DTU Physics
Department of Physics

Beta irradiation
in
The Risø TL/OSL Reader

Feb 2021

Contents

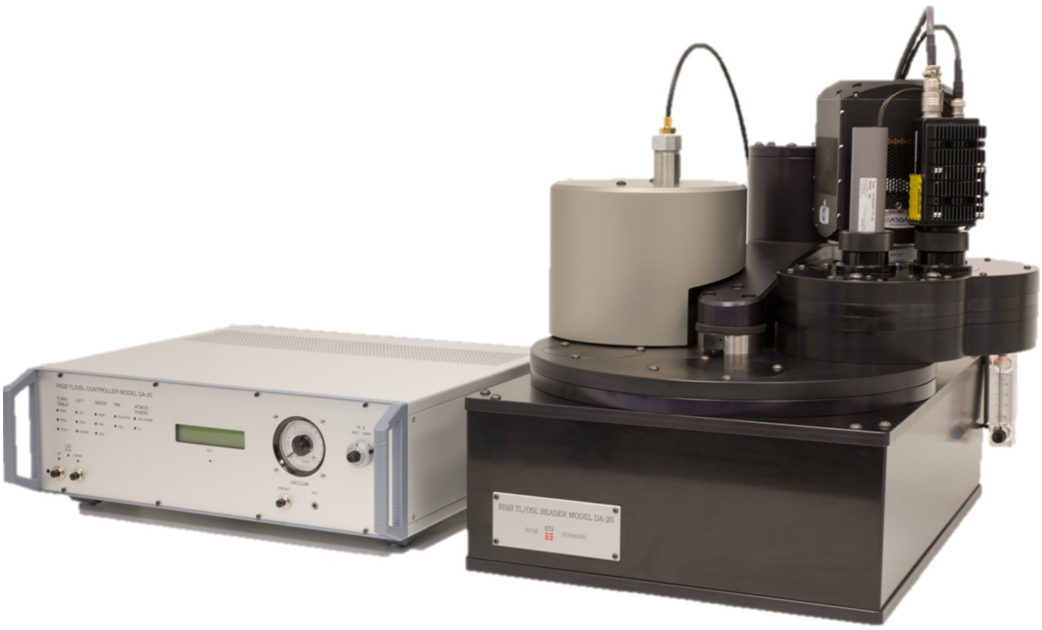

Figure 1: Picture of the Risø TL/OSL Reader. The Controller is shown on the left.

1 Overview of the Risø TL/OSL Reader

The Risø TL/OSL Reader (see Figure 1) is made by DTU Physics, which is an integral part of the Technical University of Denmark (DTU). With approximately 10,000 students and 6,000 employees DTU is the largest technical university in Denmark. The Risø TL/OSL Reader enables automated measurements of thermoluminescence (TL) and Optically Stimulated Luminescence (OSL) signals and ũnits have been manufactured and delivered all over the world (>40 countries) since 1982.

The luminescence is measured by a light detection system comprising a photon counter (either a photomultiplier tube, PMT or an Electron Multiplying Charge Coupled Device, EMCCD) and suitable detection filters. Measurements are carried out in a vacuum chamber. The software-controlled detection and stimulation head (DASH) contains light emitting diode (LED) modules, two filter changer wheels (enabling 16 filter combinations) and a detector changer with up to three detectors (see Figure 1).

In addition, the system normally includes a reference radiation source

($^{90}Sr/^{90}Y$, ^{241}Am or X-ray) to enable determination of radiation doses in natural and artificial materials. While the Reader (currently model DA-20) is under continuous development, the beta irradiation module has remained unchanged since 1995 and the alpha irradiation module since 1985. No incidents resulting in health risks have ever been reported. A schematic drawing of the system is shown in Figure 2.

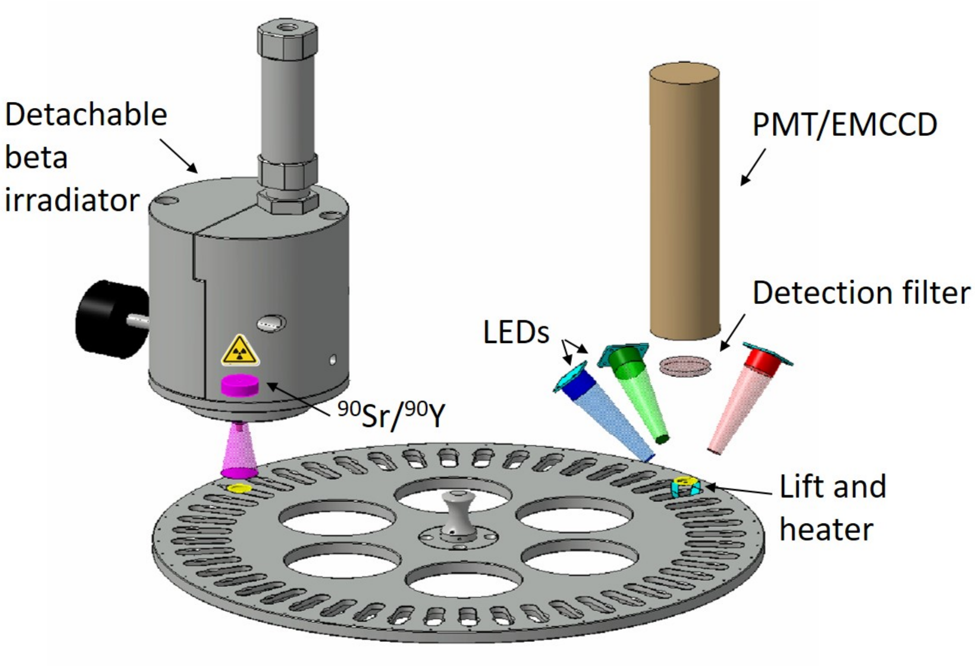

Figure 2: Schematic diagram of the Risø TL/OSL Reader

The Risø TL/OSL reader consists of two separate units:

1. The TL/OSL Reader itself (hardware, 40 cm × 55 cm × 55 cm)
2. The Controller (control of hardware, 50 cm × 55 cm × 20 cm)

The system is run using one of two programmes - the *Sequence Editor* and the CONTROL Program - installed on a standard PC.

2 Operating the radioactive source

The source can only be in irradiation mode when pneumatically activated.

The Reader is run using one of two programmes - the *Sequence Editor* (used to write elaborate measurements sequences) and the CONTROL Program (used to carry out simple tests on the equipment) - installed on a standard PC. Either of these two programs can be used to operate the installed radioactive sources. The only user-editable parameter is the duration of the radiation. The user can set the irradiation duration (in steps of 1 s) using the *Sequence Editor* or the CONTROL program.

2.1 Qualifications of operators

All operators of the Risø TL/OSL Reader equipped with radioactive sources must be clearly informed about the presence of the radioactive source, the associated risks and the meaning of the ionizing radiation trefoil warning symbol. According to Danish legislation, operators do no require special radiological classification to operate the Risø TL/OSL Reader with a standard beta source.

Users must be instructed that DTU Physics recommends that the protective Aluminium cover (helmet) of the source may only be removed by a qualified radiation expert with appropriate medical and dosimetric monitoring.

Operators of the luminescence equipment must be appropriately trained with respect to radiation protection; e.g. the operator should not touch the aperture of the irradiator and should not leave the lid open for extended periods of time.

2.2 The *Sequence Editor*

The *Sequence Editor* is used to write measurement sequences. A sequence is much like a spreadsheet in that it consists of a rectangular grid of columns and rows. The basic unit of a sequence is a cell, in which a single command is stored. Columns are labelled from left to right, beginning with “Samples” then continuing with “Run 1” through “Run n”. Rows are numbered down from “Set 1” to “Set n”. The cells in a sequence are filled in by one of the following operations:

- Using “Edit” from the Edit menu
- Pressing F2

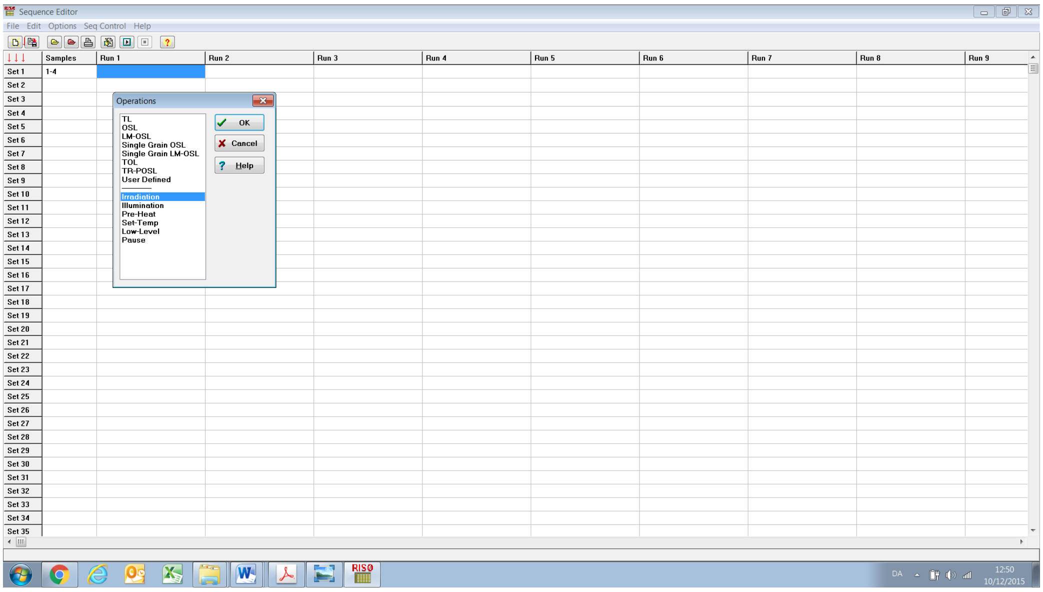

Figure 3: *Sequence Editor* and list of operations.

- Double clicking on the cell with the left mouse button
- Choosing "Edit" from the context menu. The context menu appears whenever the right mouse button is pressed

To edit a run you must first select the Sample set and run no. you do this by either using the mouse or the arrow keys to move the insertion point in the grid. If the cell was empty the Operation dialogue pops up (see Figure 3).

To irradiate a sample, click the operation "Irradiation" and then click the "OK" button or double-click the command. Figure 4 shows the dialogue window which subsequently opens. Choose the irradiation source and enter the desired "irradiation time" and then click the "OK" button. A sequence is executed by choose File|Run or the Run Speed button to run the sequence. In the example given in Figure 4, running the sequence will result in irradiation of samples 1, 2, 3 and 4 for 50 s using the ^{90}Sr/^{90}Y beta source.

A running sequence can be broken at any time by choosing: Seq Control|Break or the short cut CTRL-Q (see File|Break). Further information about the *Sequence Editor* and how to write sequences can be found in the "Sequence Editor user manual", which can be downloaded from DTU Physics's homepage and on the PC where the Risø TL/OSL software is installed.

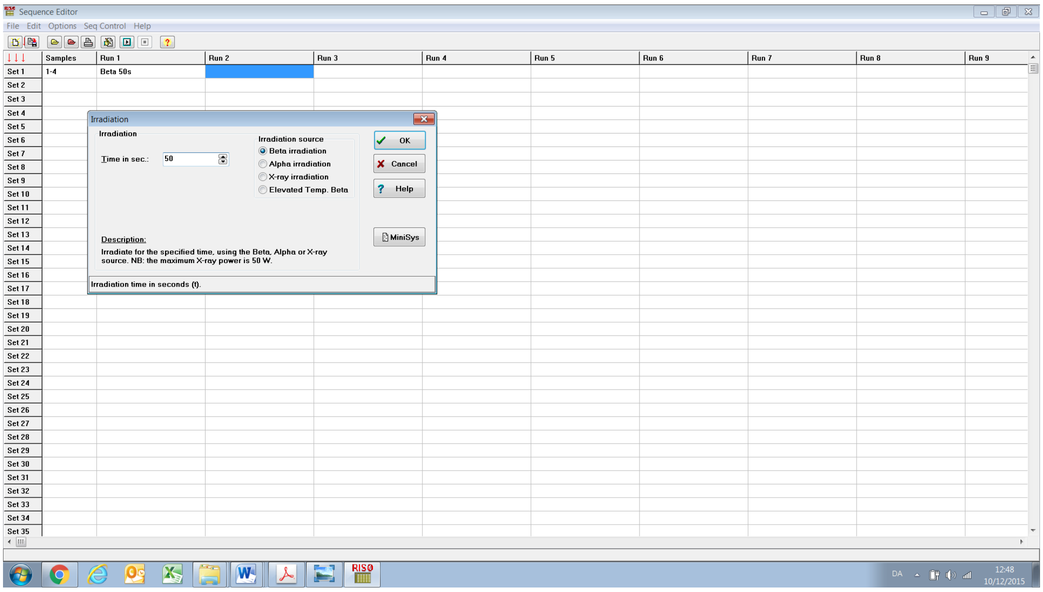

Figure 4: Irradiation commands.

2.3 The Control Program

The CONTROL program is mainly used to carry out simple tests of the equipment and is normally only used by DTU Physics staff for testing or by the user following the guidance of DTU Physics (usually in connection with maintenance).

Using this program, irradiation can be obtained by:

1. clicking the appropriate buttons on the "Services" tab
2. sending a direct irradiation command using the command field on the "Services" tab
3. sending a direct irradiation command using the command field on the "Dialogue" tab

3 Beta irradiation in the Risø TL/OSL Reader

In the Risø TL/OSL Reader samples can be irradiated *in situ* using a detachable beta irradiator located above the sample carousel. The irradiator accommodates a $^{90}Sr/^{90}Y$ beta source, which emits beta particles with a maximum energy of 2.28 MeV. The half life is ~29 years. A source strength of 1.48 GBq gives a dose rate in quartz (mounted on stainless steel discs) at the sample position of approximately 0.1 Gy/s.

3.1 Beta source

3.1.1 Beta source manufacturer

The source manufacturer of sealed radioactive sources for the Risø TL/OSL Reader is Eckert & Ziegler Nuclitec GmbH (EZN).

Contact info:
Eckert & Ziegler
Nuclitec GmbH
Gieselweg 1
38110 Braunschweig
Germany
www.ezag.com

The radioactive sources are especially designed for the irradiator of the Risø TL/OSL Reader.The radiation source is shipped directly from the source manufacturer (EZN, Germany) in a certified type A shipping container, i.e. it arrives separately from the Risø TL/OSL Reader itself. The source arrives in a 15×15×19 cm cardboard box inserted into a larger cardboard box (32×32×34 cm). The maximum dose rate directly on the sides of the inner box is $150\mu Sv/h$ and $2\mu Sv/h$ at a distance of 1 m. The shipping box should only be opened by certified personnel and stored according to local regulations until loaded into the irradiator (which is shipped with the Risø TL/OSL Reader itself).

3.1.2 Beta source description

The $^{90}Sr/^{90}Y$ beta source has a diameter of 18.3 mm, a height of 6 mm and is encapsulated in stainless steel(see Figure 6). Five pellets of Strontium ceramic is deposited in circular grooves and covered by a $50\mu m$ thick stainless steel window.

Figure 5: Source container and packaging.

Figure 6: A picture of a radioactive source

The radioactive trefoils symbol, the radioisotope (Sr-90) and the source serial number is engraved on the source.

Description of the source	
Radionuclide	^{90}Sr/^{90}Y, radioactive half-life: 29.1 a
Nominal activity	1.48 GBq
Activity tolerance	± 20%
Emitted radiation	Beta
Recommended working life	10 years
Physical and chemical form	Pellet of Strontium ceramic
Description of the shell	
Construction	single encapsulated
Material	stainless steel, window 0.05 mm thick
Kind of the sealing	welded
Source integrity	ISO/DIN-Classification ISO/12/C43342
IAEA Special Form	not applicable
Source drawing	VZ-3019-001
Packaging	
Package code	TV01L01C01CB14
Package classification	Type A, UN2915
Assembly drawing	PZ-0092-001
Outer dimensions	32 cm x 32 cm x 34 cm
Gross weight	∼ 1.6 kg
Net weight	∼ 10.3 g
Outer labeling of the carton	category yellow II
Transport index	0.1

3.2 The beta irradiator

The radiation source is safely contained in the irradiator, which is securely attached to the Reader itself. The irradiator is made of brass (outer diameter 10 cm; height 9.5 cm) and is surrounded by 20 mm of lead on the sides, and 40 mm on the top. Furthermore, an aluminum safety helmet (outer diameter 222 mm) covers the entire irradiator and lead shielding (20 mm thick at the top and 3 mm at the sides). A schematic drawing of the irradiator is given in Figure 7.

The source is securely placed inside the irradiator, and backed by a 20 mm thick aluminum spacer, a 20 mm thick lead spacer, a spring washer, and finally a 25 mm thick aluminum spacer (see Figure 8). The source is mounted inside a rotating aluminium wheel which is pneumatically activated. When the source is “off” (default position) it points upwards directly at a 10 mm

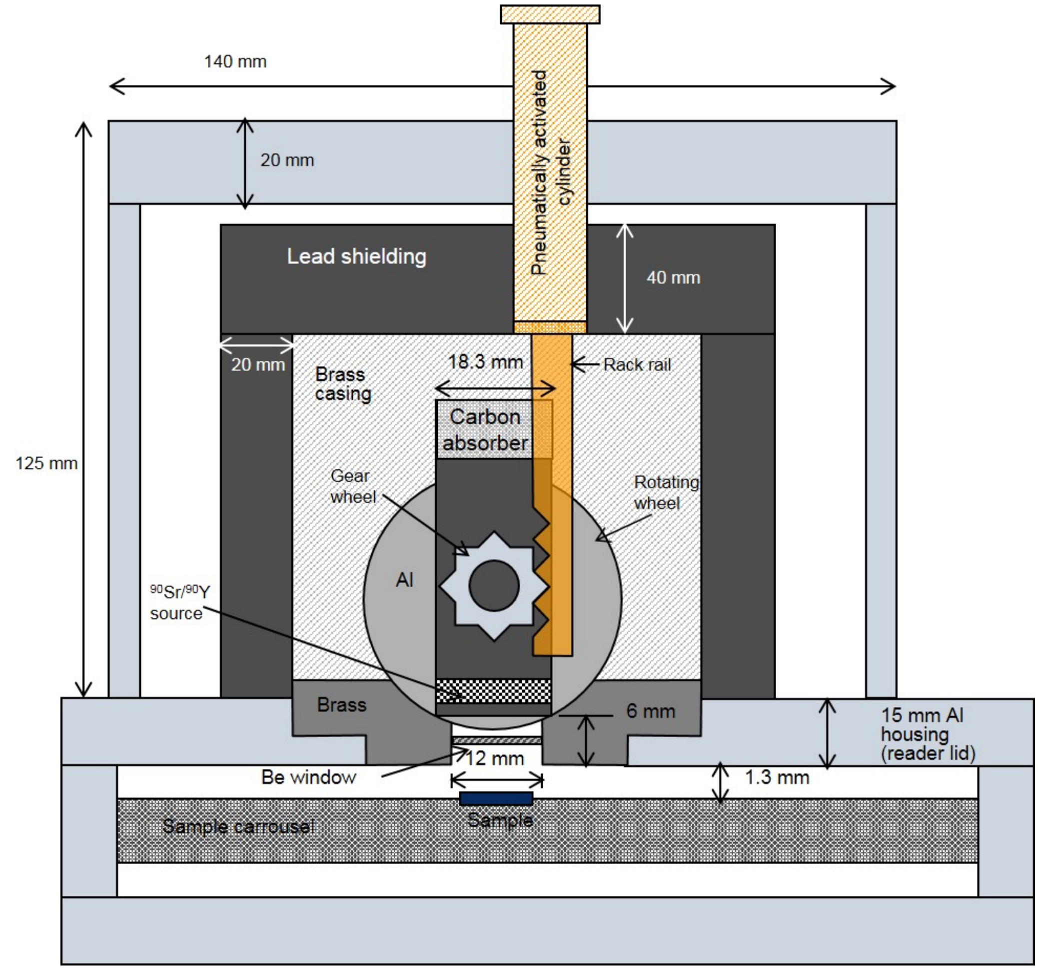

Figure 7: Schematic drawing of the beta irradiator.

thick carbon absorber (diameter 18.3 mm) completely covering the emitting surface. When the source is "on" (activated position) it points downwards towards the measurement chamber. A 0.125 mm beryllium window is located between the irradiator and the measurement chamber to act as vacuum interface for the measurement chamber.

3.2.1 Mechanical operation of the irradiator

The irradiator mechanism is illustrated in Figure 9. The spring-loaded actuator is operated by compressed air and moves a rack gear against a pinion mounted on the spindle of the source holder. This rotates the source holder

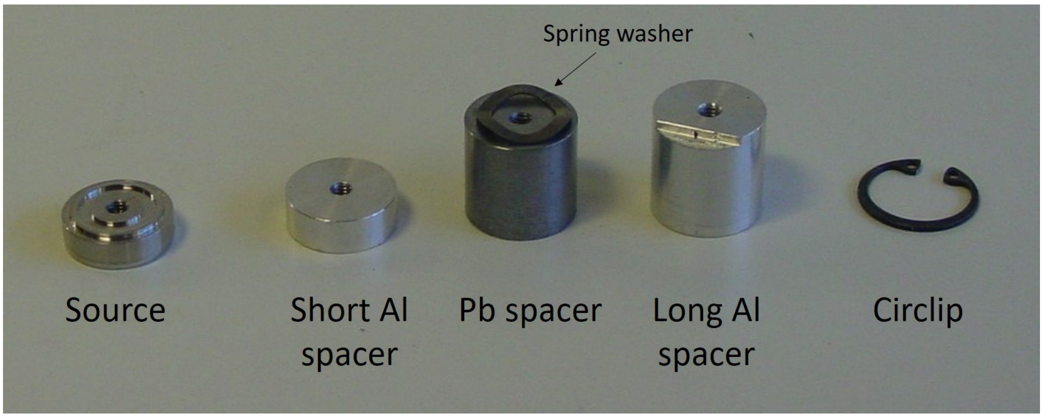

Figure 8: Items in the irradiator.

from pointing vertically upwards into the carbon absorber ("off"), to pointing vertically downwards through the Be window ("on"). At the same time, the eccentric wheel mounted on the end of the spindle also rotates and depresses the push rod, which consequently switches on the double micro switch. When the air pressure is released, the actuator returns to its rest position, rotating the source holder so that the beta source is returned to the safe position pointing at the carbon absorber ("off"). The eccentric wheel rotates through 180° and removes pressure from the push rod. The push rod lifts as the micro-switch returns to the off-position.

3.2.2 Source status

The status of the source (active or safe) can be checked in the following ways:

1. On the irradiation indicator on the front display of the Controller. If this LED is lit an irradiation is in progress
2. On the text display on the front of the Controller
3. The colour of the Status LED positioned to the left and back on the top plate of the Reader. If this LED is red an irradiation is in progress. If it is green the source is in safe position
4. If a sequence is running, the status of the source can also be checked in the *Sequence Editor* program
5. A direct visible indicator of the source position is provided by a white mark on the visible face of the eccentric wheel. When the source is activated ("on"), the white mark is visible below the safety helmet

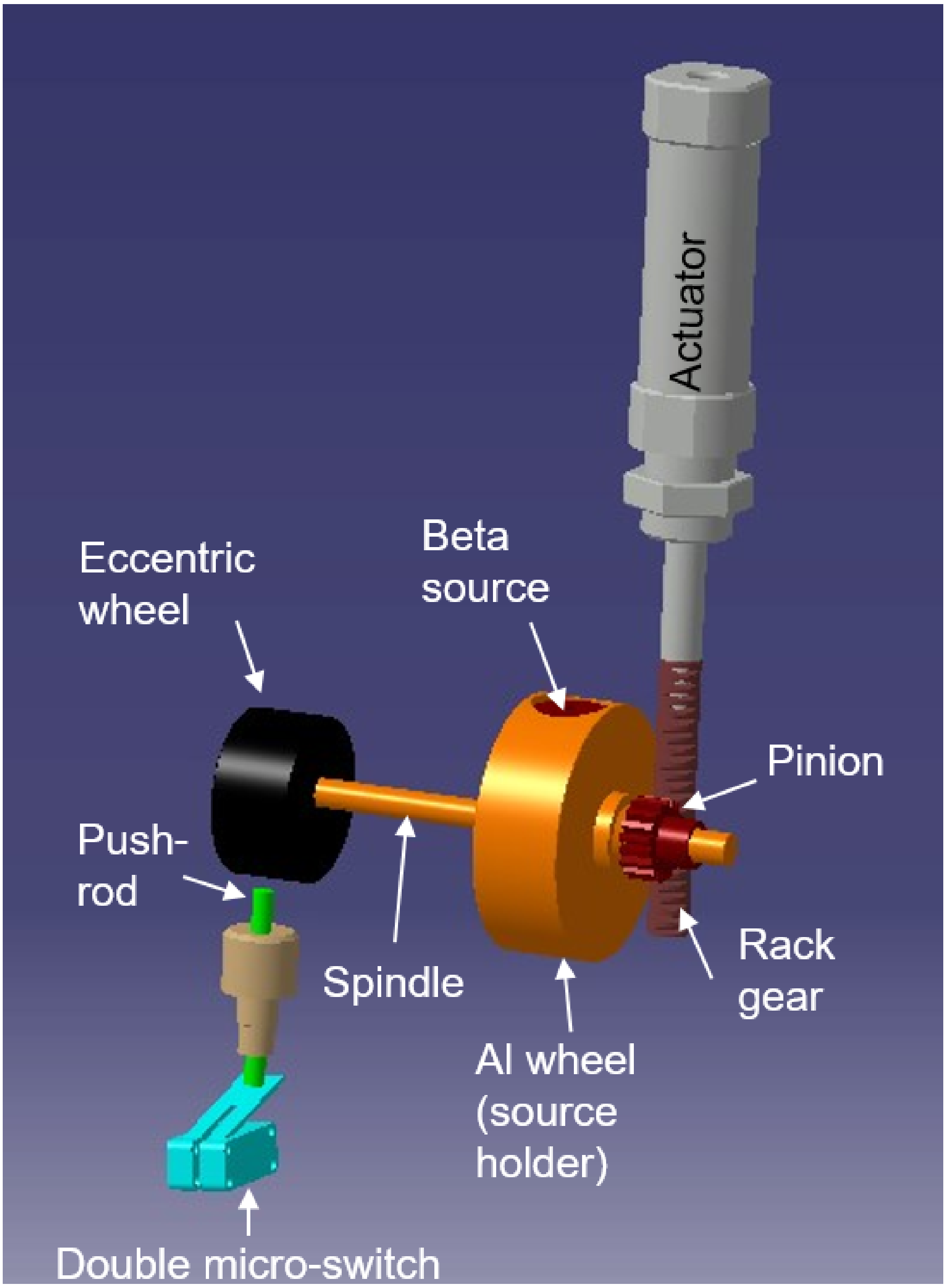

Figure 9: Beta irradiator mechanisms.

Figure 10: Picture of a Controller performing an irradiation of sample number 45.

6. The end of the beta source spindle has a machined flat, which locates the eccentric wheel. This flat is facing downwards when the source is inactivated ("off") and upwards when the source is activated ("on"). Note that this machined flat is only visible when the safety helmet has been removed

Ad 1,2

All direct hardware control of the Reader has been incorporated into the Controller. The Controller is equipped with a two-line text display, which shows the current system status and the command which is currently being executed. If an irradiation is in progress the display states which type of irradiation (i.e. beta, alpha or X-ray), which position on the sample carousel is being irradiated and how many seconds of the irradiations remains, e.g. "Betairr #45, 345 s" means that sample 45 is being irradiated using the beta source and that 345 s of irradiation remains (see Figure 10).

The front panel of the Controller also contains a series of indicators and buttons. Whenever an irradiation is in progress this is indicated by the switching on of a dimmed red LED (third column from the right, second indicator from the top on the front panel, see Figure 10).

Ad 3

The status of the source is furthermore relayed to the status LED positioned on the Reader itself. This LED is red when the source is activated and green when it is inactivated ("off"). The status LED is placed at the back of the Reader, because exposure of luminescence samples to green light will lead to an undesired loss of signal.

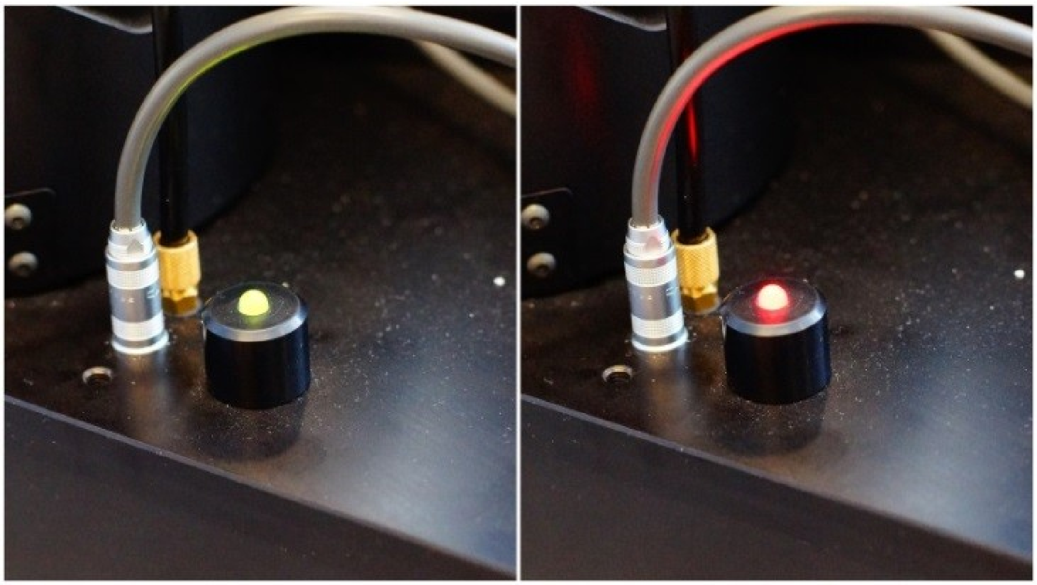

Figure 11: Pictures of the status LED. When the LED is red the source is activated ("on") and when it is green it is inactivated ("off")

Ad 4

The SEQUENCE EDITOR is a windows based program installed on the user PC. The *Sequence Editor* is used to write elaborate measurements sequences. The *Sequence Editor* translates commands (e.g. "OSL") into low level commands which the Controller can understand, checks that the commands have actually happened, and collects data. If an irradiation is in progress this is indicated in two places in the *Sequence Editor* window: 1) Top left corner (Current operation) and 2) the bottom window showing which command is currently being executed (see Figure 12).

Ad 5

A direct visible indicator of the source position is provided by a white mark on the visible face of the eccentric wheel (see Figure 13 and Figure 14). When the source is activated ("on"), the white mark is visible below the safety helmet. The colour white is chosen because the instrument is usually used in dim red light (i.e. photographic darkroom conditions). As discussed above, the actuator is located on the source spindle in such a manner that it cannot become disengaged. Thus, even in the complete failure of all electronics, a reliable mechanical indicator of source position is always available.

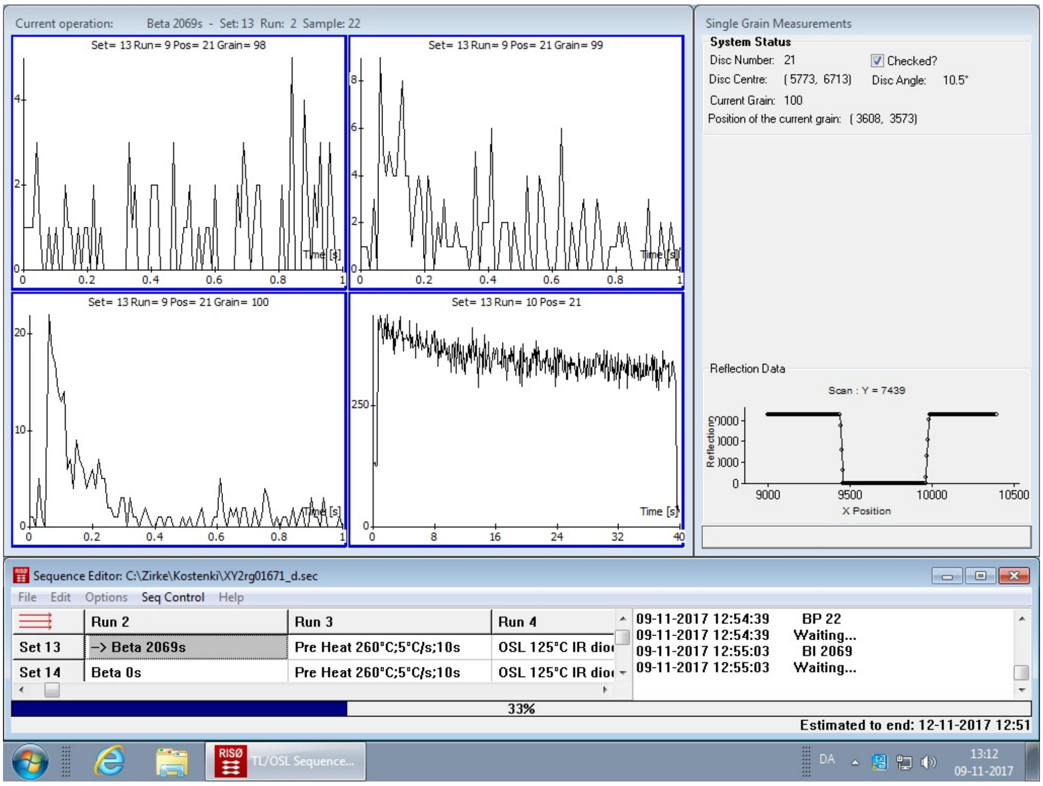

Figure 12: Screenshot of the *Sequence Editor* program while an irradiation is executed

3.3 Safety aspects

The presence of a radioactive source in the irradiator is indicated by the ionizing radiation trefoil warning symbol placed on the safety aluminium helmet. The user ought to also indicate the type of radioelement and its activity at manufacture (e.g. ^{90}Sr/^{90}Y, 1.48±20%, May 2020).

The purpose of the safety helmet is to prevent the manual rotation of the eccentric wheel and so manual movement of the source holder.

In general, the safety features of the Reader are designed in such a way that an accidental irradiation of personnel requires the simultaneous failure of at least two safety features.

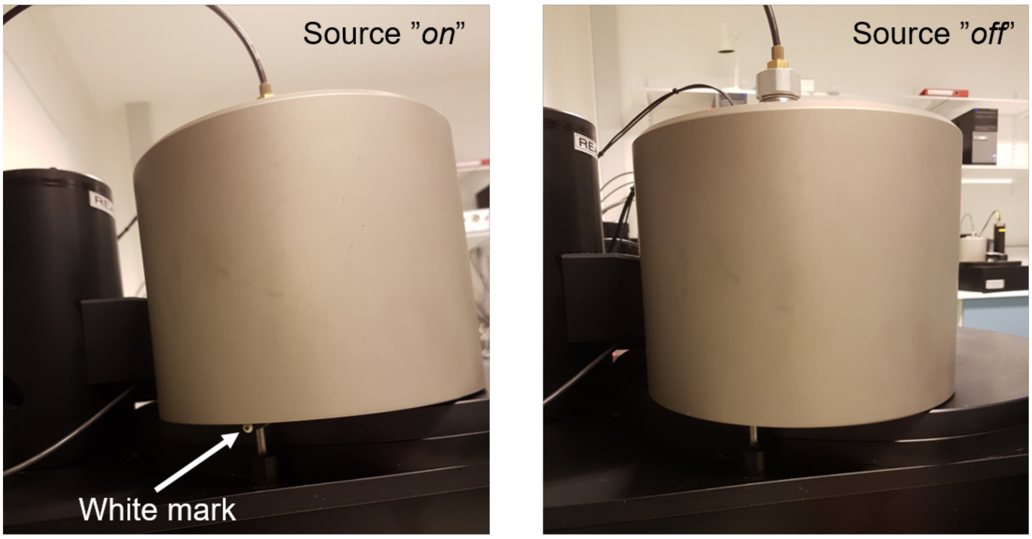

Figure 13: Direct visible indicator of the source position is provided by a white mark on the eccentric wheel. Only the bottom part of the eccentric wheel is visible under the safety helmet. The white mark is only visible, when the source is activated (“on”)

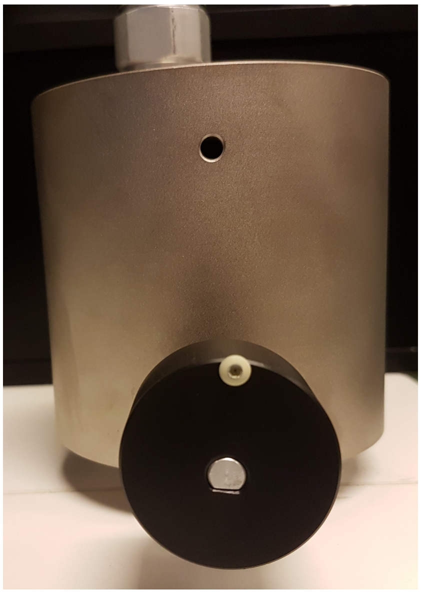

Figure 14: The beta source spindle has a machined flat, which locates the eccentric wheel. This flat is facing downwards when the source is inactivated (“off”) and upwards when the source is activated (“on”). In the picture shown the source is inactivated. Note that this machined flat is only visible when the safety helmet has been removed and is thus not visible during normal operation

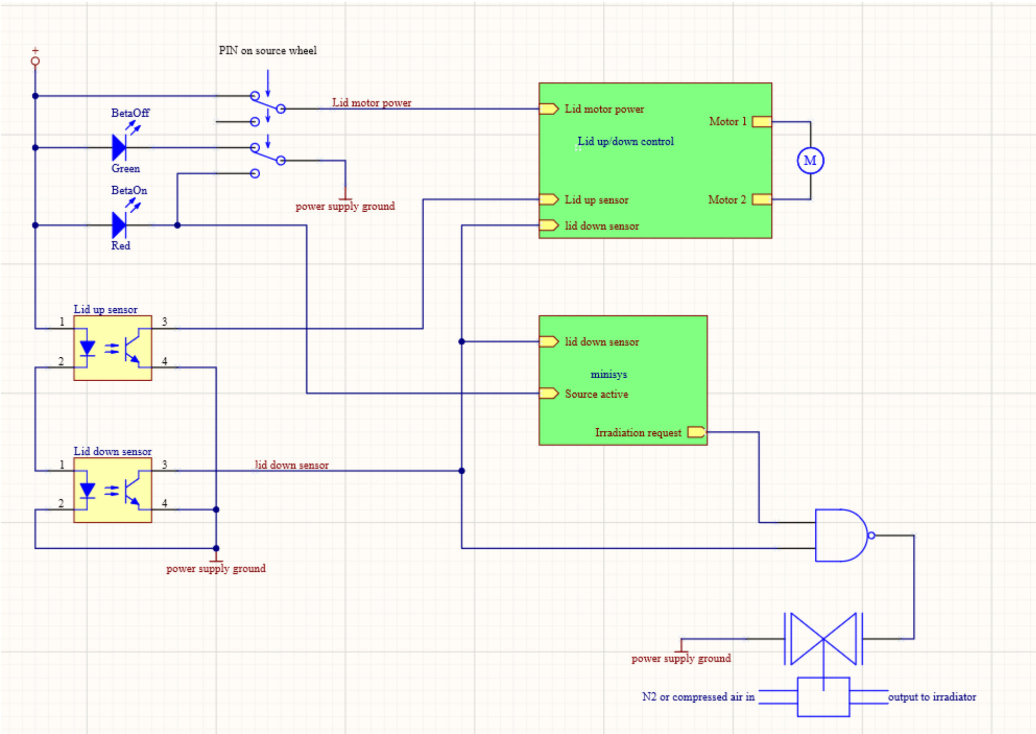

Figure 15: Beta irradiation control circuit

3.3.1 Hardware safety features

There are both mechanical and electrical hardware safety features in place. The irradiation source control circuit is given in Figure 15.

i) The inlet pressure detector informs the system Controller of the presence of compressed air. If the compressed air is not present, no software controlled irradiation operations are allowed.

ii) When depressed by the push rod, the double micro-switch disconnects lid motor power, preventing lid operation with the source in the "on" position; the LED indicator indicates red.

iii) The "*lid down*" and "*lid up*" sensors must provide opposite signals and the "*lid down*" sensor must be active (i.e. lid completely closed) to allow the source to be actuated.

3.3.2 Software safety features

There is additional software protection, which disables irradiation under the following conditions:

I) The lid is down and the beta source is activated by software, but there is a fault in the gas supply such that the source holder does not rotate. Then the micro switch is not activated and the software deactivates the command to rotate the source holder after 1.5 s and delivers error code 11 (on the display of the Controller). This prevents the accidental activation of the source by a failed compressed air supply, which is later reactivated.

II) The lid is down and the compressed air supply valve fails in such a way that compressed air is delivered directly to the actuator. The source then activates. Since there is no request of irradiation from the Controller, the software sends a deactivation command (which must fail because the supply valve has failed) and delivers an error on the Controller display: "*Irradiator is faulty*". Because the micro-switch is still activated, the lid cannot be opened and so there is no danger to the operator.

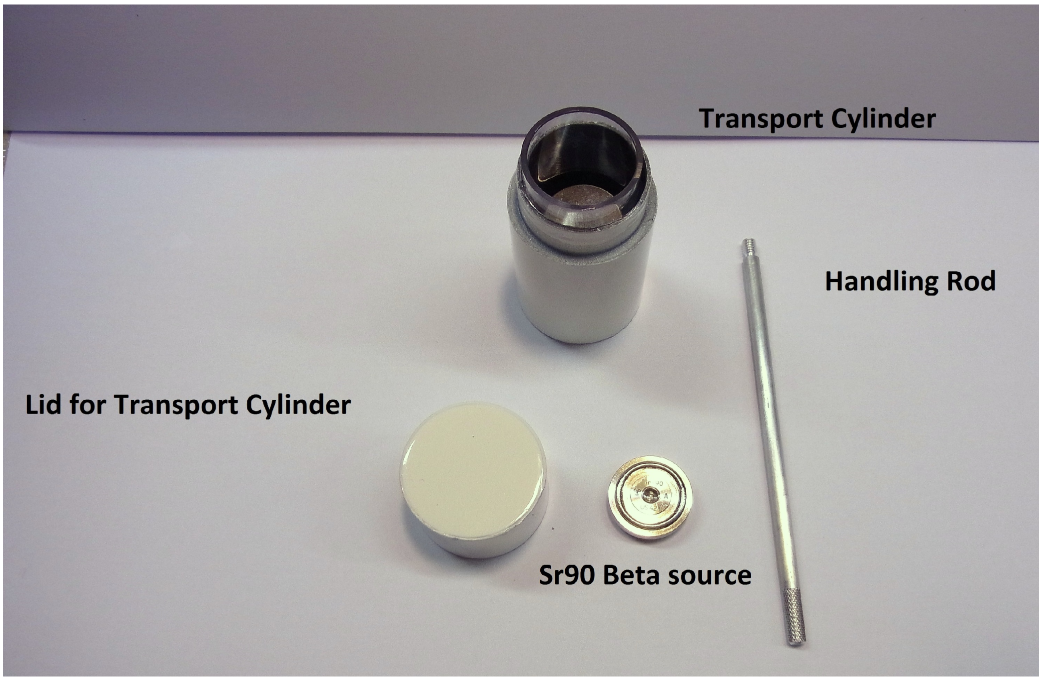

Figure 16: The $^{90}Sr/^{90}Y$ source, the inner container and the handling rod

4 Loading and unloading the $^{90}Sr/^{90}Y$ beta source in the irradiator module

In this section we describe the procedure for loading and unloading the beta source into/out of the irradiator. If installation by DTU Physics is ordered, a DTU Physics will perform this procedure. Authorisation to carry out this procedure for DTU Physics personnel is given by the responsible radiation safety officer at DTU Physics.

4.1 Absorbed dose during loading/unloading of the beta source

The entire process of loading/unloading the $^{90}Sr/^{90}Y$ beta source in the irradiator module takes about 2 min, but the source itself is only exposed for two to three seconds, i.e. the time it takes to lift up the source from its container and place it in the irradiator module using the dedicated source handling rod (see Figure 16). In this process the fingers are $\sim$ 8.5 cm away from the radioactive material.

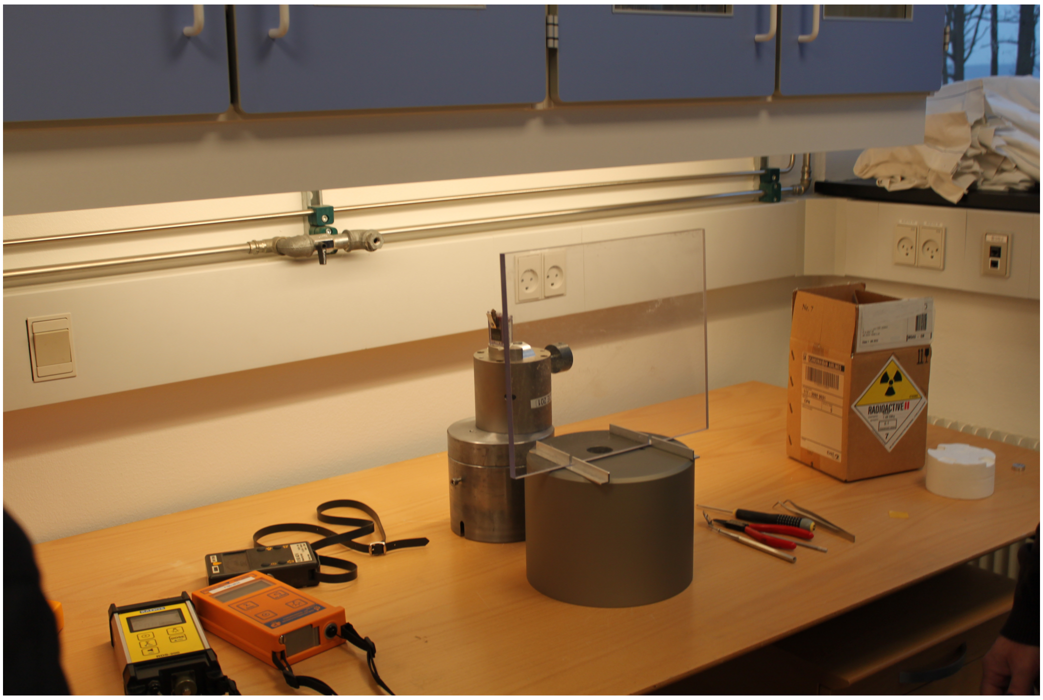

Figure 17: Setup when loading/unloading a ^{90}Sr/^{90}Y source into the irradiator.

The maximum energy of the beta particles from ^{90}Sr/^{90}Y is 2.28 MeV and the CSDA range in PMMA is thus < 1 cm. A PMMA plate (or equivalent) of at least 10 mm thickness must be placed between the operator and the source (see Figure 17), and so it is very unlikely that the operator will absorb a significant beta dose to chest or abdomen.

In addition, the operator must also wear safety glasses and is instructed to at all times to look through the PMMA plate during the operation. Thus it is also very unlikely that the operator absorbs a significant dose to the forehead/eyes. However, it is likely that the operator will absorb a detectable beta dose to the fingers.

The absorbed doses to forehead, torso (chest and abdomen) and fingers were measured using TLDs (MCP; minimum detection limit of 100μSv) by loading and unloading the source 3 times (i.e. a total of 6 operations). These dosimeters are specifically intended for measurement of surface dose (Hp(0.07)) from beta radiation. The positions of the dosimeters are shown in Figure 18.

As expected, we were not able to detect any absorbed dose using the dosimeters placed on the head and torso of the operator. However, doses from 4 of the 6 dosimeters placed on the hands of the operator were detectable (i.e. the

Figure 18: Position of TLD (MCP) dosimeters on the operator.

left thumb, the left and right 3rd finger and the right thumb) with a maximum dose of $130 \pm 15\,\mu$Sv for the 3rd finger on the left hand. This corresponds to 0.03% of the maximum permissible dose to the extremities, of 0.5 Sv (ICRP).

4.2 Loading/unloading the beta source

This section describes the procedure of loading the ^{90}Sr/^{90}Y source in the Risø beta irradiator. For unloading the same procedure must be followed in reverse order.

The source must only be unpacked by trained personnel. Authorization to carry out this procedure for DTU Physics personnel is given by the responsible radiation safety officer at DTU Physics. At least two authorised personnel must be present during the procedure.

All maintenance on the irradiator module, particularly the dismantling and removal of the source, must only be undertaken by authorised and radiological classified personnel with medical and dosimetrical monitoring appropriate to the risks of exposure.

In the following sections, we provide detailed instructions on how to load/unload a source. These instructions are provided to the user on the operating PC and are also available on-line. In case of doubt, DTU Physics should always be contacted.

4.2.1 Preparing for loading/unloading the beta source

Please read the instructions carefully and watch the video showing how to load the source (C:\Risoe\Movies\Cable connection.mpg) before attempting to unload/load the source.

Before beginning the procedure of unloading/loading the beta source, make sure that

1. an empty desk space of 60×60 cm is available to handle the irradiator during unloading/loading
2. the following tools are kept within reach:
   - Two hexagonal keys (Allen keys), 4 mm and 5 mm
   - The circlip pliers (delivered with the Risø Reader)
   - The source handling rod (delivered with the source)
   - 10 mm perspex/plexiglass plate and a vice to hold it. This plate is to be used as protection when the source is exposed
3. Unauthorized personnel or personnel not required for the procedure (including members of the public) should not be present in the room.
4. The person loading the source must wear appropriate eye protection.

The setup is shown in Figure 17.

4.2.2 Unpacking the source

Radiation levels must be checked using an appropriate dose rate meter at each stage of unpacking.

i The dose rate directly on the sides of the inner card board box (see Figure 5 is expected to be less than 150μSv/h and 2μSv/h at a distance of 1 m. If the measured dose rates are a factor of two greater than the maximum expected dose rates the procedure must be stopped and the source manufacturer contacted.

ii Open the outer cardboard carton and take out the inner cardboard box. Verify that the labels on the cardboard box match the ordered source.

iii Open the inner cardboard box and remove sufficient internal packing materials to reveal the sealed metal can storage container.

iv Verify that the labels on the source container match the ordered source.

v Carefully lift out the sealed metal can. Remove the lid.

vi Take out the inner container and place it in a shielded position ready for removal (i.e. behind the 10 mm perspex plate).

vii When the shielding is in place and source remote handling can be carried out safely, the lid or cap of the container may be removed.

viii The radioactive source should be inspected immediately taking care to restrict personnel dose levels by the use of suitable shielding (the perspex plate), remote handling (the handling rod) and viewing using a dental mirror.

ix Verify that the source serial number agrees with the accompanying paperwork and write down the serial number. If there are differences the source is repacked, placed in a secure area and the source manufacturer/DTU Physics notified immediately.

4.2.3 Procedure of loading/unloading the source

You should now be ready to begin the procedure of loading/unloading the beta source. The source will be exposed in items 8 and 9 described below.

1. Remove the plastic air tube (Figure 19). If the irradiator module is fitted with an aluminium helmet (new models) remove it. Then remove the lid of the lead shielding

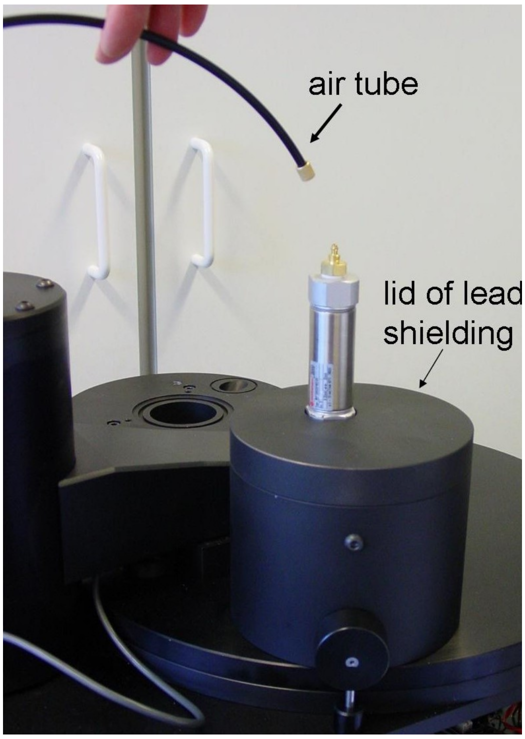

Figure 19: Removing the air tube.

2. Remove the lead shielding cylinder by removing the socket screw using a 4 mm hexagonal key (Allen key, see Figure 20)

3. Remove the irradiator from the Reader by unscrewing the two screws on the top using a 5 mm hexagonal key (Figure 21)

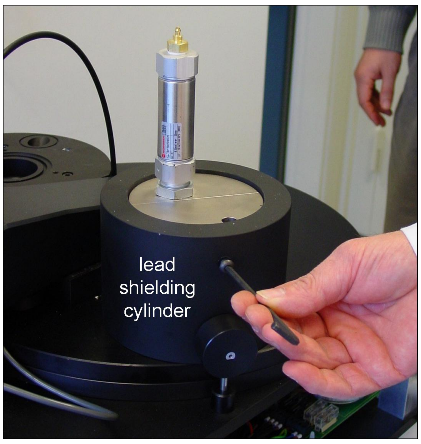

Figure 20: Removing Pb shielding.

Figure 21: Removing the irradiator.

4. Place the lid of the lead shielding UPSIDE DOWN on the circular lead shielding as shown in Figure 22a. Lift up the irradiator from the Reader (Figure 22b). Place the irradiator upside down using the hole in the lid (Figure 22a)

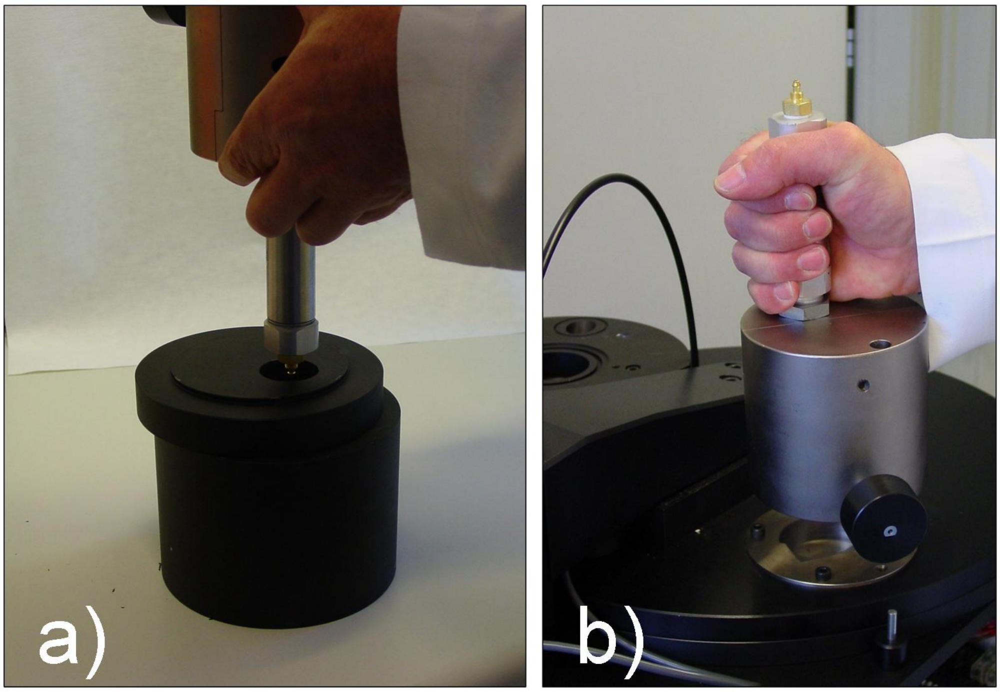

Figure 22: Preparing for loading/unloading.

5. The items shown in Figure 23 are located within the irradiator and must be removed and handled individually using the special tools delivered with the beta source. The source will only be present if the irradiator is to be unloaded

6. Remove the circlip using the circlip pliers delivered with the equipment (Figure 24)

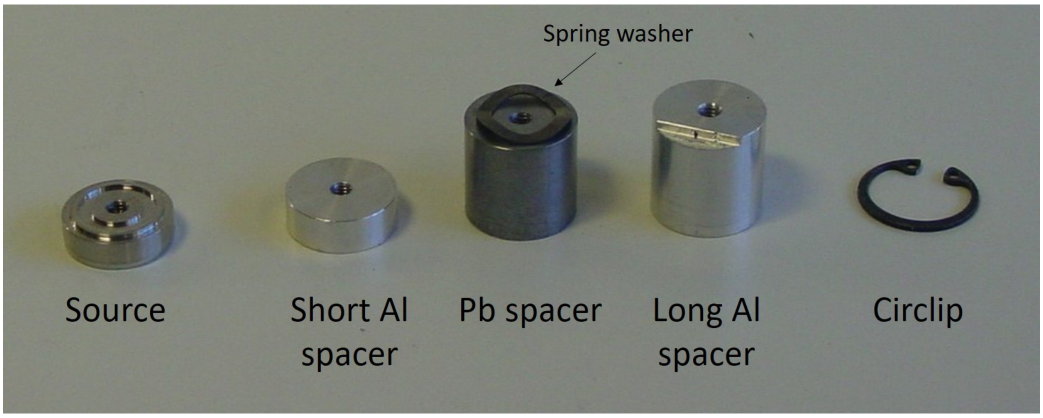

Figure 23: Items in the irradiator.

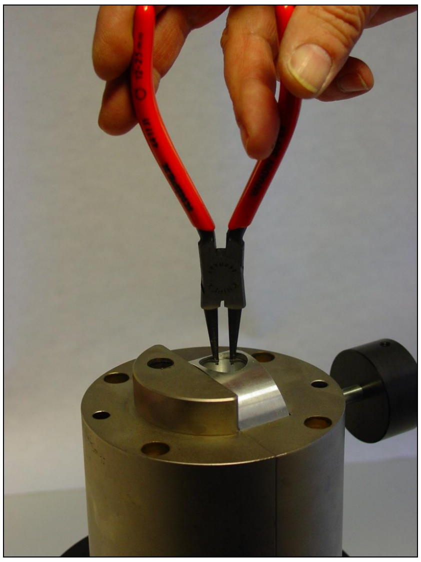

Figure 24: Removing the circlip.

7. Remove the long Al spacer using the special handling rod with thread (included in the beta source packing) and then the Pb spacer with spring washer and finally the short Al spacer (Figure 25)

Figure 25: Removing items in the irradiator.

8. Place a 10 mm thick perspex/plexiglass plate (or another beta-thick transparent absorber e.g. 3 mm of window glass) in front of the irradiator (this transparent sheet will absorb all beta rays during loading). Place the lead container with the source behind the perspex and take off the container lid. Remove the plastic lid from the inner container as quickly as possible. Lift out the foam plastic packing using a pair of tweezers. Then use the handling rod to lift up the source from the container (turn rod clockwise to fix it in the tread hole of the source). The source must always be pointed away from the operator. The operator must wear safety glasses and must at all times look through the perspex plate during the loading operation (Figure 26)

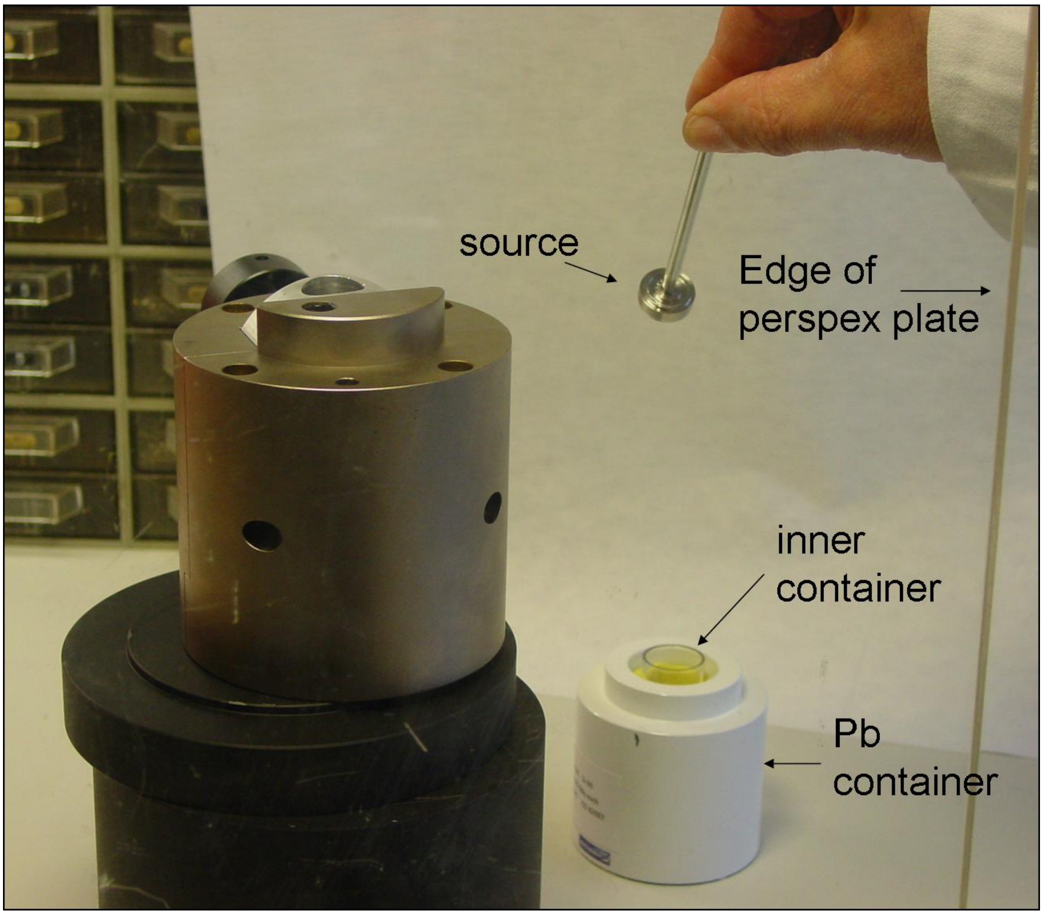

Figure 26: Inserting the source I.

9. Place the source in the irradiator and gently unscrew the handling rod from the source (Figure 27)

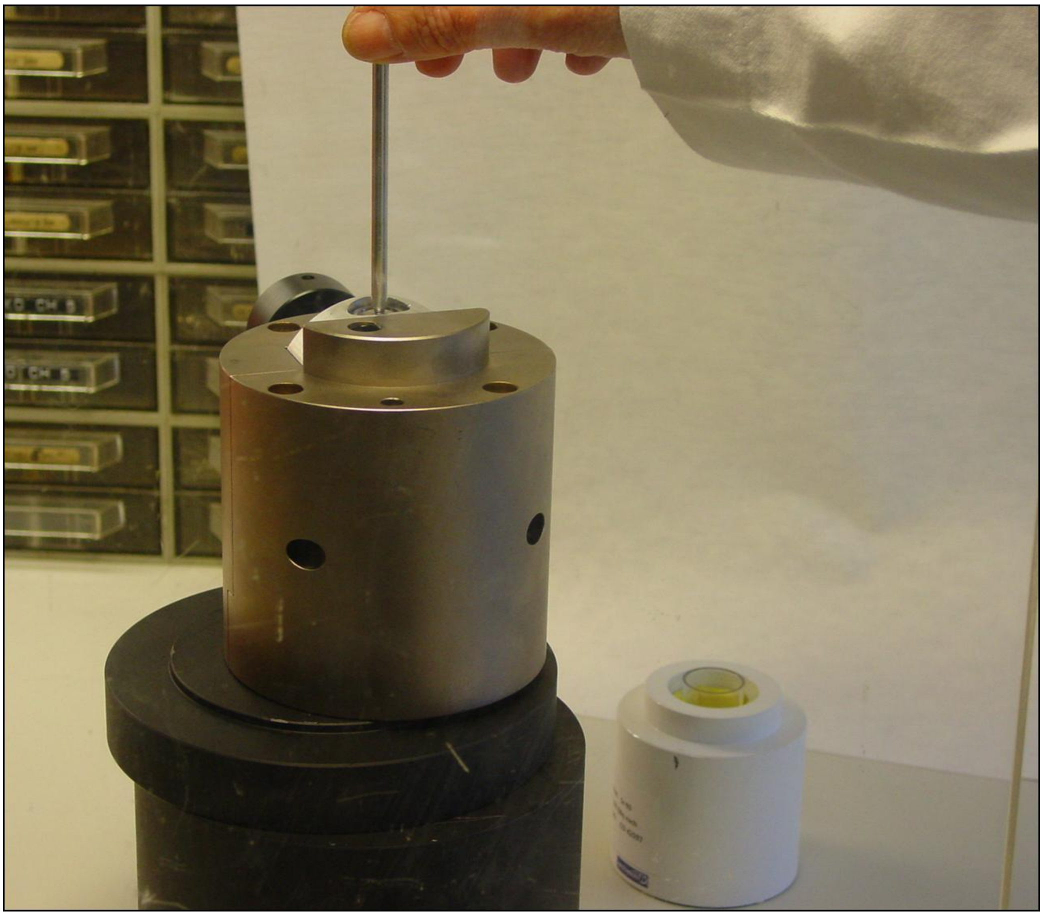

Figure 27: Inserting the source II.

10. The perspex plate can now be removed for ease of access. Use the handling rod to place the short Al spacer, then the Pb spacer with spring washer and finally the long Al spacer on top of the source (Figure 28)

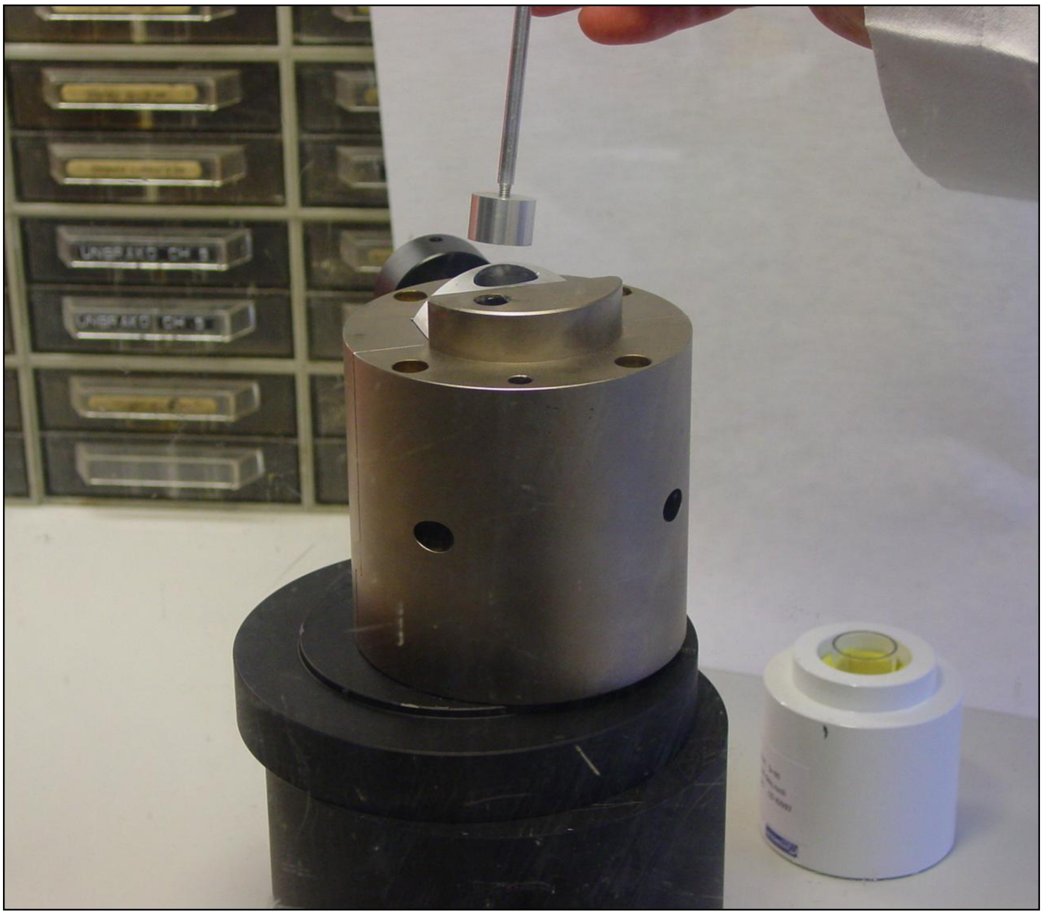

Figure 28: Reinsert spacers.

11. Mount the circlip using the circlip pliers (Figure 29 left). Hold the circlip in your left hand and use the pliers to squeeze the circlip closed with your right hand. Keep holding the circlip with the left hand and the pliers and insert on the top of the irradiator. Ensure that the points of the pliers and the pliers line up with the cut step (Figure 29 right) in the long Al spacer (already fitted in the irradiator). Use the points of the pliers to press down around the circlip to ensure that it is fitting properly in the groove of the irradiator body. (Hold the black plastic wheel (Figure 29 left) firmly to prevent the irradiator from rotating accidentally). Ensure that the circlip is fixed securely in locked position

12. Put the irradiator back onto the Reader and bolt firmly in place

13. Place the Pb shielding around the irradiator, making sure that the slot

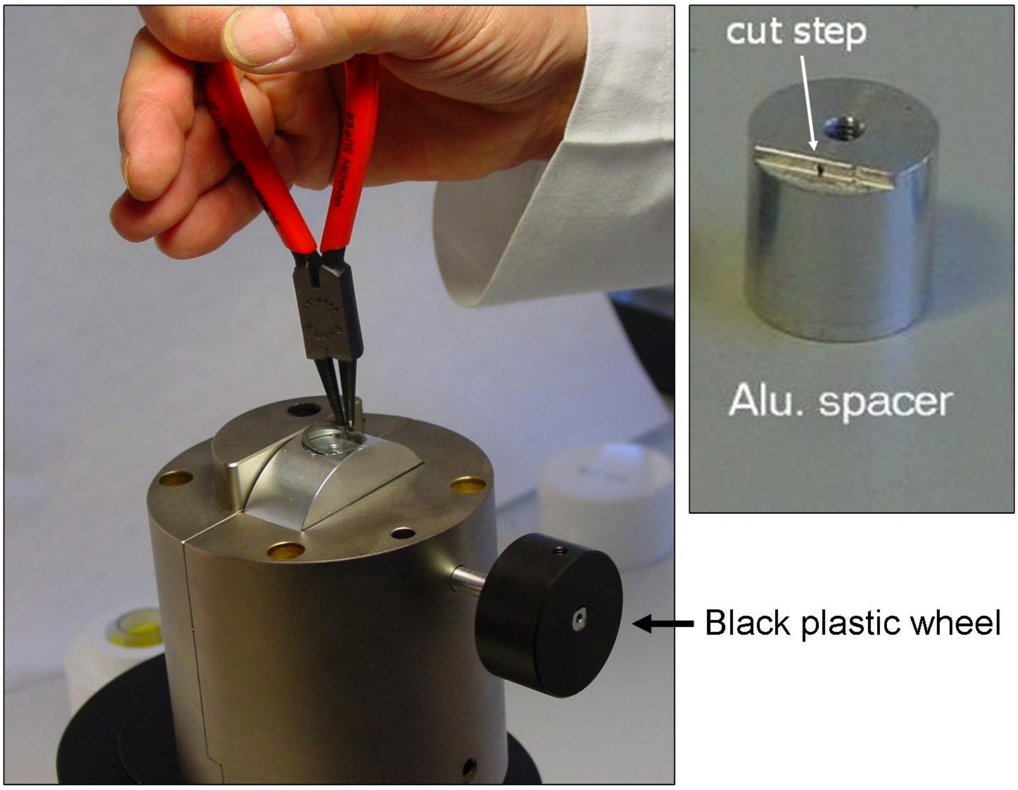

Figure 29: Mounting the circlip.

in the Pb cylinder fits over the metal shaft of the black plastic wheel. Insert the screw and secure. Ensure that the wheel and shaft are able to freely rotate without touching the lead shielding

14. Place the lead lid on the top and check that it is located correctly. If the source module is fitted with an aluminium helmet then replace this

15. Re-connect the plastic air tube

16. Open the CONTROL program and initiate an irradiation to check that everything is working satisfactorily

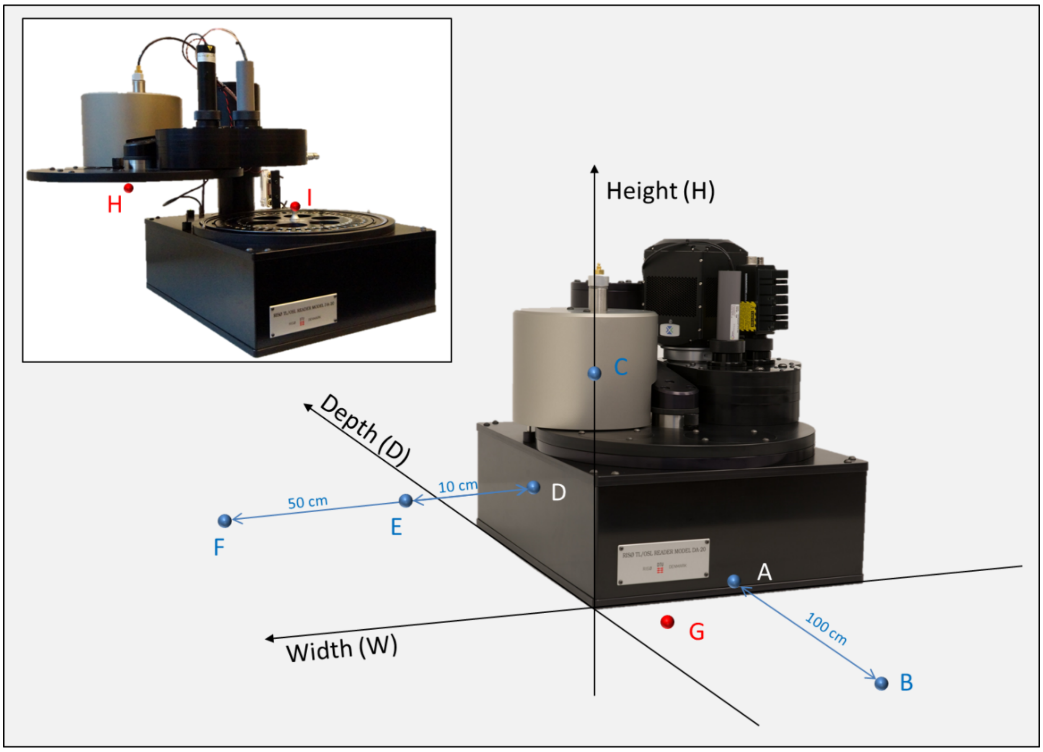

Figure 30: Picture of the Risø TL/OSL Reader with the lid closed. The inset shows the Reader, when the lid is opened (i.e. for sample loading/unloading). Also shown are the positions of key external dose rates measurements (see Figure 32 and 33) along with the used coordinate system. Note that position "G" is under the table top on which the instrument rests.

5 External dose rates (normal operation)

The external dose rate originates entirely from bremsstrahlung due to interaction of beta particles in the surrounding materials. Here, we present external dose rates measured for a type 1.48 GBq ^{90}Sr/^{90}Y beta source (providing a dose rate of 0.1 Gy/s at the sample irradiation position for quartz mounted on stainless steel sample discs). The dose rate measurements were made using a calibrated plastic scintillation detector, specifically intended for measuring dose rates from photons down to 40 keV. The measurements were made in a room with a background dose rate of 0.20μSv/h.

Figure 30 shows a photograph of the Risø TL/OSL Reader along with the coordinate system used to define the position of the measurement points. Figure 32 shows external dose rate measurements in μSv/h for a 1.48 GBq

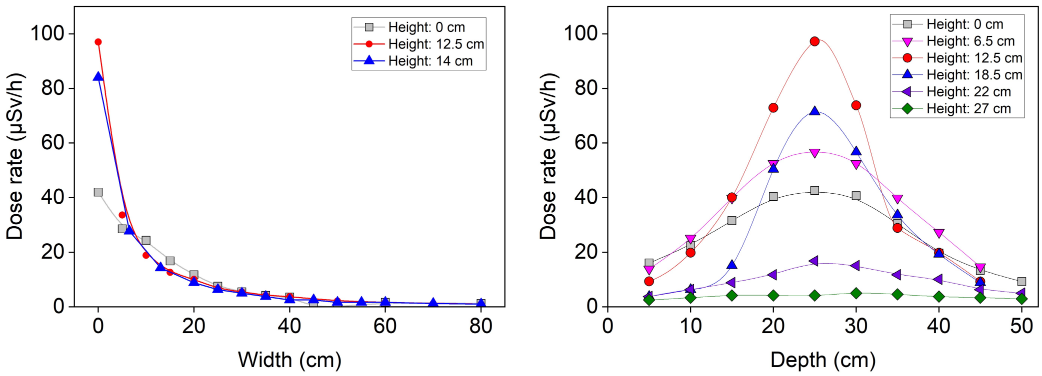

Figure 31: External dose rates measured at different depths, widths and heights along the left side of the Reader for a 1.48 GBq type $^{90}Sr/^{90}Y$ beta source. Left: External dose rates measured at a fixed depth of 25 cm (where the maximum dose rate occurs) for different widths and heights from the left side of the side of the Reader. Right: The highest dose rate is at a height of 12.5 cm from the tabletop and at a depth of 25 cm (half the depth of the Reader body).

type $^{90}Sr/^{90}Y$ beta source loaded in the Risø beta irradiator. A graphical representation of the dose rates measured directly on the left side of the Reader and at different distances to the left of the Reader are shown in Figure 31.

When the source is not activated the dose rate at a distance of 1 m from the front surface of the Risø Reader ("B" in Figure 30) is $< 0.2\mu$Sv/h. When the source is activated the dose rate is $< 0.3\mu$Sv/h.

The dose rate directly on the surface of the irradiator ("C" in Figure 30) is $< 5\mu$Sv/h both when the source is activated and not activated.

The maximum dose rate directly on the side of the Reader ("D" in Figure 30, the side closest to the irradiator) increases from 5μSv/h to $< 100\mu$Sv/h when the source is open. For all reasonable use, no part of the worker should be in contact with this side of the Reader. However, by placing 2.5 cm thick lead (Pb) along the left side of the Reader, these dose rate can be reduce to $< 0.8\mu$Sv/h and $< 4\mu$Sv/h, respectively. However, we do not regard it as necessary to shield either the front or the other sides of the Reader. Instead we recommend that the Controller is placed on the left side of the Reader to prevent desk space from being used as work space (see Figure 1) and thus prevent unnecessary exposure of users.

We also recommend that the Reader is positioned in such a way that the

1.48 GBq	(W , D , H)	On	Off
On/above safety helmet	(-13 , 19 , 22)	13	2
	(-13 , 19 , 26)	**4**	**2**
	(-13 , 19 , 29)	2	-
	(-13 , 19 , 33)	1	-
	(-13 , 22 , 34)	0.3	0.8
	(-13 , 22 , 39)	0.3	0.6
	(-13 , 22 , 44)	0.3	0.5
	(-13 , 22 , 54)	0.3	0.4
	(-13 , 22 , 61)	0.3	0.3
Left side	(0 , 5 , 0)	16	-
	(0 , 10 , 0)	23	-
	(0 , 15 , 0)	32	-
	(0 , 20 , 0)	40	-
	(0 , 25 , 0)	43	2
	(0 , 30 , 0)	41	-
	(0 , 35 , 0)	30	-
	(0 , 40 , 0)	20	-
	(0 , 45 , 0)	13	-
	(0 , 50 , 0)	9	-
	(0 , 25 , 6.5)	57	3
	(0 , 25 , 9.5)	76	4
	(0 , 25 , 12.5)	**97**	**4**
	(0 , 25 , 14)	84	-
	(0 , 25 , 19)	71	-
	(0 , 25 , 22)	17	-
	(0 , 25 , 25)	7	2
	(0 , 25 , 27)	4	-
	(0 , 25 , 30)	3	2
	(0 , 25 , 40)	0.6	0.3
	(0 , 25 , 50)	0.5	0.3
	(0 , 25 , 60)	0.5	0.3
	(0 , 25 , 70)	0.5	0.3
	(0 , 25 , 78)	0.4	0.3
	(0 , 5 , 12.5)	9	-
	(0 , 10 , 12.5)	20	-
	(0 , 15 , 12.5)	40	-
	(0 , 20 , 12.5)	73	-
	(0 , 25 , 12.5)	97	4
	(0 , 30 , 12.5)	74	-
	(0 , 35 , 12.5)	29	-
	(0 , 40 , 12.5)	20	-
	(0 , 45 , 12.5)	9	-
	(0 , 5 , 18.5)	4	-
	(0 , 10 , 18.5)	6	-
	(0 , 15 , 18.5)	15	-
	(0 , 20 , 18.5)	50	-
	(0 , 25 , 18.5)	71	-
	(0 , 30 , 18.5)	57	-

	(W , D , H)	On	Off
Left side	(0 , 35 , 18.5)	34	-
	(0 , 40 , 18.5)	19	-
	(0 , 45 , 18.5)	9	-
	(0 , 5 , 6.5)	14	-
	(0 , 10 , 6.5)	25	-
	(0 , 15 , 6.5)	40	-
	(0 , 20 , 6.5)	53	-
	(0 , 25 , 6.5)	57	-
	(0 , 30 , 6.5)	53	-
	(0 , 35 , 6.5)	40	-
	(0 , 40 , 6.5)	27	-
	(0 , 45 , 6.5)	15	-
	(0 , 5 , 22)	4	-
	(0 , 10 , 22)	6	-
	(0 , 15 , 22)	9	-
	(0 , 20 , 22)	12	-
	(0 , 25 , 22)	17	-
	(0 , 30 , 22)	15	-
	(0 , 35 , 22)	12	-
	(0 , 40 , 22)	10	-
	(0 , 45 , 22)	6	-
	(0 , 50 , 22)	5	-
	(0 , 5 , 27)	3	-
	(0 , 10 , 27)	3	-
	(0 , 15 , 27)	4	-
	(0 , 20 , 27)	4	-
	(0 , 25 , 27)	4	-
	(0 , 30 , 27)	5	-
	(0 , 35 , 27)	5	-
	(0 , 40 , 27)	4	-
	(0 , 45 , 27)	3	-
	(0 , 50 , 27)	3	-
	(0 , 25 , 14)	84	-
	(6.5 , 25 , 14)	28	-
	(13 , 25 , 14)	14	-
	(20 , 25 , 14)	9	-
	(25 , 25 , 14)	6	-
	(30 , 25 , 14)	5	-
	(35 , 25 , 14)	4	-
	(40 , 25 , 14)	3	-
	(45 , 25 , 14)	3	-
	(50 , 25 , 14)	2	-
	(55 , 25 , 14)	2	-
	(60 , 25 , 14)	2	-
	(70 , 25 , 14)	1	-
	(80 , 25 , 14)	1	-
	(5 , 25 , 0)	31	2
	(10 , 25 , 0)	24	1
	(15 , 25 , 0)	18	1
	(20 , 25 , 0)	12	1

	(W , D , H)	On	Off
Left side	(25 , 25 , 0)	8	1
	(30 , 25 , 0)	6	1
	(35 , 25 , 0)	4	1
	(40 , 25 , 0)	4	-
	(60 , 25 , 0)	2	-
	(80 , 25 , 0)	1	-
	(5 , 25 , 12.5)	34	-
	(10 , 25 , 12.5)	**17**	**3**
	(15 , 25 , 12.5)	13	-
	(20 , 25 , 12.5)	10	-
	(25 , 25 , 12.5)	7	-
	(30 , 25 , 12.5)	5	-
	(35 , 25 , 12.5)	4	-
	(40 , 25 , 12.5)	4	-
	(50 , 25 , 12.5)	**2**	**1**
	(60 , 25 , 12.5)	2	-
	(70 , 25 , 12.5)	1	-
	(80 , 25 , 12.5)	1	
Right side	(-39 , 25 , 0)	2	0.3
	(-44 , 25 , 0)	1.1	-
	(-49 , 25 , 0)	1.3	-
	(-59 , 25 , 0)	0.6	-
	(-69 , 25 , 0)	0.5	-
	(-79 , 25 , 0)	0.3	-
	(-89 , 25 , 0)	0.3	-
	(-99 , 25 , 0)	0.3	-
	(-139 , 25 , 0)	0.3	0.1
	(-39 , 25 , 8.3)	1.5	0.2
	(-89 , 25 , 8.3)	0.4	0.1
	(-139 , 25 , 8.3)	0.3	0.2
Front side	**(-19 , 0 , 0)**	**9**	**0.3**
	(-19 , -25 , 0)	1.1	-
	(-19 , -50 , 0)	0.5	-
	(-19 , -75 , 0)	0.5	-
	(-19 , -100 , 8.3)	**0.3**	**0.1**
	(-19 , 0 , 8.3)	3	0.2
	(-19 , -25 , 8.3)	0.9	-
	(-19 , -50 , 8.3)	0.2	0.1
Back side	(0 , -52 , 0)	7	-
	(-38 , -52 , 0)	3	-
Under Table	**(-13 , 25 , -2.5)**	**40**	**3**
Under Source*	**(4 , 50 , 27)**	**N/A**	**40**
Hand position**	**(-20 , 20 , 20)**	**N/A**	**0.5**

Figure 32: External dose rate measurements in μSv/h for a 1.48 GBq type ^{90}Sr/^{90}Y beta source loaded in the Risø beta irradiator. The position of each measurement point (W,D,H) is given in cm relative to the coordinate system shown in Figure 30. "On": the source is activated. "Off": the source is inactivated (in safe position). The highlighted rows are reproduced in Figure 33.

1.48 GBq $^{90}Sr/^{90}Y$	Coordinates			Lid closed				Lid open
	W (cm)	D (cm)	H (cm)	"on"	"off"	"on" +Pb	"off" +Pb	"off"
A	-19	0	0	9	0.8	-	-	-
B	-19	-100	0	0.3	0.2	-	-	-
C	-13	18.5	26	5	4	-	-	-
D	0	25	12.5	97	5	4	0.75	-
E	10	25	12.5	19	3	3	0.70	-
F	50	25	12.5	2	1	-	-	-
G	-13	25	-2.5	40	3	-	-	-
H	-13	25	20	-	-	-	-	40
I	-19	20	20	-	-	-	-	0.5

Figure 33: Summary of key external dose rates [μSv/h] for the Risø TL/OSL Reader equipped with a 1.48 GBq $^{90}Sr/^{90}Y$ source. All dose rates were measured using a calibrated plastic scintillation detector, specifically intended for measuring dose rates from photons down to 40 keV. The background dose rate measured approximately 2 m away from the Reader was 0.2μSv/h. The designations "A, B, C, D, E, F, G, H and I" are shown in Figure 30. When the source is "off" it points directly at a 10 mm carbon absorber. When the source is "on" (activated position) it points downwards towards the measurement chamber. In the "on/off"+Pb measurements a 2.5 cm thick lead (Pb) brick was positioned at "B".

space underneath is inaccessible (see Figure 35). The dose rate underneath a wooden table with a thickness of 25 mm ("G" in Figure 30) is $< 3\mu$Sv/h when the source is inactivated and $< 40\mu$Sv/h when the source is activated.

6 Radiation protection considerations during laboratory work and normal operation

The activation of the source is electromechanically interlocked so that it is impossible to activate the source remotely while the lid is open. Thus, whenever the lid is open (during loading and unloading of samples) the source is always inactivated.

6.1 Occupational exposure during laboratory work

For a laboratory worker not operating the Reader, we assume that she spends 8 h a day for 200 days a year (i.e. 1600 h) in the laboratory with the source continuously activated. At a distance of 1 m from the Reader ("B" in Figure 30). This results in an annual dose of 0.8 mSv, which is below the annual dose limit for the public.

6.2 Occupational exposure during normal operation

6.2.1 Loading and unloading samples

During normal operation the lid opens and the sample carrousel is placed on the sample turntable in the measurement chamber. When the lid is open (and so the source inactivated) the dose rate directly below the aperture of the irradiator is $40\mu\text{Sv/h}$ ("H" in Figure 30). However, this is not the dose rate to which the radiation worker will be exposed. The dose rate applicable to the operator is significantly smaller. During this operation the hand will be exposed to a maximum dose rate of $0.5\mu\text{Sv/h}$ ("I" in Figure 30). During a normal day of operation the operator is expected to spend a maximum of 5 min in front of the Reader with the lid open. The operation of replacing the sample carrousel should not take more than 30 s; the 5 min period in the following calculations takes into account that this operation may be carried out several times a day. Thus, the hand of operator will be exposed to a maximum annual dose of $15\mu\text{Sv}$ (i.e. $0.5\mu\text{Sv/h}$ * 0.083 h/day * 365 days). According to the latest ICRP recommendations, the annual dose limit to the hand is 500 mSv for a radiation worker, i.e. the annual dose is more than a factor of 30,000 lower.

The dose rate on the surface of the front plate (i.e. the dose rate to the abdomen of the operator, "A" in Figure 30) is $0.8\mu\text{Sv/h}$, and using the same assumptions as given directly above the maximum annual abdomen dose is $24\mu\text{Sv/h}$. According to the ICRP, the annual whole body dose limit is 20 mSv for a radiation worker, i.e. the annual dose is more than a factor of 800 lower.

6.2.2 Writing sequences and/or making aliquots

The external dose rate directly on the left side of the Reader ("B" in Figure 30) is $< 100\mu$Sv/h when the source is open. Thus, if for instance the operator were to place the mouse connected to the PC to the left of the Reader, it may not be unreasonable to assume that the user will spend 10 min a day (365 days a year) writing sequences for the Reader. Also if the space to the left of the Reader was easily accessible, it is not unreasonable to assume that a operator could use this space as work space (e.g. to make aliquots). In this case it might be reasonable to assume that the hand of the operator will be approximately 10 cm away from the side of the Reader (position "E"), where the dose rate has been measured to be $< 19\mu$Sv/h when the source is irradiating. This gives an annual dose of 1 mSv. This remains well below the annual dose value (500 mSv/year to the hand), but is considered to be completely unnecessary and readily avoidable.

If the operator were to sit on a chair with his/her legs directly underneath the Reader while the source is irradiating the dose rate is 40μSv/h (for a wooden table of 25 mm thickness, "G" in Figure 30). If the operator were to sit like this for 10 min every day (365 days a year), the annual dose would be 2.4 mSv. This is again well below the annual extremity dose limit (500 mSv/year) and annual whole body dose limit (20 mSv/year effective dose), but is considered to be completely unnecessary and readily avoidable.

6.3 Radiation protection recommendations (normal operation)

From a radiation protection point of view no additional safety precautions need to be taken with regard to normal operation (e.g. loading and unloading samples, writing sequences, making aliquots).

For all reasonable use, no part of the worker should be in contact with the left side of the Reader. The maximum dose rate of $< 100\mu$Sv/h drops to $< 17\mu$Sv/h even 10 cm from the surface, but DTU physics recommends that this side of the Reader is made inaccessible, e.g. by placing the Controller on the left side of the Reader to prevent this desk space from being used as work space and thus prevent unnecessary exposure of users. The Controller is 45 cm wide, so the dose rate will have decreased to $< 2\mu\text{Sv/h}$ at a distance of 50 cm from the left side of the Reader.

If for instance desk space is limited, the dose rate can readily be reduced to $< 5\mu\text{Sv/h}$ by placing 2.5 cm of lead shielding along this side of the Reader (covering "D" in Figure 30).

We do not regard it as necessary to shield either the front or the other sides of the Reader.

However, we recommend that the Reader is positioned in such a way that the space underneath is inaccessible, i.e. so position "G" in Figure 30 is inaccessible.

We stress the importance of appropriate training of the operator of the luminescence equipment with respect to radiation protection:

1. The operator should spend as little time as possible close to the Reader
2. The operator should not touch the aperture of the irradiator
3. The operator should not leave the lid open for extended periods of time

The lid is both electronically and mechanically inter-locked so it cannot be opened while the source is energized. If the lid is forced open, software and hardware interlocks will de-energize the irradiator and return the source to its default safe position. An external indicator positioned next to the irradiator glows red when the source is activated and green when the source is de-energized.

7 Maintenance recommendations for the irradiator

The working condition of the irradiator should be checked at least annually by a specialist with the appropriate medical and dosimetric monitoring.
Before any intervention of the irradiator it must be checked that the source is in “non-irradiation” mode using a suitable active dose rate meter, i.e. the external dose rates (from bremsstrahlung) around the Reader should be measured.
The dose rates on and around the Reader (see Figure 30) are measured when the source is installed by DTU Physics. Similar measurements should be made (both in irradiating and non-irradiating mode) during maintenance and the measured dose rates must not deviate significantly from the previous measurement.
The protective aluminium cover (helmet) of the source may only be removed by a qualified radiation expert with appropriate medical and dosimetric monitoring.
All intervention on the irradiator modules when the sources are installed must only be carried out by authorized personnel and not until DTU Physics has been contacted. Procedures for maintenance issued by DTU Physics must be followed.

7.1 Leakage test

Testing for leakage of radioactive material using a wipe test should be done in accordance with ISO 9978 and carried out annually (note that national and local policy may require a different test interval). For the beta source, the wipe must be taken directly on the Beryllium window underneath the source. Do NOT remove the source from the irradiator module. Verify that the source is in safe position before carrying out the wipe test. If contamination is detected, additional tests must be used to determine the level of contamination. If the integrity of the source is lost, the source must be replaced by an authorized person.

7.2 Periodical tests

The following checks is recommended to be undertaken annually by a specialist with appropriate medical and dosimetric monitoring. Before any intervention of the irradiator it must be checked that the source is in “off”

(default) position using a suitable active dose rate meter and checked that the state of the status LED is green (green light: source is in “off” (default) position. Red light: source is in irradiation position).
Note that there are no user maintainable parts or systems in the irradiators. This section simply describes functional checks.

- The mechanical functioning of the irradiator is tested using the CONTROL software in which the source can be activated. When the irradiator is functioning correctly, a district clearly audible sound should be heard when the source wheel rotates. In the event of any abnormality contact DTU Physics.

- The dose rates on and around the Reader (see Figure 30) are measured when the source is installed by DTU Physics. Similar measurements should be made (both in irradiating and non-irradiating mode) and the measured dose rates must not deviate significantly from the previous measurement.

- The eccentric wheel of the irradiator must be tested to ensure that it is securely attached to the rotating axis and that the push rod of the micro switch is able to move freely. In the event of any abnormality contact DTU Physics.

- Inspection of the beryllium window located between the source and the irradiation position (see Figure 7). This visual inspection should be carried out using a mirror (see Figure 34). The window should be examined for cracks or other signs of deterioration. In case of mechanical damage the instrument should be removed from service and the manufacturer (DTU Physics) informed.

7.3 Forbidden interactions

- The protective aluminium cover (helmet) of the source may only be removed by a qualified radiation expert with appropriate medical and dosimetric monitoring.

- Under no circumstance, should a sequence be launched while the lid is open. However, note that during normal operation such an action will not result in rotation of the source module.

- Only load samples with dimensions that fit the sample holders and that do not exceed the upper edge of the sample carousel (thickness max 2

Figure 34: Visual inspection of the Beryllium window.

mm). If the sample exceed this height it may prevent the rotation of the sample carousel.

8 Failures

The source is mounted inside a rotating aluminium wheel which is pneumatically activated. When the source is “off” (default position) it points upwards directly at a 10 mm thick carbon absorber. When the source is “on” (activated position) it points downwards towards the measurement chamber. In general, the safety features of the Reader are designed in such a way that an accidental irradiation of personnel requires the simultaneous failure of at least two safety features (see section 3.3)

8.1 Failures related to malfunctions and their consequences

Below we list different failures related to malfunctions, their consequences as well as solutions.

1. **The user attempts to open the lid during an irradiation**
   Consequence: The lid cannot open, while an irradiation is in progress. When the irradiation command has been completed AND the source is in safe position, the lid will open
   Solution: Close the lid and restart the sequence

2. **The lid has not been closed completely**
   Consequence: An irradiation cannot be initiated unless the lid is completely closed
   Solution: Close the lid

3. **Loss of pneumatic air supply to the irradiator not during irradiation**
   Consequence: Next time the irradiation command is issued there will be insufficient pressure to rotate the source. An error message will appear on the PC screen and the sequence stopped
   Solution: Restore the pneumatic air supply

4. **Loss of pneumatic air supply to the irradiator during irradiation**
   Consequence: The irradiator will automatically and immediately return to the “off” (default) position. An error message will appear on the PC screen and the sequence stopped.
   Solution: Restore the pneumatic air supply

5. **Loss of power to the Reader during irradiation**
   Consequence: The irradiator will automatically and immediately return

to the “off” (default) position.
Solution: Restore power to the Reader

6. **Loss of power to the Controller during irradiation**
Consequence: The irradiator will automatically and immediately return to the “off” (default) position.
Solution: Restore power to the Controller

7. **Loss of power to the user PC during irradiation**
Consequence: The irradiator will automatically terminate after 20 s (USB connection) or 5 min (RS-232 connection) since the power loss occurred.
Solution: Restore power to the user PC

8. **The status LED is not on (i.e. neither green nor red)**
Consequence: The user cannot check if an irradiation is in progress via the status LED (but can do so on the irradiation indicator on the front display of the Controller (see Figure 10) or by the white mark on the visible face of the eccentric wheel (see Figure 13 and14).
Solution: Contact DTU Physics

9. **The status LED is continuously red**
Consequence: The user cannot check if an irradiation is in progress via the status LED (but can do so on the irradiation indicator on the front display of the Controller (see Figure 10) or by the white mark on the visible face of the eccentric wheel (see Figure 13 and14). The system cannot be operated
Solution: Contact DTU Physics

10. **The status LED is continuously green**
Consequence: The user cannot check if an irradiation is in progress via the status LED (but can do so on the irradiation indicator on the front display of the Controller (see Figure 10) or by the white mark on the visible face of the eccentric wheel (see Figure 13 and14).
Solution: Contact DTU Physics

11. **Mechanical failure (e.g. of the rack gear) during irradiation**
Consequence: The source cannot return to safe position. The status LED is continuously red and the white mark on the face of the eccentric wheel is visible.
Solution: Contact DTU Physics immediately. Do NOT attempt to open the lid of the Reader.

8.2 Failures related to inappropriate user actions and their consequences

External dose rates are consistent with the permissible limits for workers of all radiological categories. Under normal operation it is difficult to imagine any user action that will increase the radiation exposure rate due to the security devices, i.e. the lid is both electronically and mechanically interlocked so it cannot be opened while the source is energized. If the lid is forced open, software and hardware interlocks will de-activate the irradiator and return the source to its default safe position. A directly connected external indicator positioned next to the irradiator (the status LED) shows red when the source is activated and green when the source is de-activated.

The protective safety aluminium cover of the irradiation module may only be removed by a qualified radiation expert with appropriate medical and dosimetric monitoring. However, the user cannot be prevented from wilfully dismantling the source holder assembly.

In the following we assume that the user does not remove the safety cover on the irradiation module. Were the user then to directly visually examine the underside of the Reader lid (i.e. the Beryllium window directly below the source) by placing their head under the lid then it is conceivable that the eye could be exposed to a dose rate of 40μSv/h. According to ICRP, the threshold in absorbed dose is 0.5 Sv for the lens of the eye. Even assuming a completely unrealistic maximum occupancy factor of 1 the maximum annual dose to the eye could be 0.35 Sv, i.e. the recommended limit cannot be exceeded.

Mis-assembly of the source module is inconceivable if the source loading tools (i.e. the handling rod) provided are used. It is possible that the circlip does not sit properly and falls out after assembly (i.e. after the source module has been mounted on the Reader). In this case the spacers behind the source (see section 3.2 and Figure 8) would move out of the rotating wheel due to gravity when the source is in safe position. However, they can only fall a few mm before hitting the source mounting flange and this would simply lock the source in safe position with no increase in external exposure rate.

8.3 Emergency situations

8.3.1 Main possible situations

It is difficult to imagine any credible impact (fall or crushing) that would rupture the brass casing around the source.

In the event of fire the source would automatically return to its safe position when the plastic tubes providing the pressure to activate the source melts. The source is encased in an aluminium support, which is in turn enclosed in a brass casing. The aluminium support will oxidize between 500 and 650 °C, but the brass casing will not become unstable until >900 °C. The source is constructed to ISO standard 2919 - Classification C.43342, which specifies a minimum temperature of 400 °C, before the source encapsulation becomes unstable. In summary, it is very likely that the source will remain in the housing for all fire temperatures up to 900 °C.

8.3.2 Prohibited actions

All work on irradiator, particularly the dismantling of the irradiator and the removal of the source, must be performed by a qualified person with a medical and dosimetric monitoring appropriate to the risks of exposure.

The instructions for loading/unloading the source given in section 4.2. must be followed exactly and under no circumstance may the source come closer to the body than described therein.

8.3.3 Immediate actions to be implemented in case of abnormal or emergency situation

In the event of fire, local regulations take precedence but DTU Physics should also be advised immediately.

In the extremely unlikely event of significant mechanical damage, the laboratory containing the instrument should be locked and DTU Physics informed immediately.

There is no reason to expect that the external dose rates (see section 5) will increase above normal in the event of an abnormal or emergency situation

8.4 Prevention of failures

The source encapsulation has been designed so that no elevated external dose rates to the user will result from any foreseeable failure. Even if the source is stuck in the irradiation position the user is protected because the lid cannot be opened. This condition is readily identified by checking the source position indicators mounted besides the source itself and on the Controller. In the event of any failure being identified in the irradiation unit, DTU Physics should be contacted.

8.4.1 Tests of the irradiator module prior to shipment

Before shipment of each irradiator for the TL/OSL Risø Reader, the irradiator rotation undergoes repeated rotation (between "on" and "off") over a period of 48 hours. In addition, the reliability of the irradiators is demonstrated by the fact that about 400 units have been installed in the last 35 years in government and university laboratories worldwide. No incidents with the irradiator module resulting in health risks have ever been reported.

8.4.2 Tests during installation of the Reader

When installation of the TL/OSL Reader is carried out by DTU Physics a series of functional tests are performed. The mechanical functioning of the irradiator is checked by successfully activating and inactivating the irradiator at least 10 times using the "Control Program". After successful loading of the radioactive source, the dose rates in the immediate vicinity of the Reader is measured using a calibrated dose rate meter. All measured values are compared to the maximum acceptable dose rates (see Table 1 for a ^{90}Sr/^{90}Y source with a nominal strenght of 1.48 GBq).

1. If the measured dose rates are greater or equal to the maximum acceptable dose rate DTU Physics will discuss with the source manufacturer and the local radiation protection officer of the appropriate action.

2. If the measured dose rate is more than a factor of 1.3 greater than the maximum acceptable dose rates, it must be checked that the source is intact and the source must be returned to the source manufacturer.

Finally, the dose rate at the sample position when the TL/OSL Reader is in irradiation mode ("on") is measured using quartz mounted in stainless steel cups or on stainless steel discs. This dose rate determination (calibration) of the ^{90}Sr/^{90}Y source is carried out by comparing the signal induced by a well-known gamma dose to the signal induced by the $^{90}Sr/^{90}Y$ source. The expected dose rate of a 1.48 GBq $^{90}Sr/^{90}Y$ source is $\sim$ 360 Gy/h. The user is advised to calibrate their $^{90}Sr/^{90}Y$ source regularly.

8.4.3 Suitable laboratory conditions

The laboratory temperature should not exceed 30 °C and the humidity should be below 80% to minimize corrosion. In addition, the Reader should be kept in a corrosive free environment, because over time acid fumes will damage the electronics inside the Reader and mechanical components.

9 Radiation Safety

Responsibility

It is assumed that one person is responsible for the Reader regarding radiation protection and that this person behaves according to national legislation and directions given by the national authorities.

Radioactive source

The (beta) irradiator contains a $^{90}Sr/^{90}Y$ source (half-life $\sim$ 29 years) with a nominal activity of up to 2.96 GBq (typically 1.48 GBq $\pm$ 20%). The source emits high energy β-particles with a maximum energy of 2.28 MeV. When the particles are stopped in the source itself or in the surrounding shielding, bremsstrahlung (X-ray radiation) is generated.

Radiation protection

It is advised to use the ALARA-principle, which states that all doses shall be kept as low as reasonably achievable. This translates in practice to measuring the external dose rates around the Reader and plan the work to keep doses as low as reasonable achievable.

It is recommended that personal dose meters are used at all times.

When the beta source is placed in the irradiator, the external dose rate originates entirely from bremsstrahlung of beta particles in the surrounding materials. We recommend that the TL/OSL Reader is positioned in such a way that the space underneath it is inaccessible (e.g. by placing a cupboard) and that the user is prevented from using the space to the left of the Reader as work space (e.g. by placing the Controller here; see Figure 35). During normal operation, no additional safety precautions need to be taken (see section 6). Maximum dose rates for a type 1.48 GBq $^{90}Sr/^{90}Y$ source are given in Table 1.

The protective helmet of the source may only be removed by a qualified radiation expert with appropriate medical and dosimetric monitoring.

The use of personal dosimeters is recommended for all personnel required to work near the devices, with special monitoring for pregnant women.

Figure 35: Place the Reader such that the space underneath is inaccessible and the Controller to the left of the Reader (seen from front) to prevent users from using this space as work space

Operators of the luminescence equipment must be appropriately trained with respect to radiation protection; e.g. the operator should not touch the aperture of the irradiator and should not leave the lid open for extended periods of time.

In the event of malfunction of the irradiator, i.e. if the irradiator behaves unusually or there is any suggestion of improper operation, the user must stop using the equipment immediately, evacuate the immediate area and request the assistance of a qualified radiation expert with appropriate medical and dosimetric monitoring.

Source integrity

When the source is loaded into or unloaded from the irradiator, it is important that the detailed instructions provided by DTU Physics are followed strictly. Both written and video materials are available. In case something is unclear DTU Physics must be contacted. It is especially important to protect the eyes by wearing glasses, never to touch the source and never to direct the unshielded side of the source towards any person.

It is advised to inspect the beryllium-window between the source and the irradiation position in the TL/OSL Reader every year. This window should not show any visible cracks or deterioration. This inspection should follow the instructions given by DTU Physics and always be made by the use of a mirror (see Figure 34).
If doubt arises whether the source integrity has been compromised the apparatus should be checked for contamination. This can be done by wiping the sample holder by a cloth and checking the cloth for contamination (away from the Reader). If contamination is present further wipe testing is necessary to determine the extent of the contamination. In the case of a compromised source, decontamination and change of the source shall be carried out by a qualified person.

Dose rate and contamination measurements

The instrument used to measure the dose rates from bremsstrahlung, e.g. an energy compensated GM-detector, must be able to measure photons with energies from 50 keV to 2.3 MeV and show true dose rate. This instrument will not be able to measure dose rate contributions from direct β-radiation from the source itself or from any contamination. For a 1.48 GBq $^{90}Sr/^{90}Y$ source the measured external dose rates must not exceed the "Maximum dose rate" values given in Table 1. A GM-detector with a thin window can be used to measure $^{90}Sr/^{90}Y$-contamination.

Reference point	Expected dose rate		Maximum dose rate	
	β "off"	β "on"	β "off"	β "on"
A	1.2	15	1.6	20
B	0.3	0.5	0.5	0.6
C	6	8	8	10
D	8	150	10	200
E	5	30	6	40
F	1.5	3	2	4
G	5	60	6	80
H	60	-	80	-
I	1	-	2	-

Table 1: Expected and maximum external dose rates [μSv/h] for the Risø TL/OSL Reader equipped with a ^{90}Sr/^{90}Y source with a nominal activity of 1.48 GBq. The "Expected dose rate" is 1.5 times the dose rate measured on a type Reader (see Table 33) to allow for the 20% uncertainty of the nominal activity. The "Maximum dose rate" is 2 times the dose rate measured on a type Reader. The Reference points "A - I" are shown in Figure 30.