REMOTE HANDLING AND EXAMINATION OF RADIOACTIVE MATERIALS

AN INTRODUCTION TO THE LABORATORY FOR STRONGLY-RADIOACTIVE OBJECTS (LSO)
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1. INTRODUCTION

The Laboratory for Strongly Radioactive Objects (LSO) forms part of the Materials Department of ECN. It was designed from 1958 onward and it was commissioned in 1964.

Its purpose has been, and still is, to provide for post irradiation investigation of nuclear fuels and nuclear construction materials as well as for investigation of the behaviour of irradiation devices.

The building and its facilities have been tailored to suit the requirements of the HFR material testing reactor, presently owned by the Commission of the European Communities.

In addition to its main task the LSO has been engaged in investigation of materials originating from nuclear power stations both in the Netherlands and abroad.

Furthermore the LSO is regularly called upon to provide services to owners of medical and industrial irradiation sources.

Occasionally the laboratory has been called upon to render assistance in the field of theoretical and applied physics, such as mounting of positron emitter sources or the provision of rare nuclides derived from chemical separations. In this connection fuel size HFR fuel elements have been dissolved and processed.

Finally the LSO plays a role in the inspection of fuel elements of the local reactors HFR and LFR.

As a result of the existing close cooperation between ECN and JRC-Petten the laboratory's workload happens to be derived from both organizations in approximately equal proportions.
2. A BRIEF REVIEW OF THE BUILDING AND MAIN SHIELDED FACILITIES

The building comprises a variety of shielded facilities:

- the high activity (HA) cells AB, C, D and E;
- the impact testing cell E*;
- the metallographic cells F1-F8;
- the chemical preparation cells G1 and G2;
- the fatigue/tensile testing cells G3 and G4;
- the graphite testing cells G5 and G6;
- the creep testing cell L1;
- the creep testing cell L2;
- the fatigue/tensile testing cell G7;
- the fuel rod encapsulation cell H.

In addition come the auxiliary facilities:

- a water filled pool (WB) in conjunction with cell AB;
- an isotopes capsule unloading cubicle T on top of cell E;
- a tools introduction cubicle (K) on top of cell AB;
- a radioactive materials storage pit with 18 storage holes;
- six shielded storage casks for fuel rod segments;
- a variety of shielded transport flasks.

With the exception of cells G7, L1 and L2, all the shielded facilities are located around or in direct communication with the so called flask handling bay which forms the heart of the building.

The movement of radioactive materials follows in general the following pattern.

Radioactive materials from the HFR or other origin are carried in shielded transport flasks on road vehicles into the vehicle entrance lock (15.19). By means of a 25.5 tonne travelling crane the flasks can be lifted through a roof hatch into the flask handling bay (20). Usually the flasks require unloading via the high activity cell line. For this purpose a horizontal introduction port is available on the rear face of cell AB and a vertical introduction port on the roof of cell C. This requires transport flasks equipped with a mechanical shielding shutter and a scoop/pushrod assembly. Occasionally items contained within pot-type flasks have to be dealt with. These require bodily introduction of the flask into the cell line via the
loading bay (27). The flask is loaded for that purpose on a 10 ton capacity remotely controlled platform carrier which runs on a railtrack extending throughout E to AB into the loading bay (27).
The method requires opening of the shielded door between (27) and E. Subsequently the lid of the flask can be removed by means of the 1.5 ton gantry crane within the cell line.
Usually any material thus brought within the HA cell line requires some kind of processing or examination before being distributed to the other cells mentioned above.
Transports within the HA cell line are executed by means of a remotely controlled 1.5 ton travelling crane as well as by two remotely controlled power assisted manipulators, which travel on the same overhead track as the crane. Their load capacity (vertical) is 300, respectively 1000 kg.
Transports to other cells require a shielded transport flask adapted to the specific requirements of the cells to be served.
The internal transport routing and transport means are closely connected to the environment at the station of origin and destination, from a contamination hazard point of view.
For practical purposes three kinds of environment are distinguished, i.e.:
- A: high contamination potential.
- B: moderate contamination potential.
- C: low contamination potential.
These categories apply to the individual cells as follows:
- A: metallographic and chemical cells;
- B: high activity cells AB through E as well as cells G5 and G6;
- C: fatigue/tensile and creep testing cells.
The classification of HA cells as a type B category is due to the fact that the operations therein will be strictly limited, as far as nuclear fuel is concerned, to non-destructive operations, or more pertinent those operations in which the nuclear fuel matrix is not exposed.
(N.B. Chemical dissolution of fuel in properly designed metal fabricated process vessels, in a closed system, would not be excluded; the same applies to cutting of fuel rods in any ingeniously designed contained device.)
The classification of the cells listed in category C is possible owing to the special form of the material (specimens for mechanical testing), the
nature of the radionuclides involved (testing of steels and aluminium hitherto) and the nature of the process (simple fracture).
The classification of the cells within the A category is obvious. This classification system affects the material routing in a number of ways, which will not be described in detail.
Briefly attention is drawn to the fact that materials destined for type C facilities are subjected to decontamination immediately preceding departure from the HA line and are posted out through a separate roof port in a separate flask for that purpose.
Materials destined for category A facilities are posted out from HA throughout a special "double lid introduction port".
As a consequence of the category designation we have imposed one-way traffic from type C and type B to type A facilities.
Additional forms of internal transport are:
- a pneumatic conveyor system, linking cell F6 with a laboratory in an adjacent building, for the transmission of samples for electron probe microscopy;
- a pneumatic conveyor system, linkings cells G1 and G2 with the radiochemical laboratory in the same adjacent building.
3. SCIENTIFIC AND JOB-PROCESSING EQUIPMENT

3.1. Equipment for dismantling and sectioning

Dismantling of major items is carried out in cell AB.
The available equipment comprises a general purpose remotely controlled milling machine with the following main characteristics: support long-, cross- and height travel 600 * 175 * 425 mm.
Items of greater length than the long travel range can be accommodated in many instances by shifting the item in stages.
Sectioning of irradiation capsules and similar items is done with slow moving reciprocating saws, two different types of which are available. The maximum diameter of an item is limited to approximately 150 mm.
Additionally this cell is equipped with a variety of auxiliary tools, amongst which: vices, spanners, chucks, hammers, screwdrivers, mechanical and pneumatic pincers, torque spanners, electric impact wrenches; as well as special tools dedicated to current projects.
Capsules containing sodium have been handled in large quantities. For that purpose use has been made of both sodium melting equipment and reactions with various alcohols.
Liquid sodium potassium alloy has been drained from many capsules.

3.2. Preparation of specimens for optical/electron microscopy

Cell F: In the F cell suite a complete range of equipment is available for preparation of specimens for optical and electron microscopy.
Sampling takes place in F1 on the basis of available neutronographs, gammascans or local findings by means of the periscope. A rotating diamond blade cutter (100 rpm at 75 mm diameter) is available for nuclear fuels. Cutting is done dry. For the sampling of metals a diamond saw at a speed of 500 rpm and cooling fluid is utilized.
Additional cutting equipment is available for axial sectioning of fuel rod sections in order to obtain both clad halves for inspection of the inner cladding surface.
Samples intended for light microscopy are subsequently embedded in cold hardening two component resin (Hysol) and transferred to a rough grinding machine in F1. Subsequently in the case of fuels a vacuum impregnation with resin is applied and the sample is transferred to F2 for fine grinding and polishing.
The prepared samples are studied with the photomacrograph in F6 before being subjected to either chemical or electrolytical etching in F3. By judicious choice of the etching procedure very remarkable color photographs can be obtained in microscopy as a result of the formation of superficial interference oxyde layers, notably in the case of mixed oxyde U-Pu fuels.

In addition in F4 an ionic etching apparatus enables the polished surface to be bombarded with Ar ions at 3-5 KeV. Inclining the surface at an angle of 60 degrees produces a cleaning effect which is of value in the case of porous surfaces.

3.3. Visual examination

Cell D : A binocular periscope, angular zoom power 5x to 15x, equipped with a photographic attachment for a Nikon F3 camera. The linear magnification in the image plane is variable from 0.625x to 3.10x. The objects are supported on a motorized stage, the X and Y ranges are 720 and 1000 mm respectively. Items with a length exceeding the travel range can be accomodated by scanning from two ends in separate runs (feasible for items with maximally 2000 mm length). The object stage is provided with a rotatable support for cylindrical items. The X coordinate and the rotation angle are digitally recorded in the film image plane.

Cell E : A black and white closed circuit TV-camera, equipped with a 50 mm radiant resistant objective is available for close-up inspection of fuel rods. The magnification in the vidicon image plane can be set at either 0.64x or 1.56x, resulting in an overall linear magnification on the screen of a 410 mm diagonal monitor of 25x and 62.5x. The fuel rods are supported in a vertically wall mounted stage, with step motor driven vertical and rotational movements. The coordinates of the field of view are digitally mixed into the video picture. The resolution of the system is 30 microns.
During the inspection the camera is held by the power manipulator. It is provided with a narrow beam spotlight. The depth of view is 6 mm due to the combination of a small diaphragm aperture (F:16) in combination with an extremely sensitive newvicon image tube and an illumination level of 20,000 Lux.

**Cell F1:** A binocular periscope with variable angular power from 3.5x to 75x the field of view is variable from 75 to 3,5 mm; a photographic attachment for 90 x 120 mm Polaroid film is available. In addition a 35 mm SLR camera can be mounted.

**Cell F5:** A Reichert Telatom microscope with photographic attachment. The magnification range is 50x to 1000x.

**Cell F5A:** A Leitz MM5RT microscope, with various photographic attachments. The magnification range is 50x to 1000x.

**Cell F6:** A macro camera for metallographic specimens, with 9 x 12 photographic attachment. The linear magnification ranges from 5.5x to 7.5x.

**Cell G3:** A monocular periscope, angular power 3x and 6x, field of view ... , respectively ... mm and photographic attachment for 24 x 36 mm film.

**Cell F6:** A scanning electron microscope, ISI-super III-A.

### 3.4. Gammaspectroscopic scanning of radionuclide profiles

Three independent gammascanning stages are available in the HA-cell line. These machines are controlled simultaneously by one PDP-11/04 computer. The equipment comprises a Canberra Scorpio console, a display terminal, a printer, two floppy disk and two hard disk external memories, an amplex tape unit, Camac interfaces for stepping motor control and coordinates sensing, coordinate display units etc.

The three gammascanning setups are each provided with radiation collimators with adjustable slit size (0.1 - 7.0 mm) and Ge-Li coaxial detectors (resolution at FWHM less than 2 keV for $^{60}$Co).

The specifications of the object stages and their location are as follows:
Cell D: Vertical travel 750 mm, cross travel 120 mm, rotation infinite, increments in steps of 0.1 mm and 1.8 degrees. This machine can take up short experimental fuel pins and entire irradiation capsules of usual HFR size.

Cell E: Two identical object stages, with a vertical translation of 2000 mm, no cross travel, an infinite rotation and motion increments in steps of 0.1 mm and 1.8 degrees.

The position of the objects with respect to the collimator on these three machines is sensed by magnetic vernier type position encoders to within 0.05 mm and the software ensures that programmed positions are actually reached.

A comprehensive software package is available for data reduction and analysis, both by means of the PDP 11/04 system as by means of the site central Cyber 175 computer.

In a single gammascan run up to 10 nuclides can be specified and up to 10 axial regions of interest along the fuel rod can be defined.

3.5. Autoradiography

Cell F7: Finely ground or polished flat specimens of nuclear fuel when brought into intimate contact with an appropriate emulsion produce an imprint of the qualitative distribution of either beta-gamma or alpha emitting nuclides in the specimens' surface. For the exploitation of this technique a special exposure device has been developed, which embodies a rapid approach of the specimen to the emulsion and exposure times in the range of 0.3 seconds to 6 hours. By using an appropriate Al filter a considerable improvement in the image sharpness is obtained in the case of alpha autoradiography, by stopping obliquely emitted alpha particles.

3.6. Eddy-current flaw detection of fuel rod clads

Cell E: Flaw detection can be carried out on fuel rods up to a length of 2000 mm. The object stage is the same as the one mentioned for visual examination (3.3) and diameter gauging (3.7). The object stage is identical to the two gammascanning object stages, except that instead of a radiation collimator an eddy-current coil (respectively a diameter gauge) is installed.
The associated equipment comprises:
- an eddy-current generator/analyzer from Automation Industries Sperry Division, type EM-300;
- coil units of the encircling type (2 coils in differential arrangement);
- a Gould Brush Dual Trace, type 200 recorder;
- a Hewlett Packard type HP-85 microcomputer;
- a Hewlett Packard HP-3437A digital voltmeter.

The frequency range is 1.0 kHz to 2.5 MHz.
The EM-30's storage oscilloscope can display the combined phase and amplitude vector.
The X and Y components of the eddy-current signals are stored on the HP-85 tape unit.
Subsequently the HP-85 program analyses the data and produces a plot of the X and Y components with respect to their axial location, the maximum and minimum values and the peak to peak width. Additionally print output is obtained.

3.7. Fuel rod diameter gauging

Cell E: The object stage is identical to the one utilized for eddy-current and video examination. The diameter sensor is a compact assembly situated at the bottom of the stage. It comprises two parallel diamond bars, having a radius of 3 mm, which contact the fuel rod. The diamond bars can float freely in the horizontal plane, remaining parallel to each other. Their relative displacement is sensed by a Sony magnetic vernier and displayed digitally to within 1 micron.

The fuel rod moves past the stationary sensor in a vertical direction. Its motion (also rotationwise) is controlled from an LSI-II minicomputer. This computer is provided with a display terminal and is situated in the gammascanning control room. It is linked with the PDP-11/04 computer system and its peripheral equipment. Diameter readings can either be written on an analogue stripchart recorder or digitally on floppy disk, hard disk or magnetic tape, along with the axial and rotational fuel rod coordinates.
Conversion of the machine for eddy-current inspection can be effected by a pneumatically lowering the diameter sensor, at the same time the eddy-current coil swinging into position.

3.8. Tensile/fatigue testing

Cell G3: Two servo hydraulic and one electromechanical fatigue testing machines are available.

Cell G7: The Instron 1251 hydraulic machine is a four column type device with a dynamical capacity of +/- 200 KN. The maximal frequency is 50 Hz. Various wave forms such as "sine", "sawtooth", "block" can be applied. This machine enables determination of fracture mechanics phenomena such as crack propagation, determination of KIC and JIC values.

The plunger stroke is 15 mm.

An additional furnace enables experiments to be conducted up to 800 degrees centigrade.

The associated instrumentation comprises X-Y and X-T plotters and microprocessor controlled data acquisition equipment.

Measurement of crack propagation can be studied by means of either optical (closed circuit TV in conjunction with video recording) or electrical (DC-potential) methods.

The Instron 8000 machine has the following characteristics:

dynamic capacity: +/-50 KN at maximally 50 Hz; the amplitude range is 0-50 mm. The other features are identical to the ones of the 1251 machine.

The Instron 1362 machine (electromechanical) has a maximal operating frequency of 1 Hz; the frame is identical to that of the 8000 machine. It is mainly used for low cycle fatigue experiments. The strain measurement can be made both axial as well as diametrical. This machine is equipped with a furnace for use up to 1000 degrees centigrade.

A block programmer enables programmed low cycle fatigue experiments to be conducted. The dynamic range is +/- 100 KN at an amplitude of 50 mm.
3.9. Charpy impact testing

Cell E*: In an open top lead shielded enclosure, designated as E*, a semi-automated charpy impact tester has been installed. It is provided with hot and cold thermostated baths. The specimens are submerged collectively within a magazine and automatically transported to the anvil and struck. An interlock prevents the hammer from falling in the event that the transport to the anvil has exceeded the permissible time.

3.10. Creep rupture and elongation testing

Cell L1: 10 Creep rupture machines are installed in L1 and 3 identical Cell L2 machines are installed in L2, all being of Mayes manufacture. They are equipped with three zone resistance furnaces and a strain gauge. The load capacity is 30 KN, which is applied through a lever/deadweight system. Experiments up to 1000 degrees centigrade can be executed. Rupture times over 10,000 hours have already been obtained. Strain measurement is achieved with electronic displacement transducers which are read with advanced data acquisition equipment. The accuracy of displacement readings is 1 micron. The furnace control is programmable such that temperature fluctuations can be held to within +/- 1 degree centigrade. Software is available for rapid and accurate data analysis.

3.11. Hardness testing

3.12. X-ray macro inspection

Cell D: An X-ray macro inspection setup has been installed in the right hand front corner of cell D. It comprises an Andrex 250 KeV/6 MA integrated X-ray tube located at the bottom of the cell and radiating upward through a plastic covered opening in the work bench towards the film holder. The film holder is situated within a contamination free cylindrical tube, which projects from the cell face horizontally inward and is equipped with a rapid insertion mechanism and shielding at the entry port.
3.13. Sampling for chemical burnup measurements

Cell G1: Burnup and fissile isotopes analysis is performed on selected fuel samples of 1.5 - 2.0 grams. These are dissolved in an appropriate acid, usually nitric acid with some HF added to achieve complete dissolution. The solutions are diluted approximately 250-fold and a few ml transferred to the chemical laboratory. These aliquots are subjected to fractionation by anion exchange in a HCl-HN0₃ environment; the rare earth fraction is further separated by high pressure cation exchange to yield neodymium. The nuclide $^{148}_{\text{Nd}}$ with a fission yield of 1.68% for both $^{235}\text{U}$ and $^{239}\text{Pu}$ is used as a burnup monitor.

The absolute amounts of the different isotopes of uranium, plutonium and neodymium are determined by isotope dilution mass spectrometry. $^{238}\text{Pu}$ is determined by alpha spectrometry on electroplated samples obtained from the appropriate anion exchange fraction.

3.14. Fission gas extraction

Cell C: Fission gas extraction from fuel pins is executed in cell C. The puncturing head for low pressure pins (1-5 bar) is a modified version of a similar device described by J.M. O'Keefe (TRG Report 2644 (W) (1975)). The device has a minimal dead volume. It is provided with an extreme low volume pressure transducer in the range 0-500 PSI. The entire dead volume is thus limited to only 2.05 ml. For pins of higher pressure (up to 70 bar) a puncturing device with 20 ml dead volume is used.

The puncture head is connected to the gas sampling unit by a 500 cm long, 11.05 mm outer diameter flexible stainless steel tube. A solids filter prevents ejected fuel dust to enter into this tube. The gas sampling unit is housed within a perspex containment box on the outside cell face. It enables gas samples to be pumped into calibrated glass bulbs with a well defined internal pressure. These are taken to the chemical laboratory for mass spectrometric analysis.
Cell G1: Fission gases retained in the fuel matrix are determined by dissolution of fuel samples in closed glass equipment.

By means of a helium sweep krypton and xenon are collected on a molecular sieve at the temperature of liquid nitrogen. This trap can be disconnected from the equipment and can be discharged in the gas sampling unit described previously.

The isotopic composition of the gas samples thus obtained is analyzed on the Riber QMM 17 mass spectrometer of the analytical group (Chemistry department). Total amounts of He and Ar are measured by the isotopic dilution method.

In addition to the analysis just described, gas chromatographic analysis enables other constituents i.e. H₂, Ar, O₂, total Kr, N₂, CH₄, He, CO and CO₂ to be determined.

3.15. Various chemical separations
4. SHIELDING CAPACITY OF CELLS

The shielding capacity will be expressed in terms of material and thickness, rather than in terms of "curies", as the latter practice is incorrect without further definition.

AB, C, D and E : 1200 mm barytes concrete, density 3.5 gr/cc.

Fl and H : 250 mm lead, density 11.4 gr/cc.

Remaining : 180 mm lead, density 11.4 gr/cc.
5. **TELEMANIPULATION EQUIPMENT**

The telemanipulation equipment comprises the following items:
- one power assisted gantry suspended GEC manipulator (lifting capacity 300 kgs vertically);
- one similar Draht & Schrader manipulator (lifting capacity 1000 kgs vertically);
- one hoist capacity 1.5 tons.

These three machines are installed in the HA-cell line and of common use to cells AB through E.

In addition come masterslave manipulators of three different types: i.e.
14 heavy duty masterslaves (Nuclear Equipment Ltd. model 9), 9 of which are installed in HA-line, 5 are spare.
2 Heavy duty masterslaves (CRL model F), one installed in cell C, the remaining one is a spare unit.

The remaining cells are equipped with CRL model G masterslave manipulators, 16 are installed, 6 are spare units.

Exceptions are F2 through F8 and L1/L2, which are equipped with ball mounted tongs.
## 6. ORGANIZATION

The laboratory operations involve in total 30 employees, belonging to different departments and/or groups as follows:

<table>
<thead>
<tr>
<th>Department</th>
<th>Group/Group Name</th>
<th>Count</th>
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</thead>
<tbody>
<tr>
<td>Materials Department</td>
<td>LSO operations group</td>
<td>19</td>
</tr>
<tr>
<td>Materials Department</td>
<td>Metallography group</td>
<td>5</td>
</tr>
<tr>
<td>Materials Department</td>
<td>Metals science group</td>
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<tr>
<td>Chemistry Department</td>
<td>Radiochemical group</td>
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</tr>
<tr>
<td>Health Physics Department</td>
<td>Radiation control</td>
<td>1</td>
</tr>
</tbody>
</table>
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