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Integrated Waste Management Approach WP 1 Summary Report – Japan

Executive summary

Japan is in the process of decommissioning the Tokai-1 power station, a graphite-moderated reactor of Magnox design. This was Japan's first commercial nuclear power plant and ceased generating at the end of March 1998, after 32 years of operation. Tokai-1 is the first commercial nuclear power plant to transfer to the decommissioning stage in Japan. The project therefore has important roles for demonstrating the safe and economical decommissioning of a nuclear power plant and establishing key technologies for future reactor decommissioning in Japan.

This chapter presents in the section 'Background' an outline of the main technical details of the Tokai-1 plant and the more recently commissioned High Temperature Test Reactor (HTTR). An explanation is given of the importance of being able to deal safely and cost-effectively with the graphite waste from Tokai-1, which will arise when the reactor is eventually dismantled. It is clear that the graphite itself represents a significant element in relation to the challenge of the Tokai-1 decommissioning project as a whole.

The chapter also describes the legislative and regulatory framework within which the Japanese nuclear industry operates national policy for nuclear energy and decommissioning reactors and how this fits with international guidelines and regulations.

The remainder of the chapter is concerned with the current status of decommissioning of the two reactors, in particular Tokai-1 reactor, the strategy for taking forward decommissioning and technical development of methods for removal and treatment of the graphite moderator. This section describes two main strategies under consideration as a final disposition for graphite:

- packaging for direct disposal in a geological facility;
- incineration with subsequent treatment of off-gas to reduce levels of the long-lived radionuclide C-14

When examining the option of packaging for direct disposal, it has been found that by judicious cutting of some of the blocks and placing the pieces in free space within and between blocks, a much better packing factor may be achieved, bringing welcome economy in the number of waste packages required - contributing largely to reducing the disposal cost. The ultimate disposal method of the graphite waste, geological disposal or incineration, has not yet been decided but at the present time incineration would appear to be more cost-effective.

Revisions

Rev.	Date	Short description	Author	Internal Review	Task Leader	WP Leader
01	22/12/08	Issue for WP review	A Hetherington (NDA)	H Eccles (UK NNL)	H Eccles (UK NNL)	H Eccles (UK NNL)
02	7/01/09	Inclusion of HTTR material	H Eccles (UK NNL)	M P Metcalfe (UK NNL)	H Eccles (UK NNL)	H Eccles (UK NNL)

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1 Background

The only commercial graphite-moderated reactor in Japan is Tokai 1, a Magnox-type reactor imported from the UK. This was Japan's first commercial nuclear power reactor and was operated by Japan Atomic Power Company (JAPC) from 1966 – 1998. This contains some 1600 tonnes of graphite. Dealing with the graphite moderator represents a major challenge and accounts for a very significant proportion of the total waste management costs for decommissioning of the Tokai-1 power station. **Figure 1** shows the graphite structures in the reactor. The Japanese Atomic Energy Authority is currently operating a High Temperature Test Reactor (HTTR) located on its Oarai, Ibaraki site. This is a 30 MW graphite-moderated helium-cooled reactor design with graphite used for the hexagonal fuel bricks, fuel compacts and the side reflector.

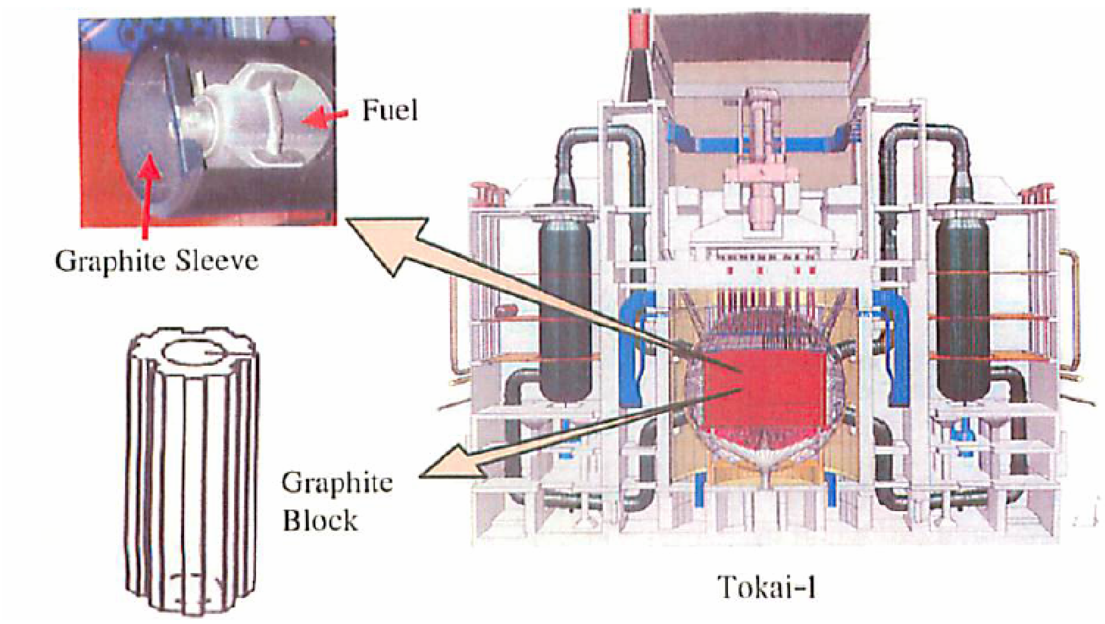

Figure 1 Graphite Structures in Tokai-1[1]

Tokai-1 power station data is reported in Table 1

Table 1: Tokai 1 Power Station Data

Reactor Type	Gas-cooled Reactor
Capacity	166 MWe
Fuel	Metal Natural Uranium with Magnox Cladding
Moderator	Graphite
Coolant	Carbon Dioxide Gas
Reactor Vessel	Spherical shape, 18m diameter
Steam Raising Unit	4 Units
Turbine Generator	83 MWe x 2 Units
Operation term	1966 - 1998
Defuelling and shipment	28.5.1998 – 21.6.2001

In March 19991, the Japan Atomic Energy Research Institute (JAERI) started to construct the High Temperature engineering Test Reactor (HTTR) which is a 30MW(thermal) helium gas cooled reactor with a core composed of prismatic blocks piled on the core support graphite structures. Two types of graphite materials are used in the HTTR. One is the grade IG-110, isotropic fine grain graphite, the other is the grade PGX, medium-to-fine grained moulded graphite. These materials were selected on the basis of the appropriate properties required by the HTTR reactor design. The HTTR attained its first criticality on 10 November in 1998 and has a plant lifetime of 20 years. The structure of the reactor internals and major specifications of the HTTR are provided in Figure 2 and Table 2 respectively.

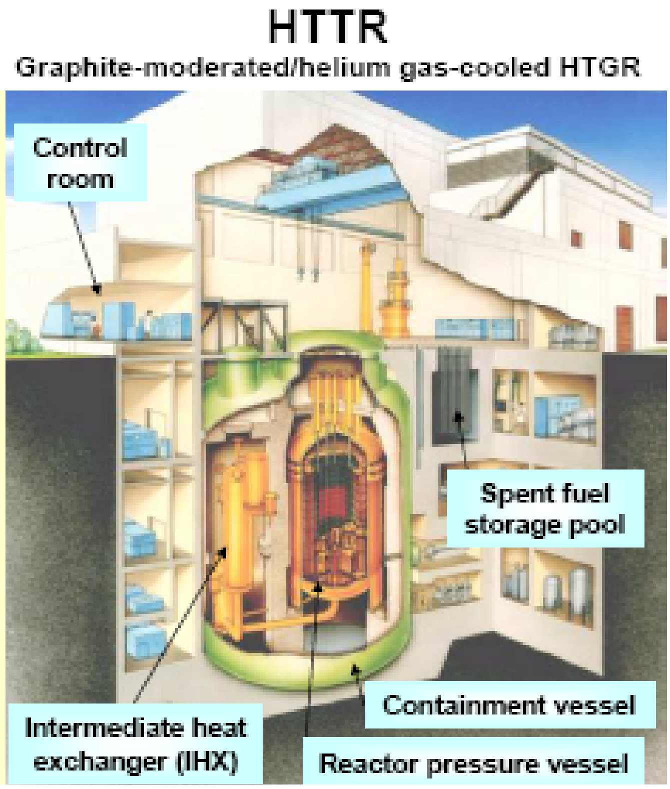

Figure 2 Structure of reactor internals[2]

Table 2 Major specifications of the HTTR

Thermal power	30 MW
Outlet coolant temperature	850/950^{0}C
Inlet coolant temperature	395^{0}C
Fuel	Low-enriched UO_2
Fuel element type	Prismatic block
Direction of coolant flow	Downward flow
Pressure vessel	Steel
Plant lifetime	20 years

The fuel element of the HTTR is the so-called pin-in-block type, which is made up of fuel rods and a hexagonal graphite block. The fuel rod is classified into 4 types; A-type fuel rod, which is used as a driver fuel and the B-type fuel rods, B-1, B-2 and B-3 which have different specifications of coating layers of coated fuel particles (CFPs) and are used in irradiation tests for advanced fuels.

The configuration of the fuel elements is shown in Figure 3. A coated fuel particle consists of a microsphere of low enriched uranium oxide with the TRISO (Tri-ISOtropic) coating. The CFPs are incorporated into fuel compacts with a graphite matrix. The fuel rod, which is composed of fuel compacts and a graphite sleeve, is contained within a vertical hole of a graphite block.

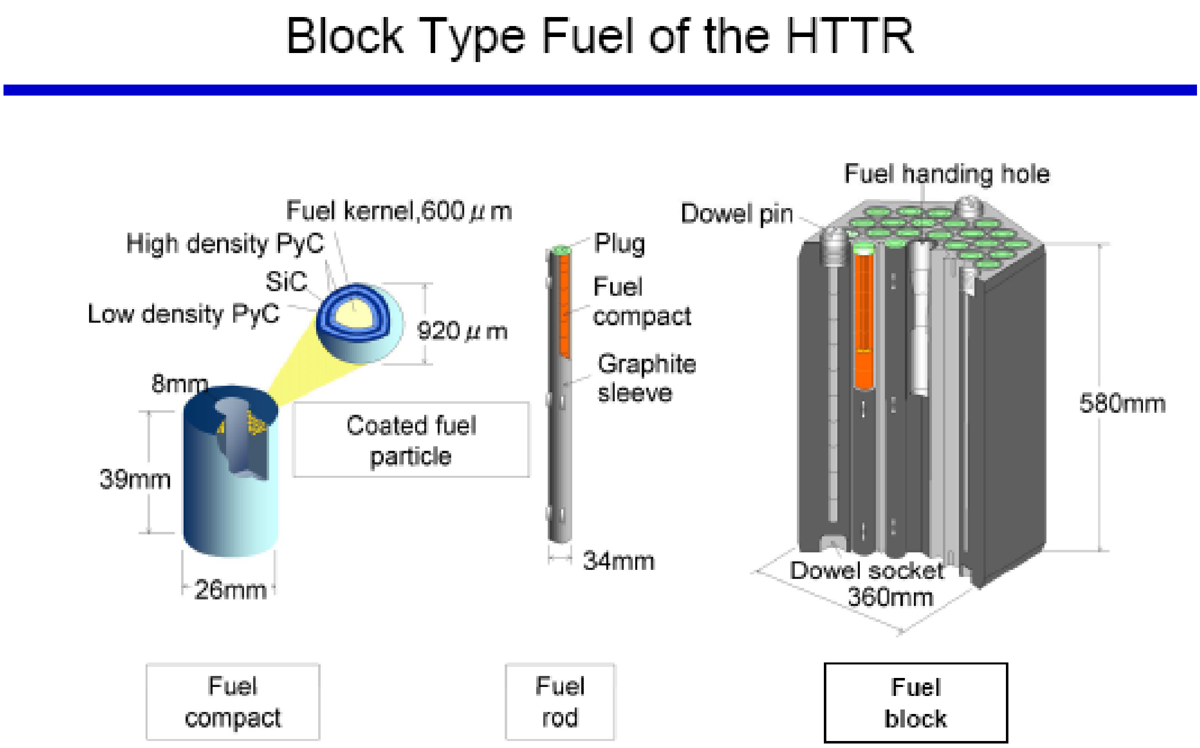

Figure 3 Configuration of fuel elements[2]

2 Legislative and regulatory framework

The nuclear industry in Japan is governed by the 1955 Atomic Energy Basic Law. This legislation created the Nuclear Safety Commission - the regulatory body for Japan's nuclear industry. The Commission itself is part of government; regulatory functions are carried out on the Commission's behalf by the Nuclear and Industrial Safety Agency (NISA), which has responsibility for licensing and regulatory oversight of nuclear plants.

Operators are required to establish and manage funds for eventual decommissioning. The regulatory authorities ensure the adequacy of such funds by financial audit and review of an accounting report submitted by the operator. Responsibility for managing radioactive waste lies with the nuclear plant operator, in line with the principle established in legislation that the polluter should pay.

The Atomic Energy Commission of Japan (AEA), also part of government, has responsibility for formulating policy and coordinates the entire nation's plans in the area of nuclear energy. The AEA concluded a new "Framework for Nuclear Energy Policy", endorsed by the cabinet in 2005. The main commitments in the framework were to: maintain or increase the nuclear ower's present share of 30-40%; steadily advance the nuclear fuel cycle; aim towards the commercialisation of Fast Breeder Reactors (FBR).

Figure 4 shows Japan's organisation chart in nuclear power, comprising of government regulatory authorities, electric power companies and contracting engineers/suppliers.

The Japanese government carried out administrative reform in January 2001. The Atomic Energy Commission and Nuclear Safety Commission (NSC) of the Cabinet Office gave high-level, independent and proper directions to other ministries and agencies.

The Ministry of Education, Culture, Sports, Science and Technology (MEXT) was created through a merger between the former Ministry of Education, Science, Sports and Culture and the Science and Technology Agency (STA). In MEXT, three Bureaus and four Divisions are in charge of nuclear energy. MEXT is responsible for the administration of nuclear energy for science and technology. Its key roles are nuclear research and development (including nuclear fuel cycle, FBR, quantum research, fusion, and accelerators), utilisation of radiation and radioisotopes, nuclear liability, safety regulation and disaster prevention testing and research for nuclear reactors, use of nuclear fuel material, and regulation for ensuring peaceful use and safeguards. It is also responsible for the supervision of the National Institute of Radiological Science, the Japan Atomic Energy Research Institute and the Japan Nuclear Cycle Development Institute.

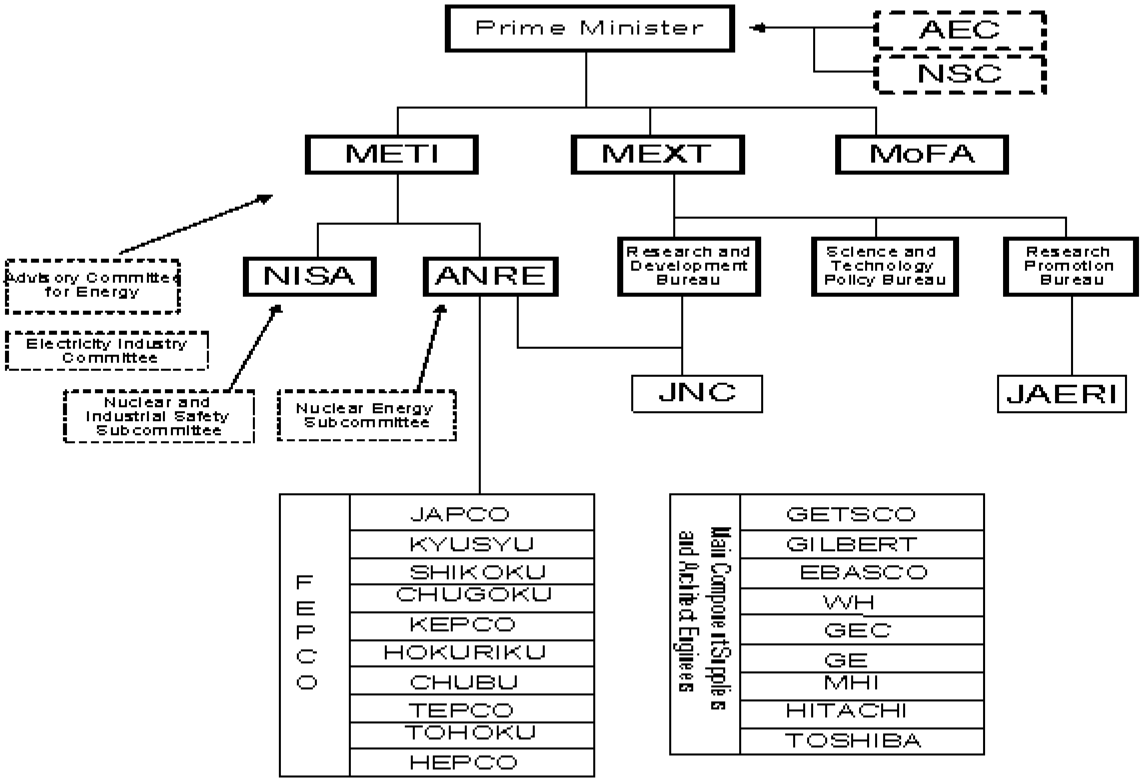

Figure 4 Japan's Organisation Chart in Nuclear Power [3]

Legend to Figure 4	
AEC:	Atomic Energy Commission
NSC:	Nuclear Safety Commission
METI:	Ministry of Economy, Trade and Industry
ANRE:	Agency of Natural Resources and Energy
NISA:	Nuclear and Industrial Safety Agency
MEXT:	Ministry of Education, Culture, Sports, Science and Technology
MoFA:	Ministry of Foreign Affairs
JAERI:	Japan Atomic Energy Research Institute
JNC:	Japan Nuclear Cycle Development Institute
FEPCO:	Federation of Electric Power Companies
HEPCO:	Hokkaido Electric Power Co.
TOHOKU:	Tohoku Electric Power Co.
TEPCO:	Tokyo Electric Power Co.
CHUBU:	Chubu Electric Power Co.

HOKURIKU:	Hokuriku Electric Power Co.
KEPCO:	Kansai Electric Power Co.
CHUGOKU:	Chugoku Electric Power Co.
SHIKOKU:	Shikoku Electric Power Co.
KYUSHU:	Kyushu Electric Power Co.
JAPCO:	The Japan Atomic Power Co.
TOSHIBA:	Toshiba Corporation
HITACHI:	Hitachi Ltd.
MHI:	Mitsubishi Heavy Industries Ltd.
GE:	General Electric Co.
GEC:	The General Electric Co. Ltd.
WH:	Westinghouse Electric Corporation
EBASCO:	Ebasco Services Incorporated
GILBERT:	Gilbert/Commonwealth International
GETSCO:	General Electric Technical Services Co.

The Ministry of Economy, Trade and Industry (METI) will be in charge of not only those areas that it was previously - as the Ministry of International Trade and Industry (MITI) - and the areas taken over from STA - related to the nuclear fuel cycle business (refining, enrichment, fabrication, reprocessing and waste disposal), but also the regulation of nuclear reactors including Monju and Fugen, that are in the research and development stage for use in the generation of electricity. Nuclear power-related issues will continue to be the responsibility of the Agency of Natural Resources and Energy. In addition, the Nuclear and Industrial Safety Agency (NISA), with its ten sections related to nuclear energy, was added as a special institution, to play a central role in safety regulations for industrialised nuclear power. NISA is responsible for regulating nuclear safety. The drafting of safety regulations and the licensing of milling and refining, nuclear fuel fabrication, spent nuclear fuel reprocessing and storage, disposal of radioactive waste and decommissioning of nuclear power plants, are now carried out by NISA. A double check safety review system of nuclear facilities by NSC and NISA or MEXT is continuously being applied.

The Ministry of Foreign Affairs (MoFA) is responsible for the international aspect of nuclear energy utilisation, including the implementation of the related international treaties and conventions.

2.1 Main national laws and regulations concerning nuclear power

1. The Atomic Energy Basic Law [no186, 19 December 1955, as amended].

2. 2004 Japan Atomic Energy Agency Law

3. The Law for the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors [no166, 10 June 1957, as amended].

The law, usually abbreviated as LRNR, prescribes the regulations necessary for the installation and operation of reactors, refining, processing, and disposal of nuclear waste.

4. The Electricity Utilities Industry Law (1964.7.11 - Publication) as amended in 2002.

5. The Law concerning Prevention of Radiation Hazards due to Radioisotopes, etc. [no167, 10 June 1957*, as amended]*.

The law intends to prevent radiation hazards by regulating the use and disposal of radioisotopes and the use of radiation producers. In a nuclear power plant, the law applies when neutron sources are used or radioisotopes are employed for the calibration of equipment.

6. Special Law of 1999 on Emergency Preparedness for nuclear disaster [no156, 17 December 1999].

7. The Law on Compensation for Nuclear Damage (1961.6.17 - Publication) as last amended in 1999.

8. Law on Final Disposal of High Level Radioactive Waste (2000)

The law prescribes the establishment of implementation for disposal, a funding mechanism for securing disposal costs, and a three-step site selection process.

3 Policy objectives of decommissioning

Motivation for decommissioning in Japan has policy drivers that are very different from those which apply in the UK. Japan is committed to continued use of nuclear power for reasons of security of supply and there is a strong will to re-use existing nuclear sites for new nuclear facilities. Policy therefore is oriented towards early final site clearance. Financial drivers appear to be much less of a consideration than the need to make space for new nuclear development.

The decommissioning of Tokai-1 is the first decommissioning project for a commercial reactor in Japan. This project has important roles for demonstrating the safe and economical decommissioning of a commercial nuclear power plant.
It is Japan's fundamental policy to dismantle and remove decommissioned nuclear power generation facilities that have completed their service life, while ensuring complete safety in that process. Based on this fundamental policy, the standard procedure (standard work schedule) is one of 'safe storage plus disassembly/removal'. It is considered appropriate to choose a safe storage period of five to ten years and a disassembly/removal period of three to four years.

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4 Compliance with international guidelines and recommendations

Japan's nuclear industry was initially focussed domestically but over the last two decades there has been a clear move towards international collaboration. An International Nuclear Power Safety Working Group was set up in 2008 to cooperate in the field of nuclear safety with emerging countries, primarily in Asia, planning to introduce and expand their use of nuclear power. There is rather less evidence of collaboration with other countries in the field of decommissioning and radioactive waste management.

Nevertheless the Japanese policy towards decommissioning sits comfortably within international guidelines and regulations on the safe termination of nuclear facilities, with safety standards and remediation strategies reflecting the rationale of the IAEA in terms of decommissioning and site remediation.

5 Decommissioning of nuclear reactors – current situation

Tokai-1 is the first commercial nuclear power plant to be decommissioned in Japan. The Japan Atomic Power Company, implementer of the Tokai-1 decommissioning project, plans to decommission over a period of 17 years. After an initial period of safe storage to allow radioactivity levels to decay, peripheral structures will be removed, the reactor dismantled and the site finally cleared and the land reused for future nuclear power operation.

The 17 year timescale over which decommissioning is planned to take place, comprises 3 phases: 5 years to safe-store; 5 years to remove boilers and install radwaste system; 5 years to dismantle the core and 2 years to demolish buildings and clear the site for re-use.

The decision to opt for a 10 year safe-store period was the result of a strategic case study, in which both qualitative and quantitative factors were taken into account. The following were key considerations for scenario selection:

- Radiation exposure, waste and cost
- Workload balance
- Availability of experienced personnel
- Managerial Risk
- Conformity with Japanese national policy and guides
- Construction of disposal facility
- Public acceptance
- Site for re-utilisation

Studies of 10, 35 and 135 years safe-store showed the cheapest option is 30 years, followed by 10 years and most expensive 135 years (only 5% difference in cost between 10 and 30 year options). The strong drive to make the site available as soon as possible for new nuclear development, along with other factors, led to the 10 year option being chosen. The total cost will be 93 billion yen (667 million Euro) - 35 billion (250 million Euro) for dismantling and 58 billion (420 million Euro) for waste treatment including the graphite moderator (which escalates the cost significantly).

Waste management, and in particular the availability of waste disposal routes will affect the timing but indications at the moment suggest that decommissioning is unlikely to be completed in less than 20 yrs and there are signs that even this may be optimistic. Current plans indicate that the waste disposal facility will be constructed prior to reactor dismantling. It is intended not to dismantle the core until there is an agreed disposition for the waste arising; if no disposal facility is available the safe-store period is to be extended.

The site end-state at Tokai is clearly brown field with buildings demolished but foundations left in place. The exact detail will depend on future use of the site but it is expected that a further station will be built there.

6 Graphite characteristics

Table 3 and Table 4 below summarise the data available on the graphite in the Tokai-1 plant. The type of graphite used (Pile Grade A) is the same as that used in the first generation of power stations in the UK.

Table 3 Radioactive inventory (graphite sleeve and moderator block)

	Weight (tes)	Activity (Bq/te (total Bq))
Graphite Sleeve	820	6.7+9(5.5E+12)
Graphite Block	1,670	8.4E+10(1.4E+14)

Table 4 Graphite type, history and radionuclides present

Origin of virgin graphite	Pile Grade A
Irradiation history	32 years@ 62% av. load factor, av. core flux 6.327 x 10^{10} n/cm^2/s (Ref [4])
Radionuclides present	C-14, H-3, Cl-36, Co-60, Nb-94, Eu-152, Eu-154, Cs-137, Cs-134, Ba-133, Ag-108m

The HTTR graphite data provided in Table 5[5] are for the virgin material as little irradiated graphite data/information relevant to decommissioning and treatment considerations have been acquired. It is more than likely that the retrieval of the graphite core, reflector will be as challenging as with other graphite moderated reactors and the treatment could be on one hand more difficult due to fission product presence/activity but on the other hand the influence of C-14 could be insignificant.

Table 5 Graphite and carbon materials in HTTR

	IG-110	PGX	ASR-ORB
	Fuel block and sleeve Replaceable reflector Control rod guide block Support post	Permanent reflector block Hot plenum block Bottom block	Carbon block
Bulk density [kg/cm^3]	1.78 x 10^3	1.73 x 10^3	1.65 x 10^3
Mean tensile strength [MPa]	25.3	8.1	6.8
Mean compressive strength [MPa]	76.8	30.6	50.4
Thermal conductivity [W/m K]	80	75	10
Ash content [ppm]	100 [max]	7000 [max]	5000 [max]

7 Graphite retrieval options

7.1 Tokai 1 Power Station

7.1.1 Layout of core

Ref [6] describes in detail the layout of the core and a study on methods for removal and treatment of graphite blocks. The core and reflector comprise 30,000 blocks in 10 layers. Each block is a hexagonal column with a face-to-face distance or approximately 240 mm, length of approximately 850 mm, an axial bore diameter of 90-150 mm and weight of 50-70 kg per piece. **Figure 5** shows the layout of the graphite core.

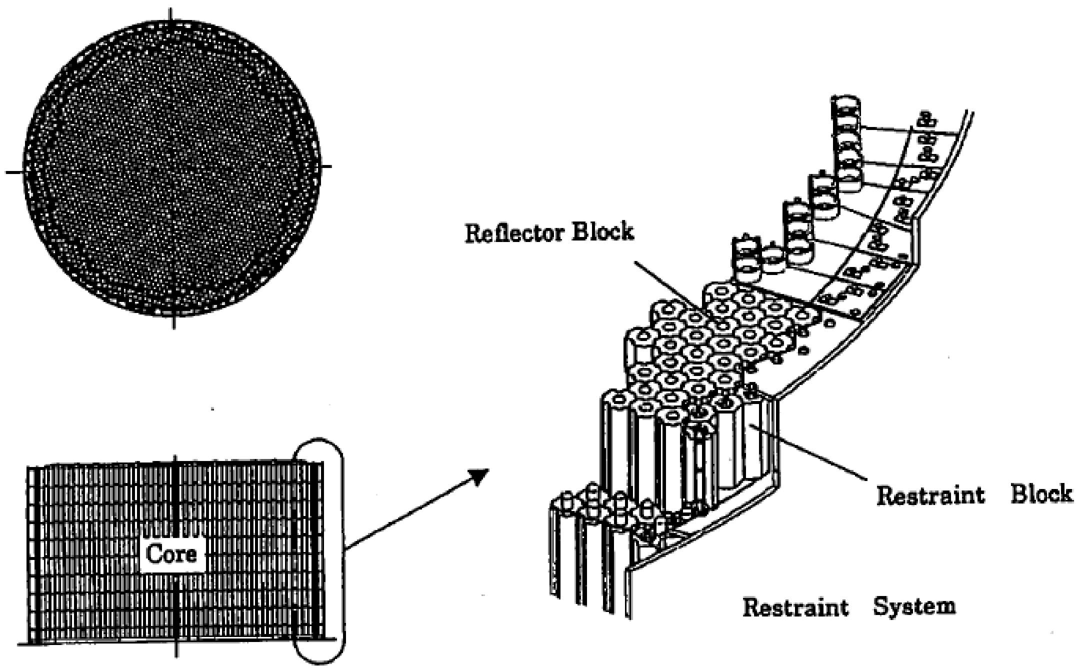

Figure 5 Layout of core graphite in Tokai-1 reactor[2]

7.1.2 Graphite block removal

Reactor dismantling is still very much in the development stage. An off-site development rig has been constructed to facilitate the development of tools and techniques for dismantling. The information available indicates the JAPC approach utilises similar techniques to those planned or already used in other countries. The reactor structure is to be dismantled by remote operation manipulators, designed to remove several blocks at a time, as shown in **Figure 6**. It is planned to withdraw reactor inserts and take out graphite blocks in a manner reverse that of the original construction.

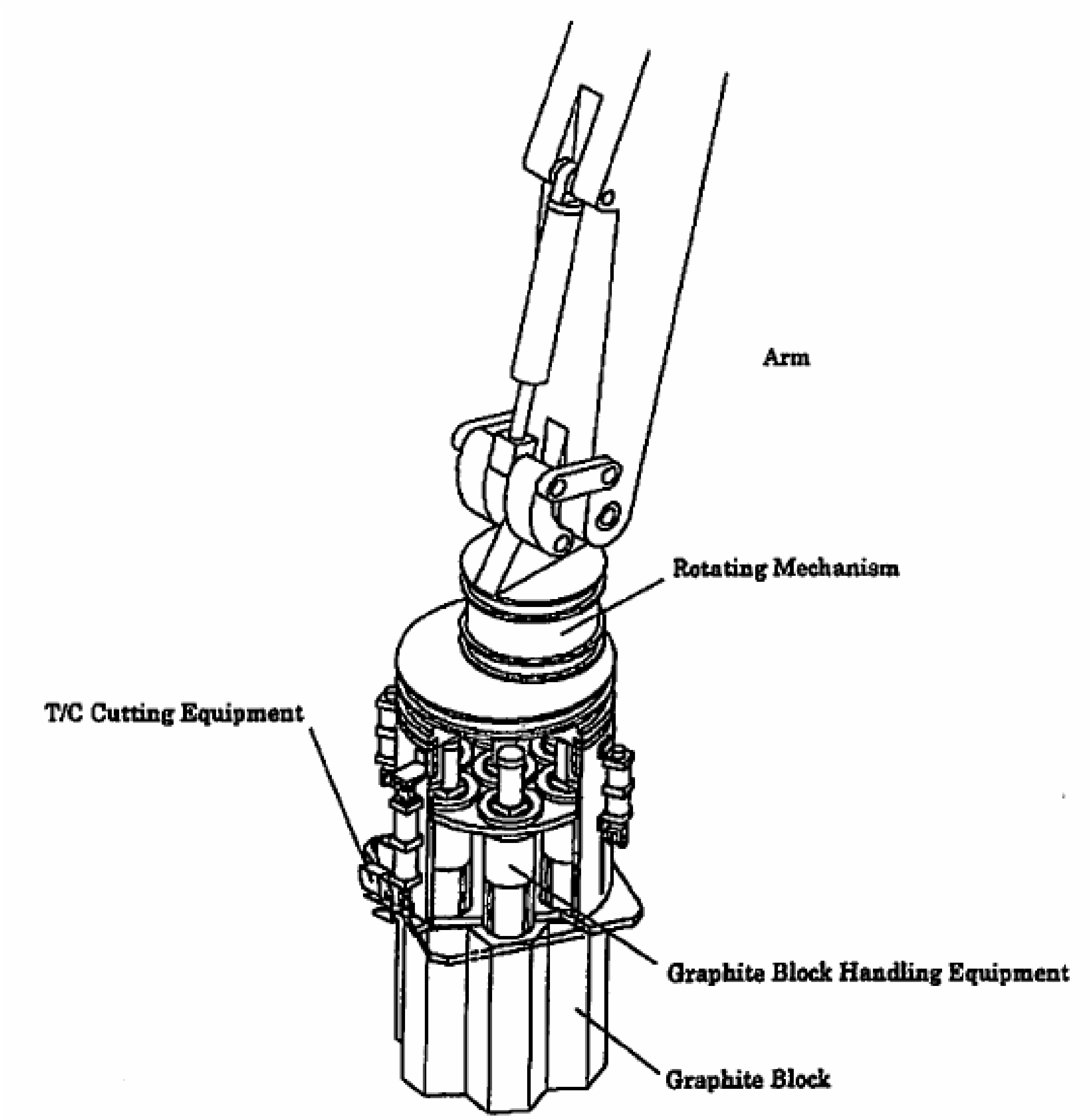

Figure 6 Remote handling machine for removal of graphite blocks from core[2]

7.2 HTTR

For a more detailed explanation of the design of the HHTR readers should consult report JAERI 1332[7]. Aspects pertinent to the CARBOWASTE project relate to coated fuel particles, graphite block and other graphite/carbon reactor components.

The CFP consists of spherical fuel kernel of low enriched uranium dioxide with the TRISO coating. The coating consists of a low density porous PyC buffer layer (60µm) adjacent to the fuel kernel (600µm) followed by high density isotropic pyrolytic carbon (PyC) layer (30µm), a SiC layer (25µm) and a final (outer) PyC coating (45µm). The CFPs are incorporated into the fuel compact, which is 10mm in inner diameter, 26mm in outer diameter and 39mm in height, with a graphite matrix. The fuel rod which is composed of fuel compacts and the graphite sleeve are contained within a vertical hole of a graphite block.

The core is an array of hexagonal graphite blocks made up of fuel, control rod (CR) guide and replaceable reflector blocks. The core consists of vertical columns of hexagonal blocks arranged on a uniform triangular pitch. Within the array of the vertical columns, 30 columns contain fuel are set up around 7 core region CR guide columns. The core is surrounded by 24 replaceable reflector columns, 9 of which are CR guide columns. The vertical structure of the columns is composed of 9 hexagonal graphite blocks.

The core is approximately 2.3m in equivalent diameter and 2.9m in height.

8 Treatment/conditioning techniques/process to be used on retrieved i-graphite

8.1 Incineration

There is considerable interest in high temperature incineration and a plant based on oil-fired combustion technology, intended for use for a wide range of active materials, has been built on the Tokai 2 site (see **Figure 7**).

They have successfully incinerated fuel sleeve graphite but can not incinerate the bulk of their core graphite as its activity is considered to be too high. It is thought however that incineration technology could be applied to graphite sleeve and relatively low activated moderator block. A volume reduction achieved from incineration of 13:1 has been claimed but it is not clear whether this was from crushing or incineration.

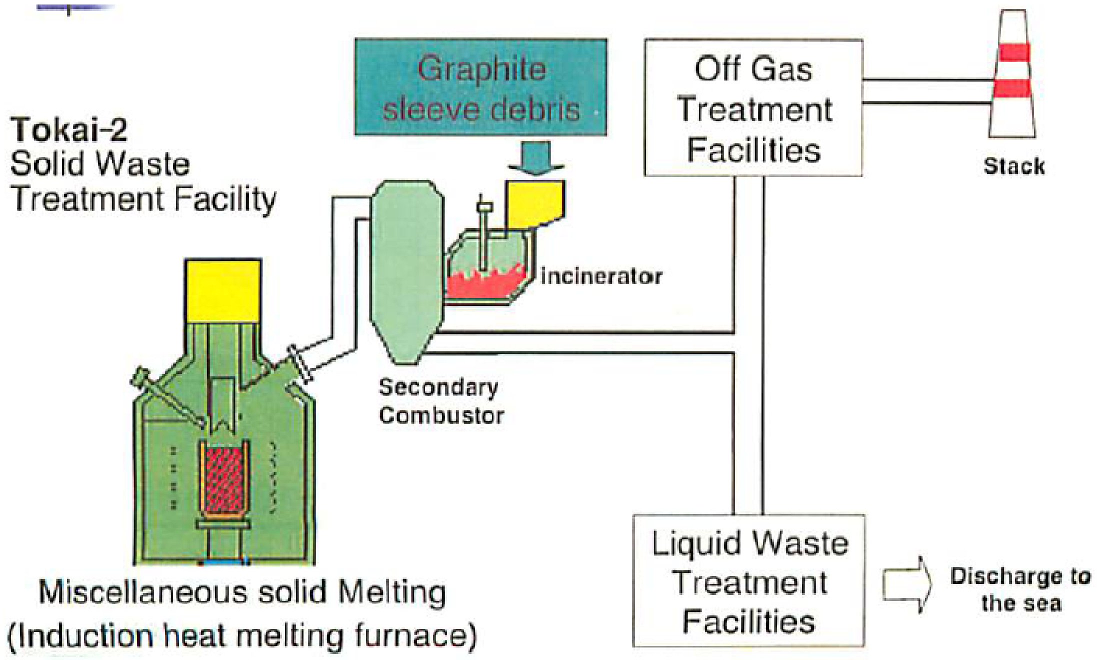

Figure 7 Outline of Graphite Sleeve Treatment System[1]

8.2 Off-gas treatment

C-14 separation and removal is thought be unavoidable in the case of highly activated graphite block incineration. Isotopic separation is still at the experimental stage but a C-14 separation technique using pressure swing adsorption is being pursued, which depends on gas pressure adsorption characteristics of Zeolite. The adsorbent tends to hold C-14 under high pressure and to release the isotope under lower pressure. It is understood that this process is working at laboratory scale and the next challenge is to increase this to a practical industrial scale. The issue of how to deal with concentrated C-14 and purity of final product remains unknown.

JAPC is trying to develop reliable and practical C-14 separation technology and such technology is currently the subject of further active investigation by JAPC.

8.3 High Density Packing

In addition to incineration, another option under consideration is packaging of graphite followed by disposal in a geological facility. The cost of this option is expected to be high due to the limited space in Japan and the technology required to meet high safety standards for disposal. It is important, therefore, to maximise the packing factor for graphite blocks in disposal containers. Reference [[8]] sets out in detail a proposal for high-density packing of graphite blocks. The scheme proposes that graphite blocks would be cut longitudinally and the pieces put in the axial fuel hole and other free space in the container. The packing factor was estimated to increase from approximately 35% to about 70% by cutting one sixth of the removed graphite blocks. The dust generated from cutting would be mixed with mortar and used to fill in the remaining space in the waste disposal container.

The decision on whether to use this as an approach for core graphite will ultimately depend on relative costs between incineration and direct disposal once a repository is available. At the present time, indications suggest that incineration is more cost-effective than underground disposal.

8.4 Recovery of carbon-14 via plasma chemical reactions

The application of a carbon isotope separation method using plasma chemical reactions in carbon monoxide plasma for the recovery of C-14 from the graphite moderator of a dismantled Japanese gas-cooled reactor, Tokai Power Station has been evaluated numerically.
Using a C-14 separation factor of 4.6 predicted by a kinetic model, calculated results show that theC-14 concentration in the cascade tails flow can be reduced to the environmental standard level of $3 Bq/cm^3$ and to the natural abundance level of 1.3×10^{-4} in 3 and 16 stage of the stripping section respectively[9].

9 References

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