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UKAEA Materials Research Facility, a new easy access hot-cell and analysis facility

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Abstract

The new Materials Research Facility (MRF) is designed to test irradiated materials for both Fusion and Fission materials development programs and will be used by Culham Centre for Fusion Energy (also part of UKAEA) as well as industry and academia. In May 2016 UKAEA opened the MRF, a new purpose-built research facility which allows researchers from UKAEA, academia, industry and other organisations to investigate post-irradiation properties of activated materials in service in today's nuclear power stations and candidate materials for use in future fission and fusion power stations. The new facility bridges the gap between activity levels that can be handled at university or industrial laboratories and activity levels that require large facilities at nuclear licensed sites.

With the MRF, the UKAEA is working on nuclear readiness for the coming decades. It aims to achieve the following goals:

- Serve both Fission and Fusion research with input to future reactor types as well as existing reactor types.
- Invest in the development of test methods for micro- and macro-sized specimens as well as in international acceptance of those methods.
- Work actively to create a change in nuclear materials research by focusing on size reduction.
- Serve research on activated materials from other fields, such as accelerators.

The MRF has the capability to receive and process activated materials with a maximum activity up to 3.75 TBq Co^{60} (or equivalent). A hot-cell line, consisting of a receiving cell and three interconnected hot-cells, provides the facility to cut, mount and polish samples in order to reduce activity by downsizing. Samples can either be transferred to one of the instrument cells for on-site experiments or be transferred to an external partner or customer. Two MRF instrument cell lines have been developed to shield samples with a maximum activity of 3.75 GBq Co^{60} (or equivalent). Each instrument cell line contains several instrument cells, all operated and controlled remotely. In the first instrument cell line a Scanning Electron Microscope (SEM), a Focussed Ion Beam (FIB), a nano-indentor, an Atomic Force Microscope (AFM) and an X-Ray Fluorescence (XRF) analyser are installed. Furthermore, three gloveboxes are installed to use for lower activity samples, Tritium and Beryllium based research. A setup for Thermal Desorption Spectroscopy (TDS) and rigs for corrosion of tritium loaded materials and plasma behaviour at tritium and deuterium are being installed in the MRF.

In 2017-2020 the MRF is planning to increase its capabilities with a Beryllium glovebox line, a Physical testing suite, a mechnical testing suite, an increase of sample preparation processes and a doubling of the hot-cell capabilities.

Introduction

The UK Government has identified that R&D is a requirement to provide informed decisions for future expansion of nuclear power generation. This is specified in the document 'Nuclear Energy Research and Development Roadmap: Future Pathways, 2013'[1]. As part of this strategy, it is recognised that technological readiness is an important aspect; support for nuclear R&D is paramount and will encompass both skills and technological development. One aspect of this strategy is that small highly radioactive samples can be tested in various facilities, including universities and other research facilities. The collaborating organisations (including the UKAEA) are collectively known as the National Nuclear User Facility (NNUF). See Figure 1 for the structure and participating parties within NNUF.

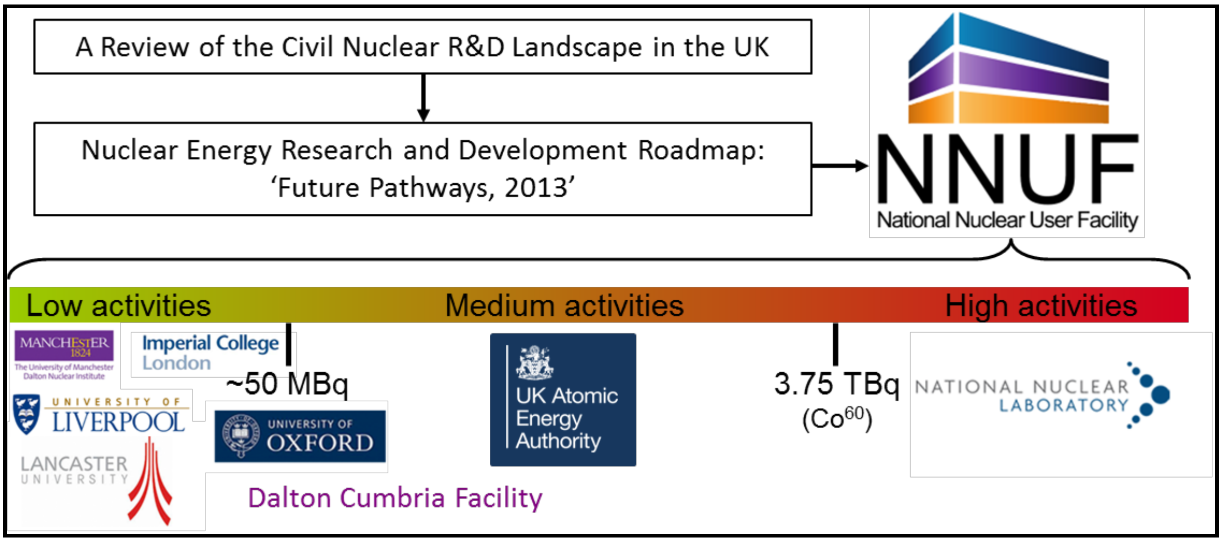

Figure 1 Development and cooperation within the UK to fulfil the Governments' requirements for future nuclear R&D programs

The UKAEA-MRF, located at Culham Science Centre for Fusion Energy (CCFE), is well placed to contribute towards this strategy as it will cooperate with researchers from UKAEA, academia, industry and other organisations to investigate the post-irradiation properties of both materials in service in existing operational nuclear power stations and candidate materials for use in future fission and fusion power stations. In addition, there will be a considerable scope for UKAEA to undertake its own fusion research and collaboration with other users for fission research. The combination of fission and fusion materials research will increase knowledge in both fields.

In the MRF (see Figure 2 for the layout and current status of development), scientists will investigate the change of material properties due to irradiation damage (e.g. comparing neutron-irradiation with proxy ion beam irradiation); gas (including tritium) retention; embrittlement and size effects from full size to micro- and macro-scale. Future fission and fusion devices will profit from access to the facilities, techniques and competences developed within the UKAEA-MRF. The main focus at the MRF will be research to implement technological readiness (as defined in [1]) by using state of the art equipment not vulnerable to relatively low level radiation from aforementioned reduced sample volumes. Size reduction of the specimens (sub-sized, macro-sized or micro-sized specimens) will allow the use of modern techniques as well as increase of data points due to the low volume of the required material(s) per data point.

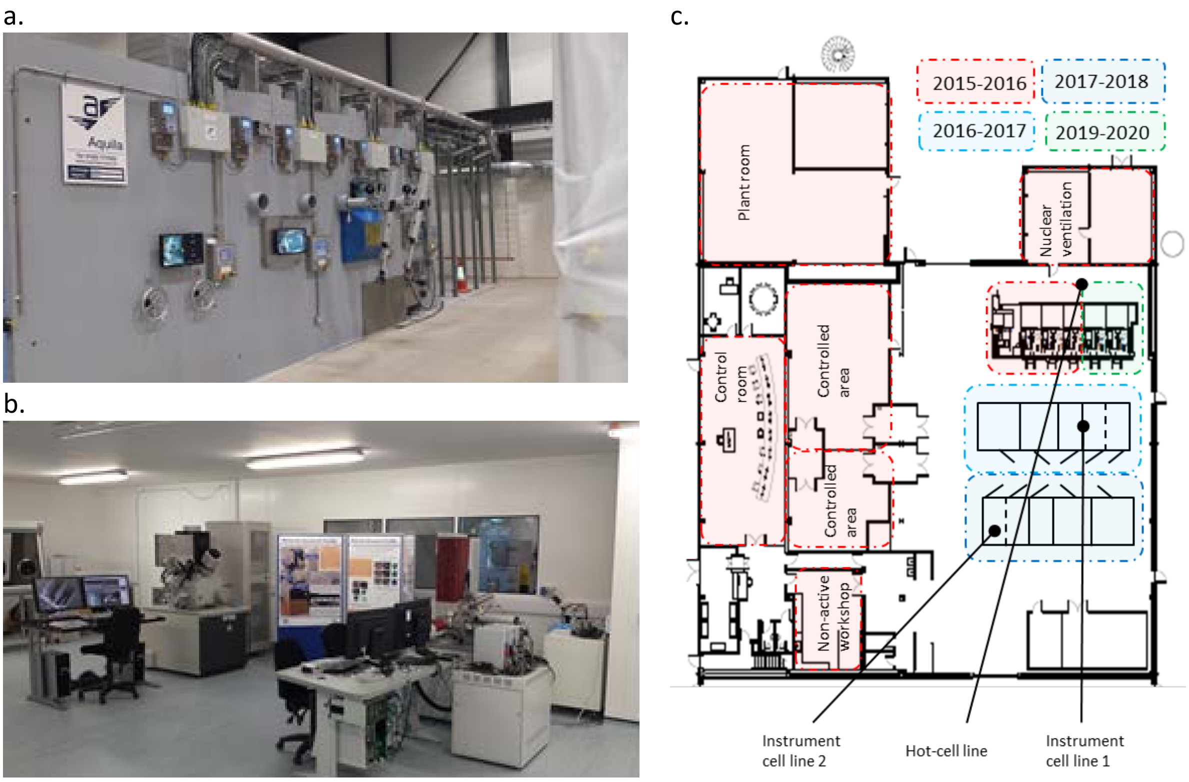

Figure 2 UKAEA MRF facility with a. the hot-cell line; b. the FIB and SEM in the controlled area; c. Layout and current status of development

MRF Capabilities

The MRF is an easily accessible hot-cell facility with a mid-range activity level working field (see Figure 1). The MRF has included a specimen preparation facility in the hot-cell line to allow for specimens fabrication based upon size reduction. The reduced specimens (from sub-sized to micro-sized) can be further evaluated in the MRF hot-cell line (≤ 3.75 TBq), one of the scientific instruments in the MRF instrument cell lines (≤ 3.75 GBq), the MRF controlled areas (≤ 200 MBq) or being transferred to one of the universities or customers, see the flow scheme in Figure 3.

The hot-cell line is capable of cutting, mounting, grinding, polishing and evaluating the sample quality using optical microscopy. In 2017 an EDM cutting device and welding equipment will be added to enable the fabrication of more complicated sample shapes. In-cell gamma spectroscopy will be used to verify and/or identify the received materials.

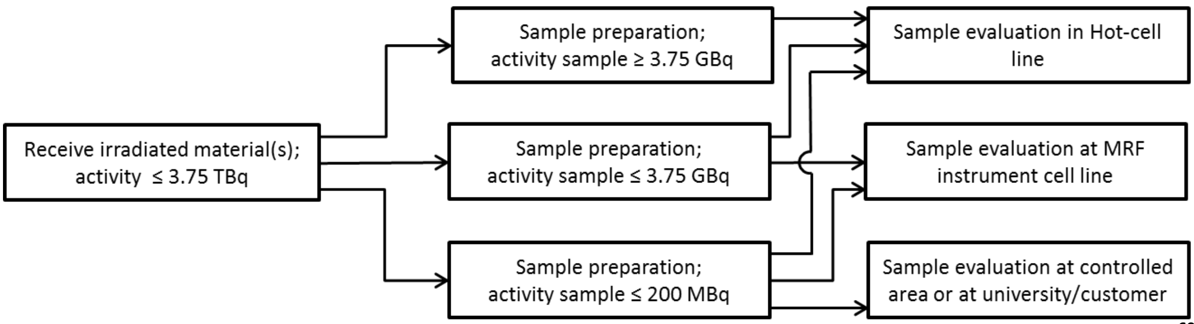

Figure 3 Overview of sample preparation and evaluation regime in the UKAEA-MRF (activities based on Co^{60} or Co^{60} equivalent)

Since 2015 the MRF operates a set of scientific instruments mainly focussed on microscopic and mechanical research. The instruments are fully commissioned for the use in the MRF with experienced materials scientists in both the unirradiated and irradiated (fission and fusion related) materials research. After completion of the instrument cells, the instruments will be installed and commissioned to be used remotely from the control room for work on active samples. Customers and visiting scientists will be able to perform their own experiments (if competent or trained to work with the equipment) without becoming a radiological worker and therefore accessing the controlled areas. Active samples will be installed by the operational team and handed over to the scientist to execute the experiments. After the experiments, the operational team will receive back the control and remove the sample from the equipment to store or process further. Table 1 shows the current instruments and their planned working field.

Table 1 Current equipment to be used in the MRF facility

MRF Sample preparation and scientific equipment	**location**		
	Controlled area (≤ 200 MBq*)	**Instrument cells (≤ 3.75 GBq*)**	**Hot-cells (≤ 3.75 TBq*)**
Slow cut saw and shear cutter			√
Hot press sample mounting			√
Cold resin sample mounting			√
Grinding and polishing			√
Optical microscopy (20 – 220x / 400 -470x)			√
Gamma spectrometry (1 cm^3 CZT detector)			√
Scanning Electron Microscope with EDX, EBSD, TKD and tensile stage (±5 kN / 1200 °C)		√	
Atomic Force Microscope		√	
Focussed Ion Beam		√	
Nano Indentor		√	
X-ray Fluorescence	√		
Static destructive testing (±10 kN)	√		
Thermal Desorption Spectroscopy (TDS)	√		
Glove boxes (including H3 capability)	√		

* Activities given are based upon Co^{60}. Maximum allowed activity of other isotopes are based on Co^{60} equivalents.

Future developments

Within the coming 4 years, the MRF will extend its capabilities in several fields. The sample preparation suite will be extended for the preparation of more complicated sample shapes (pills, cylinders, dog bone, TEM disks, and so on) to provide samples for mechanical and thermo-physical examination. The mechanical testing suite will contain instrumented hardness testing and a set of servo-mechanical and servo-hydraulic test frames to be used for static testing, fatigue testing and fracture toughness testing and will include conditioning (temperature and environment). To be able to determine the physical properties, Dilatometry, Laser Flash technique, Differential Scanning Calorimetry (DSC) / Thermo-Gravimetry Analysis (TGA) and Gas pycnometry will be added to the MRF capabilities.

Besides the purchase and commissioning of the scientific equipment in the instrument cells, two additional hot-cells will be designed and build to add full flexibility to the facility. These two hot-cells will be executed with interchangeable inner containments to allow for quick change of instruments and machining by changing the containment. If not installed in the hot-cell, the equipment in the containment can be used in two additional ways; first as a 'stand-alone' glove box in a controlled area and second as containment in an instrument cell. Two of the previous mentioned instrument cells are executed in such way that the interchangeable hot-cell containments can be driven in and connected to allow for use in the instrument cells as well.

Table 2 Future equipment to be used in the MRF facility

MRF Sample preparation and scientific equipment	location		
	Controlled area (≤ 200 MBq*)	Instrument cells (≤ 3.75 GBq*)	Hot-cells (≤ 3.75 TBq*)
Electrical Discharge Machining (EDM)			√
Electro Polishing			√
(Spot) welding			√
Instrumented Micro Hardness tester			√
Servo-mechanical testing frame(s)		√	
Servo-hydraulical testing frame(s)		√	
Furnace (up to 1000°C)		√	
Climate chamber (-170 to 400 °C)		√	
Dilatometer		√	
Laser Flash analyser (LFA)		√	
DSC/TGA		√	
Gas Pycnometer		√	
Additional Hot-cells (2)			√
Interchangeable inner containments (4-6)	√	√	√

* Activities given are based upon Co^{60}. Maximum allowed activity of other isotopes are based on Co^{60} equivalents.

The MRF facility is constructed in such way that expansion of the building by doubling the controlled area is feasable. This means that more dedicated specimens fabrication techniques and growth of the scientific capabilities will be achievable. It is foreseen that this expansion will occur after 2020. The selection of the current equipment (listed in both Table 1 and Table 2) are selected out of the interests of a user panel. As NNUF is a cooperation of several institutes and university, the interest is broad. However, future developments or leads, could add or partly change the selection listed in Table 2.

Conclusions

With its Civil Nuclear R&D landscape, the government has given the nuclear research centres and universities in the UK an opportunity to develop technological readiness in nuclear R&D. The MRF is part of this strategy, allowing UKAEA to develop techniques to support both the Fission and Fusion community.

With focussing at sub-sized, macro-sized and micro-sized specimen sizes, the amount of material(s) necessary for a full data set will be reduced. This will reduce the amount of materials to be irradiated as well as give opportunities to current surveillance programs to assess more datapoints whilst running out of conventional surveillance samples.

In the period 2016-2020 the MRF will grow its 'standard' active sample preparation facility to create several types of samples of different materials and sizes.

In the period 2016-2020 the MRF will develop into a facility with mechanical testing (micro-hardness, static, fatigue and fracture toughness), thermo-physical testing and microscopic evaluation, executed in close cooperation with NNUF partners (UK universities and nuclear facilities).

References

[1] A Review of the Civil Nuclear R&D Landscape in the UK; BIS/13/631 (2013); available from: **https://www.gov.uk/government/publications/civil-nuclear-research-and-development-landscape-in-the-uk-a-review**