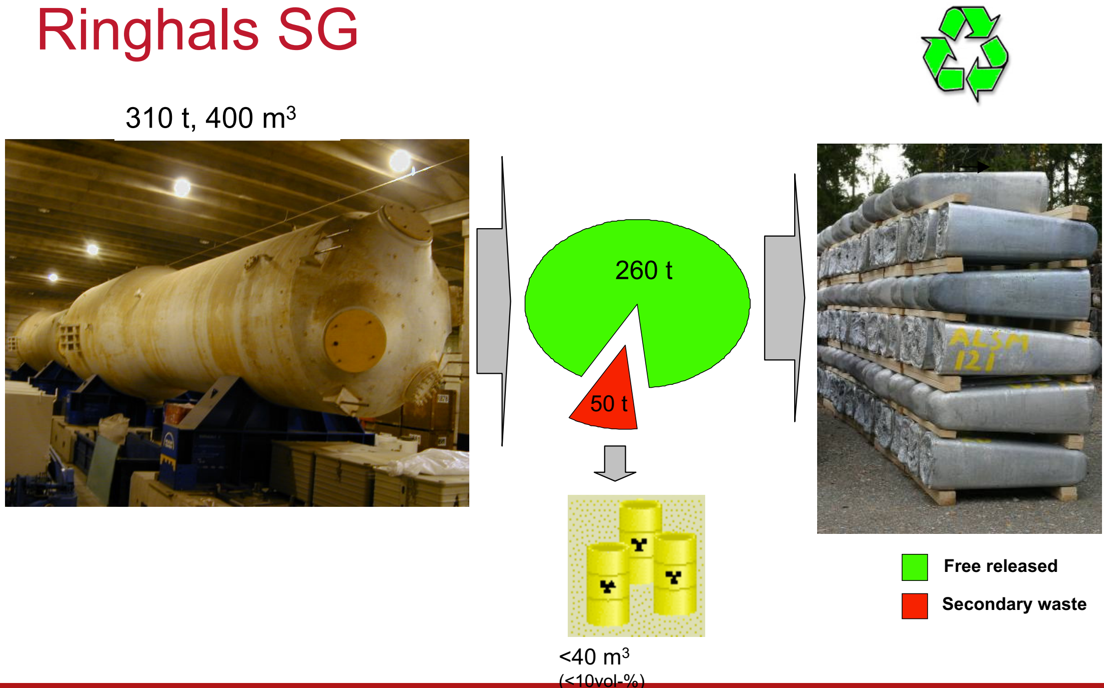
Result of the treatment of NPP Ringhals SG



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Result of the treatment of NPP Ringhals SG

- Treatment at Studsvik : Oct. 2005 – May 2006
  - (Today treatment time reduced to 3 months per SG)
- 260 ton could be free-released out of 310 ton
- LLW: approx. 10 ton
  - Final storage near Forsmark NPP
- MLW: approx. 40 ton
  - temporarily stored at interim storage at Studsvik for later storage at SFL (= the final storage for long lived nuclides)

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Other Large Component at Studsvik dockside (Turbin axel)

Waste Volume Reduction Services

by Studsvik

- Waste Volume Reduction with Studsvik is an economical choice for the Nuclear Industry to separate the bulk metal from the activity contamination
- Waste Volume Reduction by Studsvik creates a secondary waste containing the radioactive nuclides that is inert and easy to safely encapsulate
- Waste Volume Reduction saves cost for the Nuclear Industry since less space is required in repositories
- Waste Volume Reduction is the way of recycling valuable metals back to:
  - the raw materials cycle with minimal environmental impact
  - the nuclear industry as new products (shielding blocks)
- Studsvik has >20 years experience in international waste volume reduction
- Studsvik always applies ALARA for maximum personnel and environmental safety

Waste Volume Reduction Services

by Studsvik

- Studsvik has serviced the German nuclear market with waste volume reduction for the last 20 years!
- Similar services are presently offered in Great Britain
- Studsvik together with Kobelco want to offer waste volume reduction services suitable for the nuclear industry in Japan

Anders Stenmark

Studsvik

The 1st Studsvik-JAEA Meeting on Nuclear Development in Oarai
Jul.18th, 2008

JMTR Strategy on Re-operation

-Dosimetry for Standardization of Irradiation Technology-

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Introduction

Implemental agreement between the Studsvik AB and the Japan Atomic Energy Agency (JAEA) was signed on Dec., 12, 2008. Technical developments for the neutron-irradiation experiments in material testing reactors have been carried out in this implemental agreement. In the development, we go forward with standardization of neutron-irradiation tests in the world and efficiency of the facility management through the information exchange and exchange of staff. Thus, status and assignment of neutronic evaluations for materials test reactors are discussed in this meeting.

Standardization items for neutron dosimetry

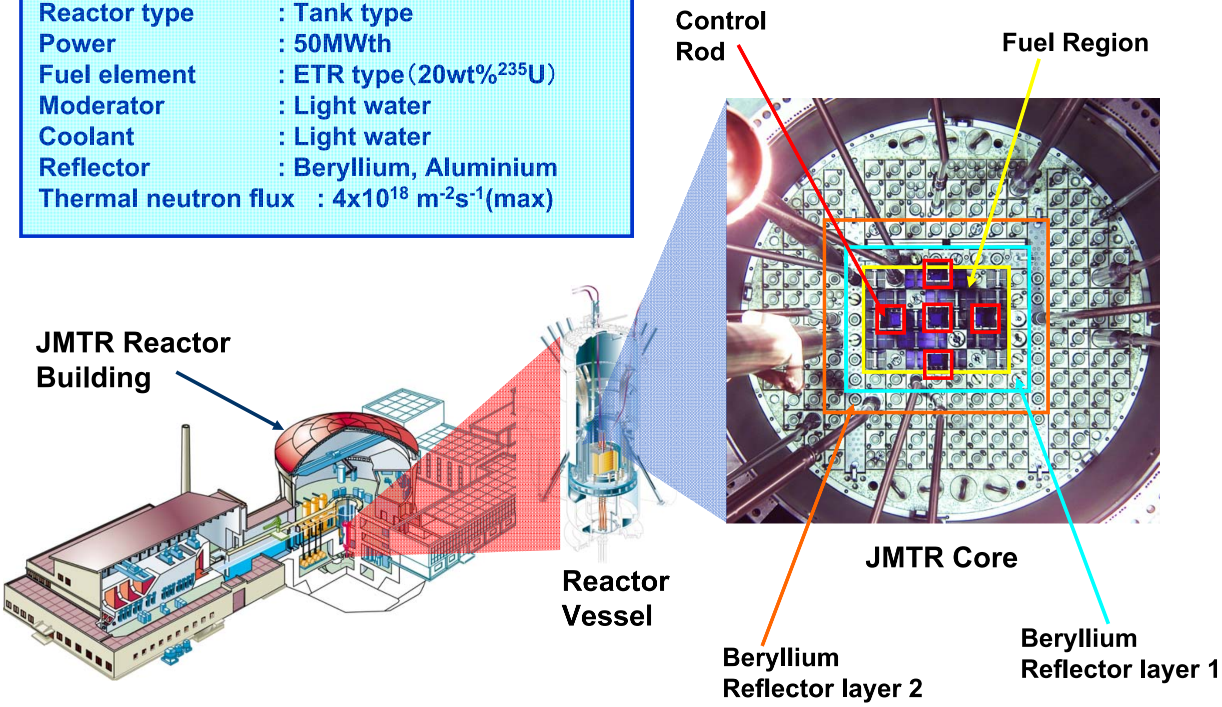
- *Dosimetry*
  Neutron Flux, Neutron Fluence, Neutron Spectrum
- *Installation*
  Re-installation, Welding/brazing technique, etc.
- *Instrument*
  Heater, Thermocouple, Pressure gauge,
  Elongation Detector, etc.
- *Post-Irradiation Examination*
  Dimension, Metallography, Tensile Strength, etc.

[Cooperation Items]

- **Neutron Flux/Fluence**
- **Neutron Spectrum, etc.**

JMTR

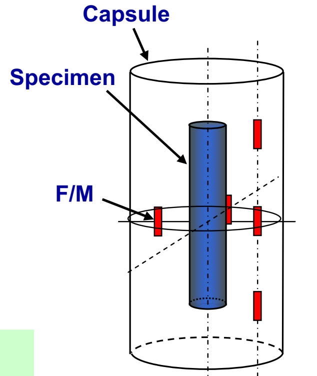
Reactor type	: Tank type
Power	: 50MWth
Fuel element	: ETR type (20wt%^{235}U)
Moderator	: Light water
Coolant	: Light water
Reflector	: Beryllium, Aluminium
Thermal neutron flux	: 4x10^{18} m^{-2}s^{-1}(max)



Neutron flux measurement

Neutron fluxes at local positions have been measured by using the fluence monitors (F/Ms).

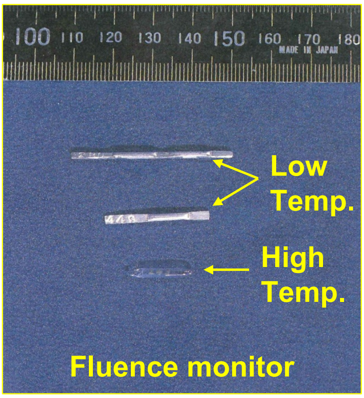
After irradiation tests, radiation activities of ^{54}Mn and ^{60}Co are measured with the germanium detector.



Typical arrangement of F/Ms in a capsule

Fast Neutron : ^{54}Fe(n, p)^{54}Mn

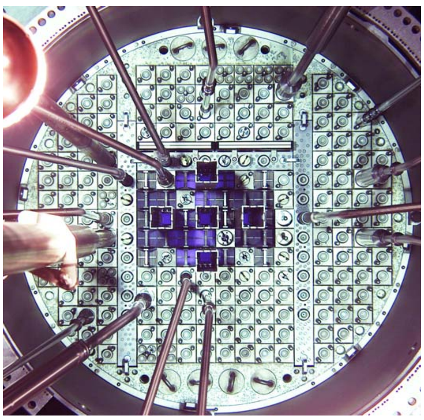
Thermal Neutron : ^{59}Co(n, g)^{60}Co



		For low temp. (~500°C)	For high temp. (500°C~1000°C)
Container materials		Al	quartz
Container		ϕ2.0mm L25mm or L40mm	ϕ3mm L15mm
Monitor Materials	Fast neutron	Fe	Fe
	Thermal neutron	Al-Co	V-Co, Ti-Co

Neutronic calculation

Code	: Continuous Energy Monte Carlo Code MCNP4B
Nucl. data lib.	: FSXLIBJ3R2 (based onJENDL3.2)
Cal. model	: Full 3D



JMTR core

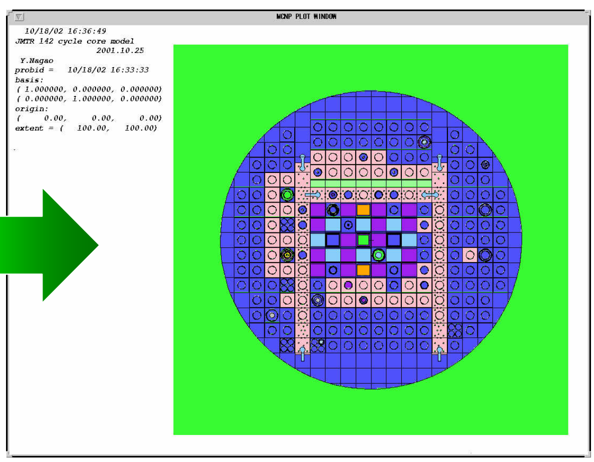


Image on Workstation

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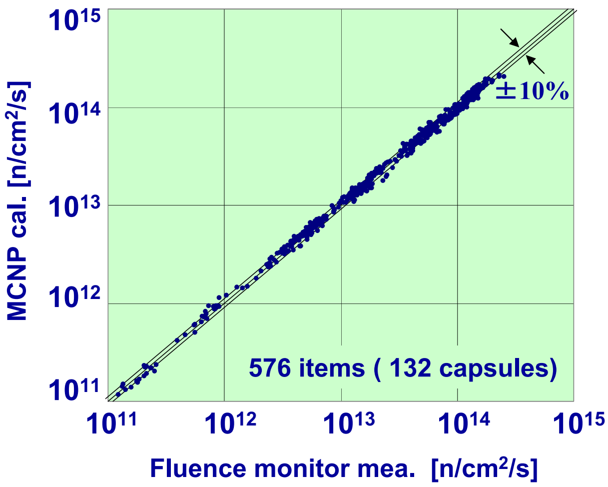
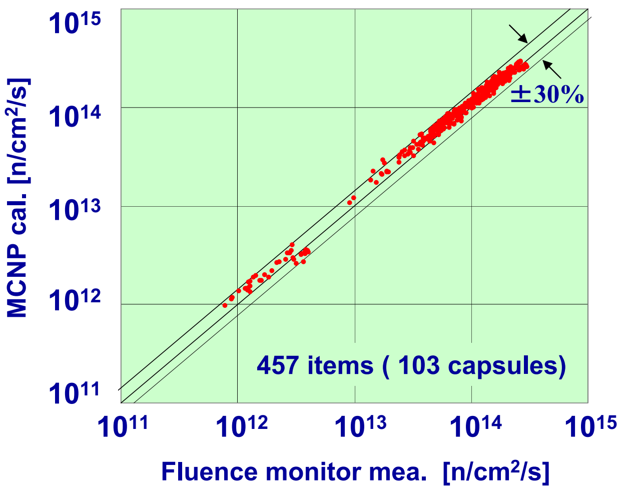
Verification results of neutron flux in irradiation tests of JMTR

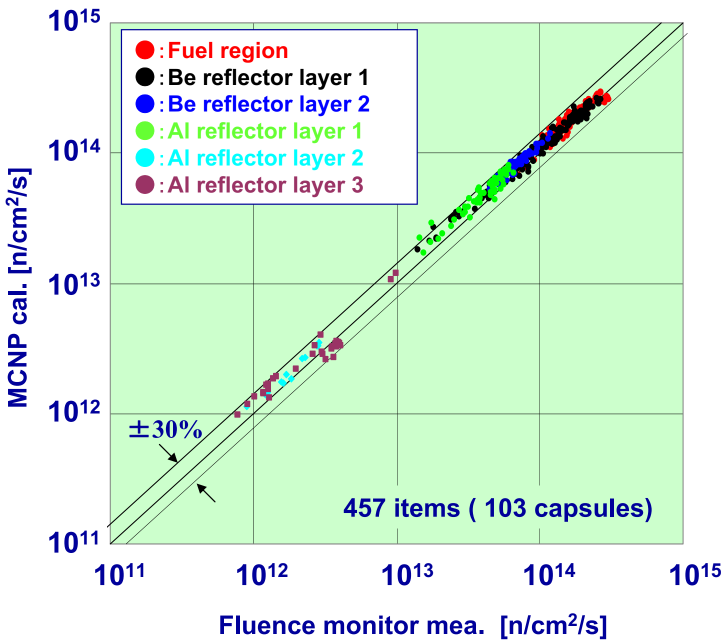


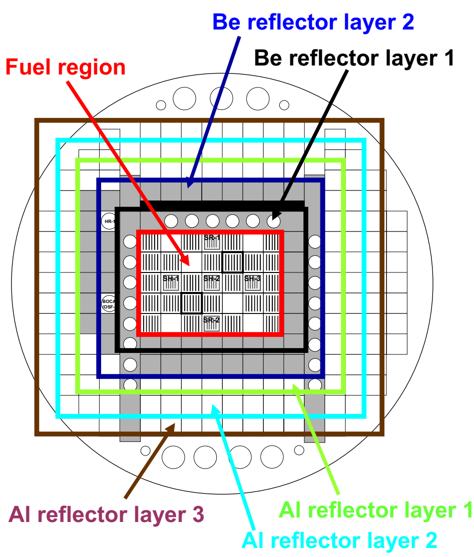


From FY1998 - FY2007

- Measurement : Fluence monitor Iron wire ($^{54}Fe(n,p)^{54}Mn$) for fast neutron flux
  Al-Co wire ($^{59}Co(n,gamma)^{60}Co$) for thermal neutron flux
- Calculation : MCNP (Ver. 4B)

Analysis of calculated / measured thermal neutron flux

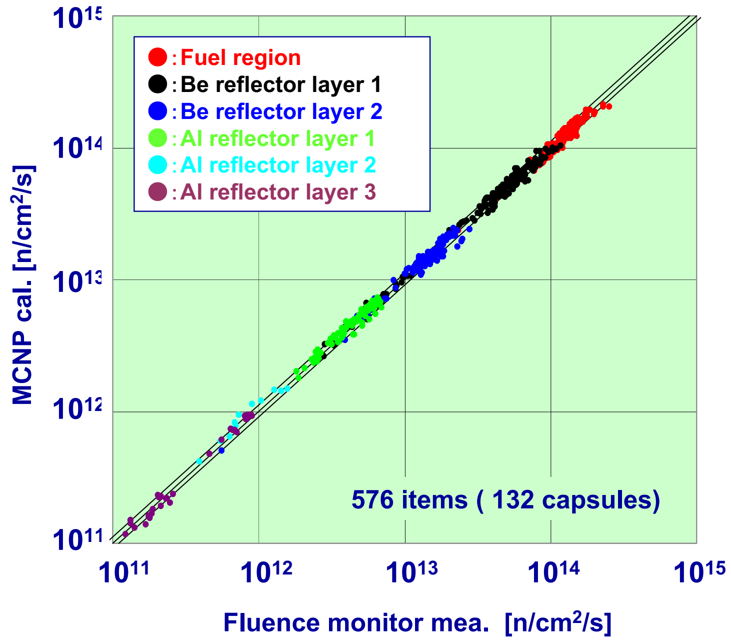


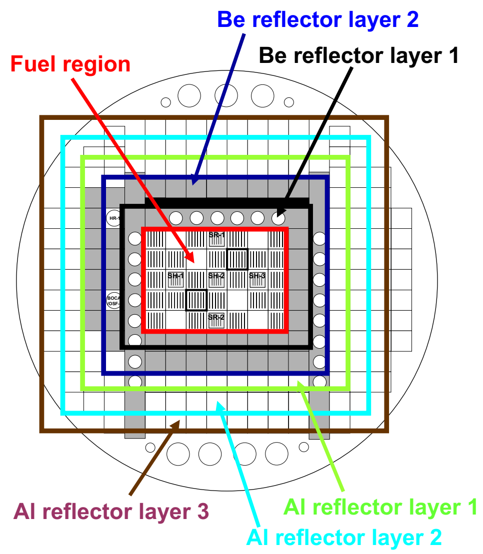


Calculated thermal neutron flux tend to overestimate in Be reflector layer 2 and Al reflector layer 1

From FY1998 - FY2007

Analysis of calculated / measured fast neutron flux





From FY1998 - FY2007

Gamma heating Calculation

Neutron and Gamma calculation

- Code : Monte Carlo code MCNP4B
- Nuclear data lib. : Neutron -- FSXLIBJ3R2 (based on JENDL3.2)
  TMCCS (S(alpha, beta), based on ENDF-B/III)
  Gamma -- MCPLIB (based on DLC-7E)
- Calculation model : Full 3D

Thermal calculation

- Code : GENGTC
- Calculation model : 1D cylindrical model

Verification procedure for gamma heating

Nuclear calculation (MCNP)

Gamma heating rate

- Prompt fission neutron
- Prompt fission + capture gamma rays
- Fission products gamma rays

Input

Thermal calculation

Heat transfer, gap heat transfer, thermal conductivity

→ Temperature at specimens

Measurement

Temperature at specimens by thermo-couples

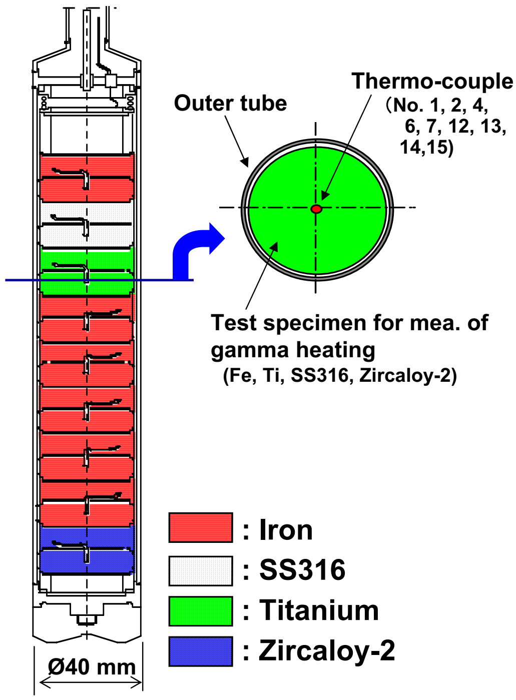
Verification of gamma heating

Gamma heating evaluation capsule

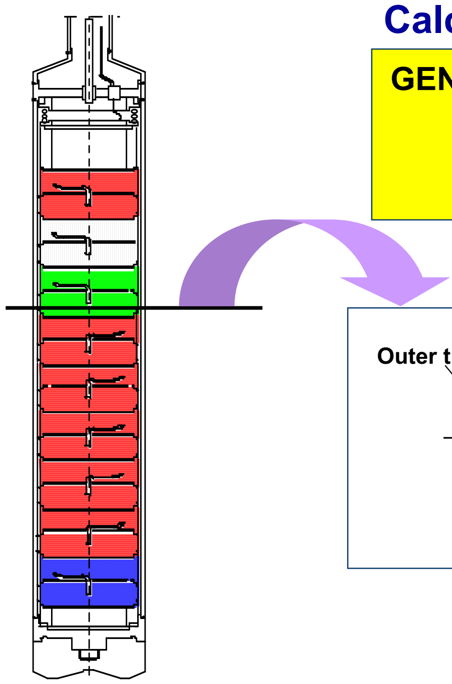
Design concepts

Reduction of uncertainties on thermal calculation

- **Capsule structure**
  Concentric circle shape
- **Materials**
  Iron, SS316, titanium, Zircaloy-2
  (Well-known and accurate data of thermal conductivity, coefficient of thermal expansion, etc.)



Thermal calculation

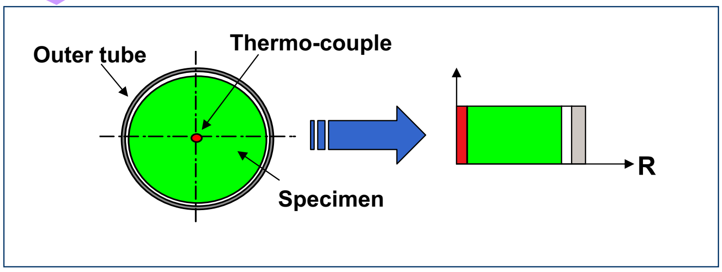


Calculation

GENGTC code :

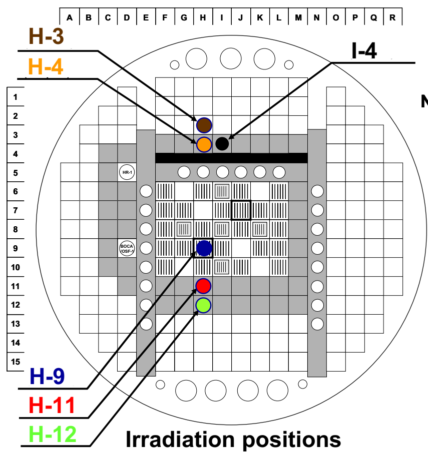
Design of irradiation capsules in JMTR.
Consideration the change of size depend on thermal expansion.

Modeling (1D geometry)

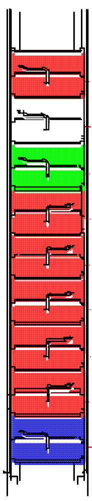


T_{cal}= f (gamma-heating, mat, geometry, …)

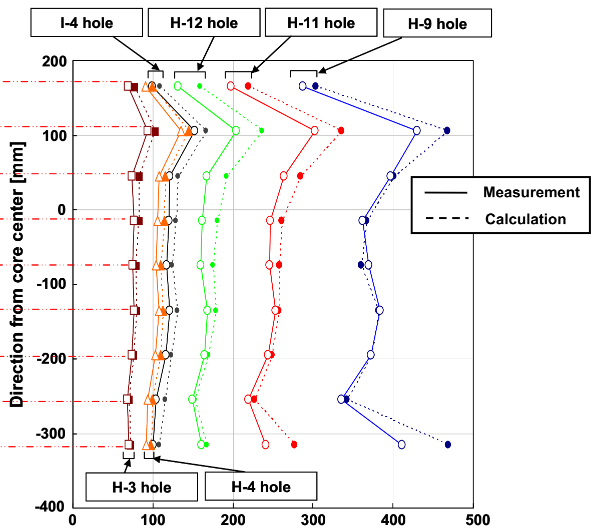
Verification results of gamma heating



Irradiation positions in JMTR core



Irradiation capsule for gamma heating rate evaluation



Position	Gamma heating rate [W/g]					
	H-9	H-11	H-12	I-4	H-4	H-3
No.1 Fe	4.62	2.72	1.65	0.87	0.71	0.43
No.2 SS316	5.73	3.38	1.97	1.14	0.89	0.51
No.3 Fe	6.98	4.41	2.54	1.45	1.13	0.63
No.4 Fe	6.72	3.96	2.25	1.27	1.00	0.55
No.5 Fe	7.06	4.23	2.29	1.29	1.01	0.55
No.6 Fe	7.29	3.94	2.23	1.33	1.00	0.53
No.7 Fe	7.08	3.78	2.06	1.21	0.96	0.49
No.8 Fe	6.39	3.34	1.79	1.13	0.83	0.42
Np.9 Zry-2	5.51	2.47	1.28	0.64	0.51	0.30

As the results, calculated temperature data agreed with measured data within -3∽+21% error.

Summary

An evaluation procedure using continuous energy Monte Carlo code MCNP and nuclear data library of the JENDL3.2 with a calculation model of the whole 3-D JMTR core has been introduced to evaluate irradiation parameters. Detailed analyses of irradiation parameters were conducted before irradiation using this procedure and these results were verified by comparing with the measured values. Calculated neutron flux/fluence was verified against measurements of irradiated fluence monitors (Iron and Aluminum-Cobalt wires).

It was confirmed that the calculated fast and thermal neutron flux/fluence agreed with measurements within ±10%, ±30%, respectively.

The 1st Studsvik-JAEA Meeting on Nuclear Development in Oarai
Neutron Irradiation and Testing Reactor Center, Jul.18th, 2008

Status and Assignment of Post Irradiation Examinations

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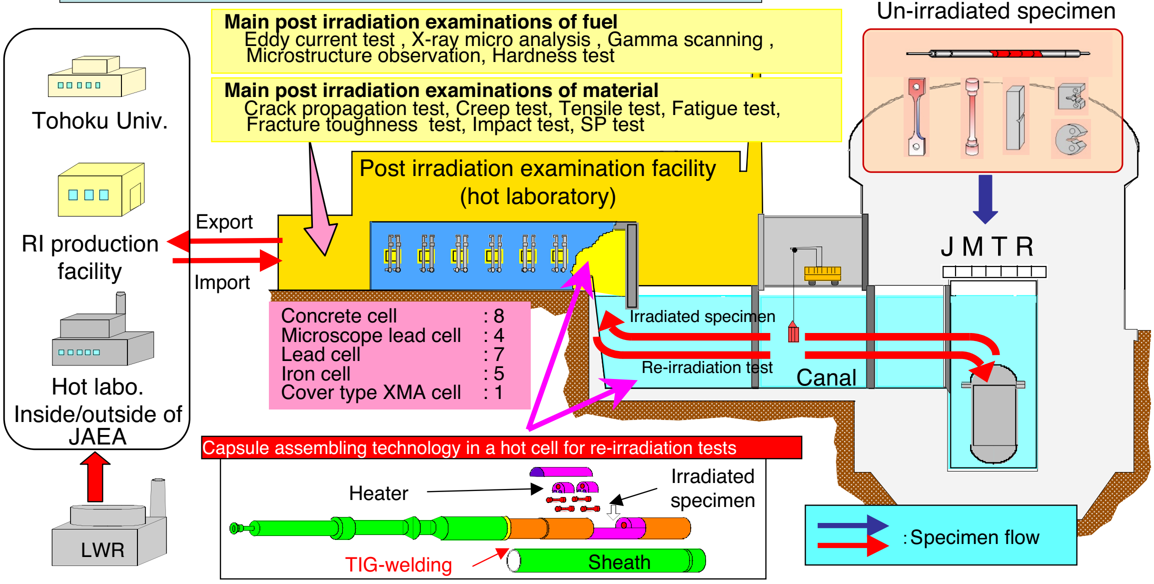
JMTR Hot Laboratory for PIEs

Characteristics

Hot laboratory and JMTR are connected directly by canal
→ Transportation of irradiated samples is easy
- Quick irradiation is possible
- Re-irradiation test of irradiated samples is easy

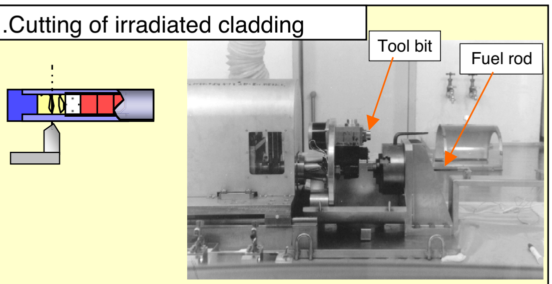


PIE technology (Fuel)

Re-fabrication and Re-instrumentation Techniques (1)

Processing technology of fuel center hole for temperature measurement

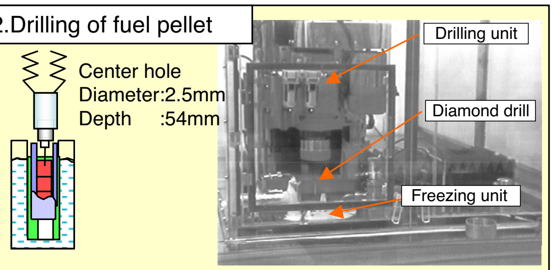
1.Cutting of irradiated cladding



Cutting machine for fuel rod cladding

Cutting of the fuel rod to remove end plug

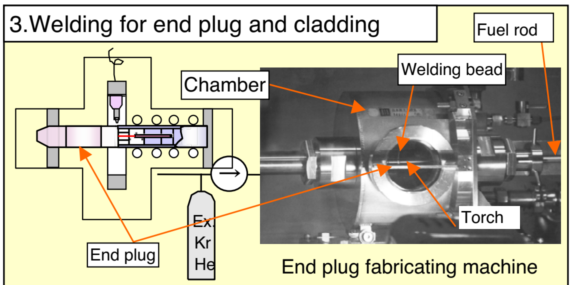
2.Drilling of fuel pellet



Drilling machine

Drilling the pellet with a maximum 54mm depth after freezing the gap between pellets by CO_2

3.Welding for end plug and cladding

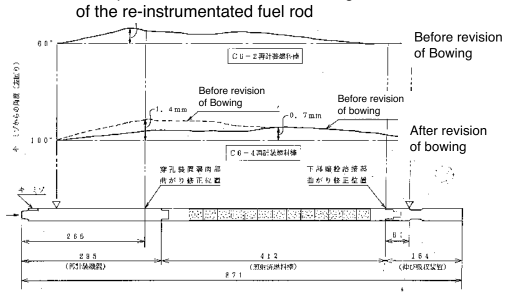


End plug fabricating machine

Circumferential welding for fuel rod end plug is performed in the chamber, followed by confirmation of bowing at the fuel rod (within 1/500mm)

Bowing measurement

Axial profile after correction of bowing of the re-instrumented fuel rod



PIE technology (Fuel)

Measurement of Crud Adhesion in JAEA

Evaluation of crud adhesion by PIE

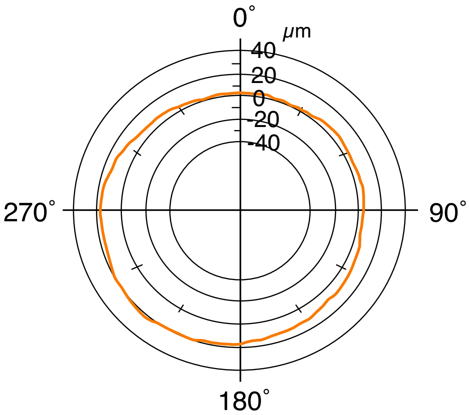
Estimation of crud adhesion by PIE on fuel rod

Experiences, etc.

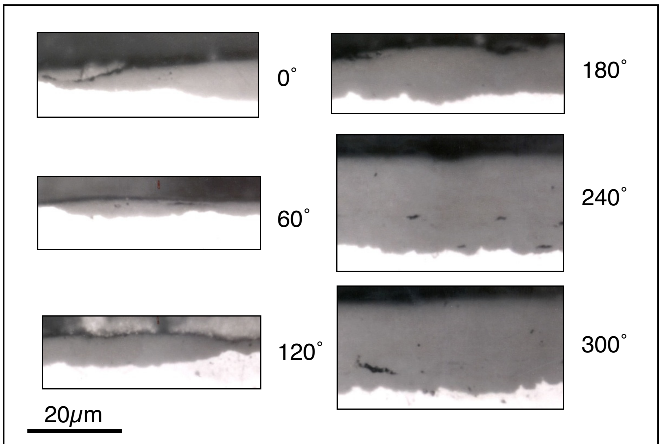
Analysis on the fuel rod cladding crud, containing oxidation products was performed by the PIE

Examination items

- XRD, SEM, EPMA
- Eddy current test, metallography



Example of oxide layer thickness of fuel cladding by eddy current test

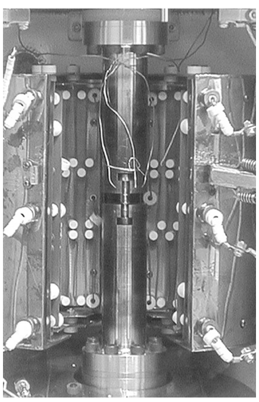


Cross-sectional micrograph of oxide layer

PIE technology (Material)

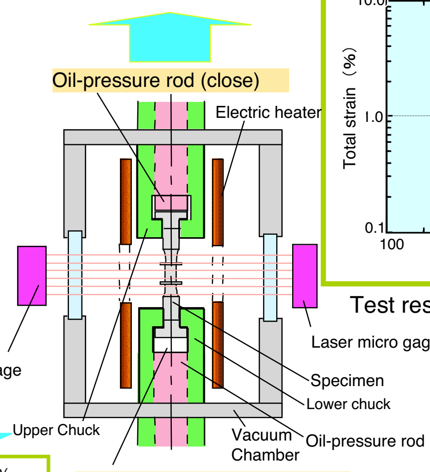
Laser-distortion Control-type Low-cycle-fatigue Test

High precision fatigue tests were carried out by use of a laser micro gauge and the improved feedback method of strain control



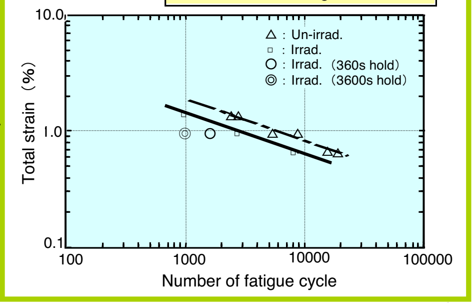
Heating furnace

Highly precise strain change was realized by feedback of a laser signal



Resolution : 0.1μm, ±0.5%
480 points/sec.

Test Conditions
Test temperature : 550℃
Test speed : 0.1%/s
Wave form : Triangular wave



Test results by small fatigue specimen

Acquisition of the quantitive data for decreasing of fatigue life of stainless steel

PIE technology (Material)

Re-weldability Test

Fabricating and welding techniques of Irradiated samples for re-weldability tests

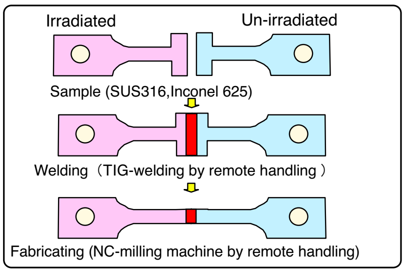
Experiences, etc.

Samples : SUS316, Inconel 625 etc.

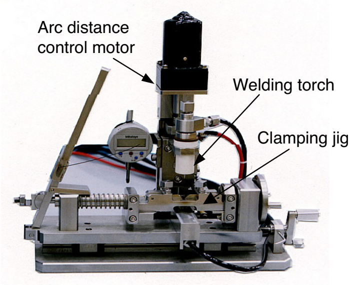
1) Welding and specimen fabricating from irradiated / un-irradiated materials
2) Welding and specimen fabricating from irradiated / irradiated materials
3) Re-irradiation after welding

PIE items

Welding test, fabricating, tensile test, hardness test, fractography

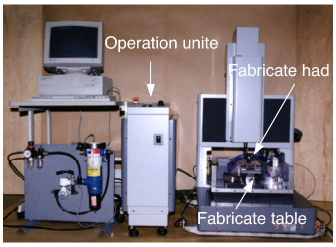


TIG-welding/Fabricating procedure for sample



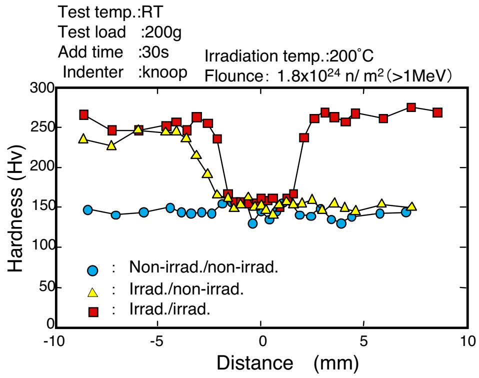
TIG-welding machine

- Specimen setting by remote control
- Welding position control
- Gap control of torch and sample
- Small heat affected area



Specimen fabricate machine

- NC controlled type
- Accuracy of 10μm

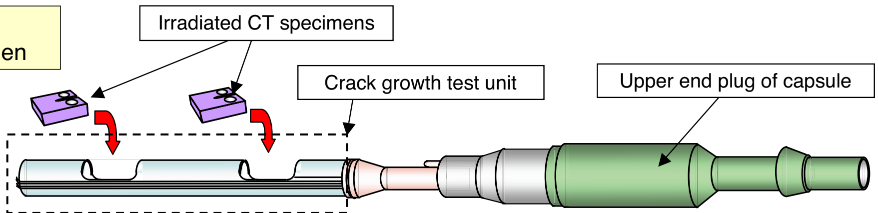


Results of hardness test (Cross section)

PIE technology

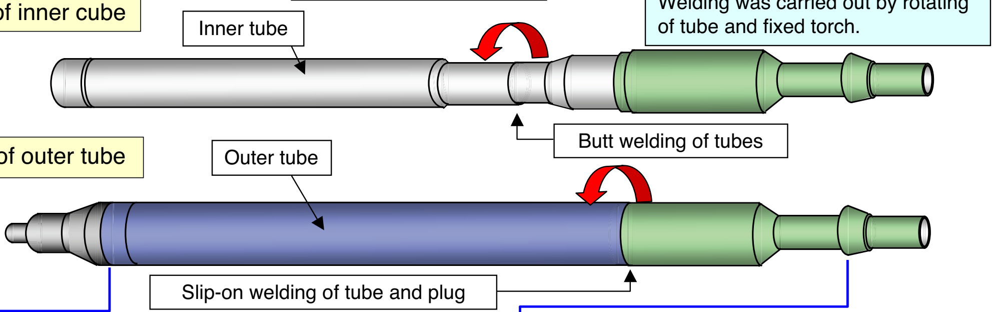
Remote Assembly Technology of Capsule

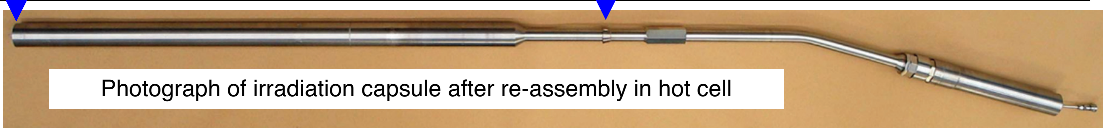
Installation of irradiated specimen



Welding technique

Welding was carried out by rotating of tube and fixed torch.





Photograph of irradiation capsule after re-assembly in hot cell

Conclusions

Mutual exchange of PIE information among these facilities, interchange of researchers and mutual utilization of PIE facilities are very desirable to raise the scientific and technical potential in the irradiation research and to get break-through of the study in the field of nuclear application.

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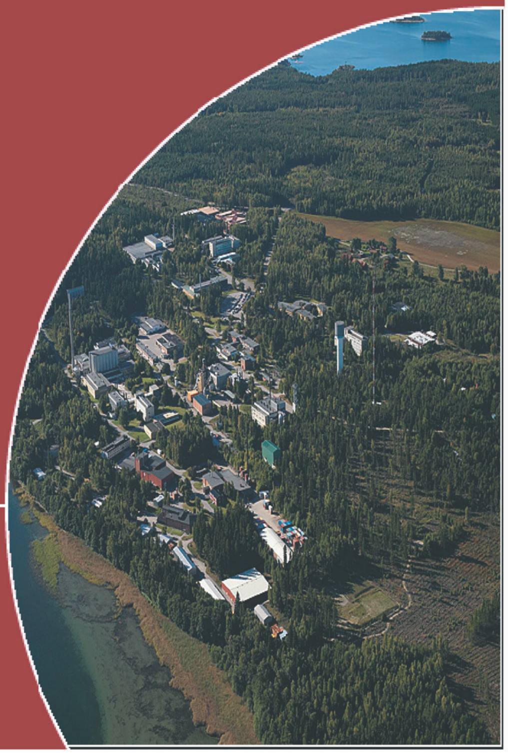

Irradiation Technique and Industrial Utilization

July 2008

MTR usage and areas of interest

There are 5 areas of interest from a commercial client point of view (Industrial Utilization):

1. Material irradiations, dose, water chemistry and corrosion (LWR and Generation IV)
2. Fuel irradiations, long and short term (LWR, Gen IV?)
3. Isotope production (irradiation)
4. Silicon irradiation
5. Medical treatment using neutrons

Then there is basic research (governmental financed)

There is also one aspect of interest only for the MTR

1. The operation of the MTR!

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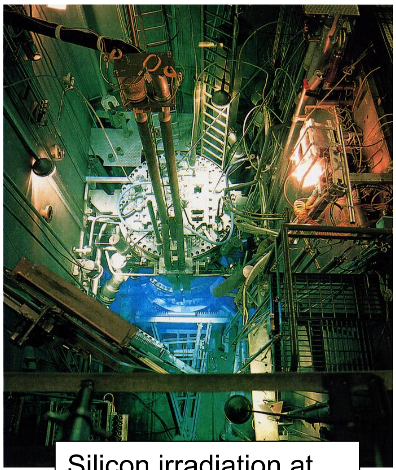
Difficulties being a MTR – too many areas to focus on

- Each area require:
  - Expertise
  - Focus
  - Commitment
  - Resources
  - Work to get experience



Silicon irradiation at the R2

- Not always paid for
- Not always suitable

- Decide what areas to focus on – all?
  - Strategy

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Industrial usage versus research purpose

The demands from the industry are very different compared to those from commissioned research!

Industry requirement:

- A result is asked for, within specified budget and time schedule, fulfilling specified test conditions
  - Mistakes rarely or never allowed

Higher demands in some aspects

Basic research:

- Not always known if there is an answer
- Not always known what is required to find it

More is accepted

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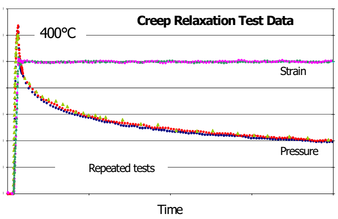
Neutron dosimetry – when and why?

- Extremely important:
  - Silicon doping (accuracy is everything, +- a few % total)
  - Medical treatment (not discussed further)
- Fairly important (different reactions, larger uncertainty)
  - Water chemistry and corrosion
  - Material irradiations
  - Isotope production
  - Long term fuel irradiations
- Has to combine detectors and modeling (often MCNP code)

Measurements of physical properties

- Extremely important (small uncertainty required):
  - Ramp tests
  - Water chemistry tests
  - Corrosion tests
  - Instrumented tests (fuel or material)



- Fairly important (typical “go for target” values):
  - Long term fuel irradiations
  - Material irradiations
  - Isotope production

Must be reliable and reproducible

Physical properties measurements

- Basic data:
  - Temperature
  - Pressure
  - Flow rate
  - ECP (Electro Corrosion Potential)
  - PH
  - Conductivity

Must measure what it is:

- In the test facility
- In the test position
- In the core

- Advanced
  - An- and Cat-ions
  - On-line fuel or special material measurements (any kind)

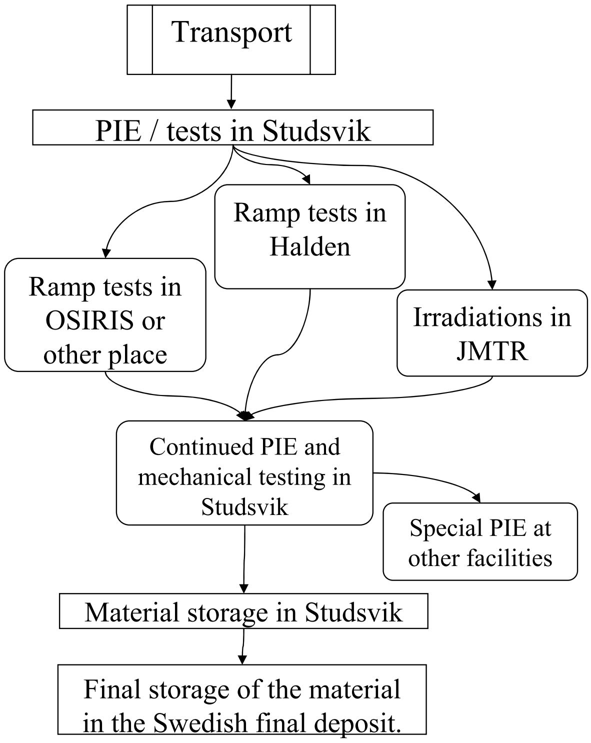
Timely delivery

- Extremely important (can be days or hours):
  - Silicon doping
  - Medical isotopes
- Fairly important:
  - All others
- Not so sensitive:
  - Basic research

Studsvik Mission

Studsvik Fuel and Material mission:

- Handle everything
- Only one contact for the client
- Manage the entire program irrespective of need
- Studsvik cooperate with the part needed to perform what a program require
- Studsvik has cooperation agreements with some organizations
- Be a complete independent supplier
- For all clients



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Different Facilities
Sometimes More Suitable in different areas

Studsvik

- No irradiations
- No very advanced techniques (as TEM & Melting point)

- Must cooperate with others (for irradiations):
  - Halden: Joint ramp test facility developed, Irradiations (all that are possible) in Halden and PIE in Studsvik
  - CEA: Ramp test in in CEA and PIE in Studsvik
  - JAEA: Under development

- These facilities have different pros and cons

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Cooperation – areas of interest

There are a number of areas of interest:

- MTR operation
- Utilization of existing expertise and facilities
  - Fuel & Material and Water Chemistry & Corrosion
  - Silicon
  - Isotope irradiation
- Support existing or new facilities
- New areas / others?

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Cooperation – MTR operation

Studsvik experience may support the JMTR

- JMTR people has visited Studsvik for two full days
- Several things were discussed:
  - Operation in general
  - Fuel usage and fuel loading principals (to save cost)
  - CR and CR driving mechanisms
  - Safety systems and operational handbook (SAR)
- Drawings were presented and discussed
- Flow diagrams were presented and discussed
- etc

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Cooperation – Industrial Utilization:

Fuel & Material and Water Chemistry & Corrosion

Interesting, need to think about:

- Complementary services - Irradiations and PIE
- Time, JMTR not in operation yet
- Geography (distance)
  (Europe & US far from Japan)

- Time schedule (time required
  for programs as not trivial transports required?)

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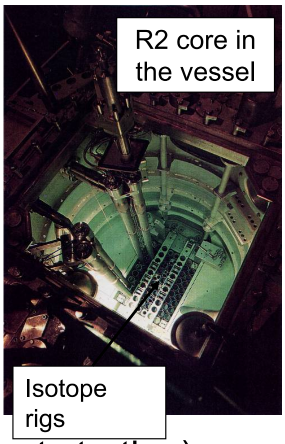
Cooperation – Industrial Utilization:

Silicon and Isotope irradiation

Silicon doping

- JAEA has studied the Studsvik way to do it
- Studsvik has forwarded their opinion



Isotope irradiation (medical and industrial)

- Discussed only slightly
- Needs timely delivery
- Authority view (regulations)
- Area of interest (Maple reactors in Canada not starting)

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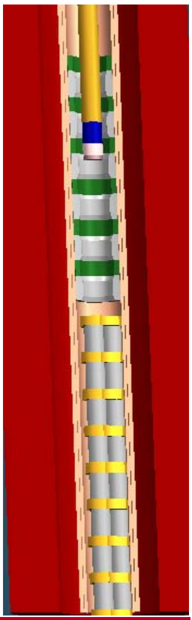
Cooperation – Industrial Utilization Support existing or new facilities



- The parties can support existing facilities with discussions and conceptual design discussions
  - Irradiations
  - PIE / Test methods
- New facilities
  - Find facilities that there is a need for in the world
  - Both irradiations and PIE

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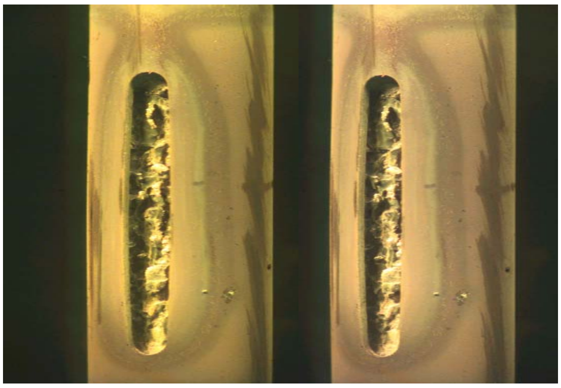
Cooperation – New areas

General approach: Whatever we can find!

(The sky is the limit!)

- Electrodes (ECP measurements) (ongoing discussion)
- New facilities for LWR fuel (for the future)
  - Irradiation
  - PIE/testing
- New facilities for Gen IV
  - Irradiation
  - PIE/testing
- Others?



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Cooperation - Logistic requirements

Transports

- Economically OK
- Authority reactions as expected

Material disposal of non-national material

- In Sweden OK for examined or tested material
- In Japan?
- Authority reactions as expected?

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Industrial utilization – expectations

Fuel and Materials and Water chemistry and Corrosion:

The industry regard the following:

1. The facility must be in operation
2. Must deliver promised test conditions
3. Must deliver on time and according to budget
4. Strict confidentiality

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Industrial utilization – expectations II

Fuel and Materials and Water chemistry and Corrosion:

Important:

- Authorities – are they predictable?

- Reliability:
  - Will the facility still be there in the future (compare the R2)
  - Will the facility develop for the future
  - Will the facility deliver as requested

The future – short term – long term

Need to continue to discuss:

- Agree on a way forward (different depending on what area)
- Help each other to find opportunities
  - Studsvik will honor earlier agreements

- Number of powerful MTR facilities will decrease
  - Capacity
  - Competence
  - Capability

Studsvik plan:

- To be there short and long term
- To cooperate with those existing

国際単位系（SI）

表１．SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表２．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m-1
密度（質量密度）	キログラム毎立法メートル	kg/m^3
質量体積（比体積）	立法メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
（物質量の）濃度	モル毎立方メートル	mol/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率	（数の）１	1

表５．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	μ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^{9}	ギガ	G	10^{-12}	ピコ	p
10^{6}	メガ	M	10^{-15}	フェムト	f
10^{3}	キロ	k	10^{-18}	アト	a
10^{2}	ヘクト	h	10^{-21}	ゼプト	z
10^{1}	デカ	da	10^{-24}	ヨクト	y

表３．固有の名称とその独自の記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン[a]	rad		$m\cdot m^{-1}=1$[b]
立体角	ステラジアン[a]	sr[c]		$m^2\cdot m^{-2}=1$[b]
周波数	ヘルツ	Hz		s^{-1}
力	ニュートン	N		$m\cdot kg\cdot s^{-2}$
圧力，応力	パスカル	Pa	N/m^2	$m^{-1}\cdot kg\cdot s^{-2}$
エネルギー，仕事，熱量	ジュール	J	$N\cdot m$	$m^2\cdot kg\cdot s^{-2}$
工率，放射束	ワット	W	J/s	$m^2\cdot kg\cdot s^{-3}$
電荷，電気量	クーロン	C		$s\cdot A$
電位差（電圧），起電力	ボルト	V	W/A	$m^2\cdot kg\cdot s^{-3}\cdot A^{-1}$
静電容量	ファラド	F	C/V	$m^{-2}\cdot kg^{-1}\cdot s^4\cdot A^2$
電気抵抗	オーム	Ω	V/A	$m^2\cdot kg\cdot s^{-3}\cdot A^{-2}$
コンダクタンス	ジーメンス	S	A/V	$m^{-2}\cdot kg^{-1}\cdot s^3\cdot A^2$
磁束	ウエーバ	Wb	$V\cdot s$	$m^2\cdot kg\cdot s^{-2}\cdot A^{-1}$
磁束密度	テスラ	T	Wb/m^2	$kg\cdot s^{-2}\cdot A^{-1}$
インダクタンス	ヘンリー	H	Wb/A	$m^2\cdot kg\cdot s^{-2}\cdot A^{-2}$
セルシウス温度	セルシウス度[d]	℃		K
光束	ルーメン	lm	$cd\cdot sr$[c]	$m^2\cdot m^{-2}\cdot cd=cd$
照度	ルクス	lx	lm/m^2	$m^2\cdot m^{-4}\cdot cd=m^{-2}\cdot cd$
（放射性核種の）放射能	ベクレル	Bq		s^{-1}
吸収線量，質量エネルギー分与，カーマ	グレイ	Gy	J/kg	$m^2\cdot s^{-2}$
線量当量，周辺線量当量，方向性線量当量，個人線量当量，組織線量当	シーベルト	Sv	J/kg	$m^2\cdot s^{-2}$

(a) ラジアン及びステラジアンの使用は、同じ次元であっても異なった性質をもった量を区別するときの組立単位の表し方として利点がある。組立単位を形作るときのいくつかの用例は表４に示されている。
(b) 実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号“１”は明示されない。
(c) 測光学では、ステラジアンの名称と記号srを単位の表し方の中にそのまま維持している。
(d) この単位は、例としてミリセルシウス度m℃のようにSI接頭語を伴って用いても良い。

表４．単位の中に固有の名称とその独自の記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	$Pa\cdot s$	$m^{-1}\cdot kg\cdot s^{-1}$
力のモーメント	ニュートンメートル	$N\cdot m$	$m^2\cdot kg\cdot s^{-2}$
表面張力	ニュートン毎メートル	N/m	$kg\cdot s^{-2}$
角速度	ラジアン毎秒	rad/s	$m\cdot m^{-1}\cdot s^{-1}=s^{-1}$
角加速度	ラジアン毎平方秒	rad/s^2	$m\cdot m^{-1}\cdot s^{-2}=s^{-2}$
熱流密度，放射照度	ワット毎平方メートル	W/m^2	$kg\cdot s^{-3}$
熱容量，エントロピー	ジュール毎ケルビン	J/K	$m^2\cdot kg\cdot s^{-2}\cdot K^{-1}$
質量熱容量（比熱容量），質量エントロピー	ジュール毎キログラム毎ケルビン	$J/(kg\cdot K)$	$m^2\cdot s^{-2}\cdot K^{-1}$
質量エネルギー（比エネルギー）	ジュール毎キログラム	J/kg	$m^2\cdot s^{-2}\cdot K^{-1}$
熱伝導率	ワット毎メートル毎ケルビン	$W/(m\cdot K)$	$m\cdot kg\cdot s^{-3}\cdot K^{-1}$
体積エネルギー	ジュール毎立方メートル	J/m^3	$m^{-1}\cdot kg\cdot s^{-2}$
電界の強さ	ボルト毎メートル	V/m	$m\cdot kg\cdot s^{-3}\cdot A^{-1}$
体積電荷	クーロン毎立方メートル	C/m^3	$m^{-3}\cdot s\cdot A$
電気変位	クーロン毎平方メートル	C/m^2	$m^{-2}\cdot s\cdot A$
誘電率	ファラド毎メートル	F/m	$m^{-3}\cdot kg^{-1}\cdot s^4\cdot A^2$
透磁率	ヘンリー毎メートル	H/m	$m\cdot kg\cdot s^{-2}\cdot A^{-2}$
モルエネルギー	ジュール毎モル	J/mol	$m^2\cdot kg\cdot s^{-2}\cdot mol^{-1}$
モルエントロピー，モル熱容量	ジュール毎モル毎ケルビン	$J/(mol\cdot K)$	$m^2\cdot kg\cdot s^{-2}\cdot K^{-1}\cdot mol^{-1}$
照射線量（Ｘ線及びγ線）	クーロン毎キログラム	C/kg	$kg^{-1}\cdot s\cdot A$
吸収線量率	グレイ毎秒	Gy/s	$m^2\cdot s^{-3}$
放射強度	ワット毎ステラジアン	W/sr	$m^4\cdot m^{-2}\cdot kg\cdot s^{-3}=m^2\cdot kg\cdot s^{-3}$
放射輝度	ワット毎平方メートル毎ステラジアン	$W/(m^2\cdot sr)$	$m^2\cdot m^{-2}\cdot kg\cdot s^{-3}=kg\cdot s^{-3}$

表６．国際単位系と併用されるが国際単位系に属さない単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86400 s
度	°	1°=(π/180) rad
分	’	1’=(1/60)°=(π/10800) rad
秒	”	1”=(1/60)’=(π/648000) rad
リットル	l、L	$1l=1\ dm^3=10^{-3}m^3$
トン	t	$1t=10^3\ kg$
ネーパ	Np	1Np=1
ベル	B	1B=(1/2)ln10(Np)

表７．国際単位系と併用されこれに属さない単位でSI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位であらわされる数値
電子ボルト	eV	$1eV=1.60217733(49)\times10^{-19}J$
統一原子質量単位	u	$1u=1.6605402(10)\times10^{-27}kg$
天文単位	ua	$1ua=1.49597870691(30)\times10^{11}m$

表８．国際単位系に属さないが国際単位系と併用されるその他の単位

名称	記号	SI 単位であらわされる数値
海里		1海里=1852m
ノット		1ノット=1海里毎時=(1852/3600)m/s
アール	a	$1\ a=1\ dam^2=10^2m^2$
ヘクタール	ha	$1\ ha=1\ hm^2=10^4m^2$
バール	bar	$1\ bar=0.1MPa=100kPa=1000hPa=10^5Pa$
オングストローム	Å	1 Å$=0.1nm=10^{-10}m$
バーン	b	$1\ b=100fm^2=10^{-28}m^2$

表９．固有の名称を含むCGS組立単位

名称	記号	SI 単位であらわされる数値
エルグ	erg	$1\ erg=10^{-7}\ J$
ダイン	dyn	$1\ dyn=10^{-5}N$
ポアズ	P	$1\ P=1\ dyn\cdot s/cm^2=0.1Pa\cdot s$
ストークス	St	$1\ St=1cm^2/s=10^{-4}m^2/s$
ガウス	G	$1\ G\ \hat{=}10^{-4}T$
エルステッド	Oe	$1\ Oe\ \hat{=}(1000/4\pi)A/m$
マクスウェル	Mx	$1\ Mx\ \hat{=}10^{-8}Wb$
スチルブ	sb	$1\ sb=1cd/cm^2=10^4cd/m^2$
ホト	ph	$1\ ph=10^4lx$
ガル	Gal	$1\ Gal=1cm/s^2=10^{-2}m/s^2$

表10．国際単位に属さないその他の単位の例

名称	記号	SI 単位であらわされる数値
キュリー	Ci	$1\ Ci=3.7\times10^{10}Bq$
レントゲン	R	$1\ R=2.58\times10^{-4}C/kg$
ラド	rad	$1\ rad=1cGy=10^{-2}Gy$
レム	rem	$1\ rem=1\ cSv=10^{-2}Sv$
X線単位		$1X\ unit=1.002\times10^{-4}nm$
ガンマ	γ	$1\gamma=1\ nT=10^{-9}T$
ジャンスキー	Jy	$1\ Jy=10^{-26}W\cdot m^{-2}\cdot Hz^{-1}$
フェルミ		$1\ fermi=1\ fm=10^{-15}m$
メートル系カラット		$1\ metric\ carat=200\ mg=2\times10^{-4}kg$
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	
ミクロン	μ	$1\ \mu=1\mu m=10^{-6}m$

（第７版，1998年改訂）