Experiences from Implementing Waste Led Decommissioning in Practice at a Research Facility – 17216

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ABSTRACT
The decommissioning of MAX-lab (a national accelerator laboratory hosted by Lund University) has been performed using a risk-based concept for dismantling of the equipment and clearance measurement of the facility. To support the concept, a radiological characterisation was performed containing scintillation and dose rate measurements as well as nuclide vector determination based on nuclide specific analysis of the activity content in material samples.

This paper describes the decommissioning at MAX-lab, performed during 2015 and 2016. Dismantled waste was sent to the Studsvik site for treatment. Clearance measurements of material were performed at MAX-lab and at the Studsvik site.

The levels of activity have been compared with the threshold values in the Swedish clearance regulations (material or buildings for free use) and the detected levels are below the limits for clearance of material with some exceptions. Activity above the clearance levels were found in a few locations in the facility. After removal of installations and small amounts of building structures at these locations clearance of the facility is possible.

Keywords: Risk based approach, fast decommissioning, on- and offsite material clearance.

INTRODUCTION
Since the MAX IV Laboratory, a Swedish national laboratory with high quality synchrotron radiation available for research and hosted by Lund University, is under commissioning at a new site, the old MAX-lab facility (MAX I-III) at Ole Römers väg in Lund is decommissioned. As part of this project, Studsvik was assigned the task of performing radiological survey, dismantling, waste treatment and clearance of material and the facility.

The objective of the decommissioning and the clearance of both material and the facility was to release the obligations the licensee of the facility has according to the Radiation Protection Act [1].

The MAX-lab Research Facility
MAX-lab consisted mainly of a linear electron accelerator, three electron storage rings used for the production of synchrotron radiation and a photon tagging facility used for nuclear physics experiments. The storage rings were named MAX I, MAX II (part of which is shown in Fig. 1) and MAX III. Facility operations were ended in December, 2015.

The acceleration process mainly took place in three steps. An accelerator system consisting of an electron gun, a linear accelerator and a re-circulator produced electrons and accelerates them to 250-500 MeV. The electrons were subsequently injected into one of the three rings where they were accelerated further reaching 550 MeV in MAX-I, 1500 MeV in MAX-II and 700 MeV in MAX-III. The electrons were stored for hours in the rings. During nuclear physics runs, electrons were continuously injected in to MAX-I and diverted down to the nuclear physics experimental area in the basement.

There were mainly three sources of ionizing radiation at MAX-lab:

1. Electrons lost from the accelerator system produced photons (bremsstrahlung) and neutrons. The radiation stopped promptly as the accelerator was turned off.
2. The radiation mentioned above induced activity in the components of the accelerator and materials nearby. The activation remained after the accelerator had been turned off and decayed with time constants specific to the induced radionuclides.
3. Synchrotron radiation produced in the electron storage rings. The synchrotron radiation stopped promptly as the electrons in the ring were dumped. The energy of the synchrotron radiation was too low to induce activity.

Fig.1. One tenth of the MAX II ring.

The time of operation for the different rings at MAX-lab was as follows (TABLE I):

TABLE I. Operational time for the MAX-lab rings.

Ring	Operational period (year)	Years in operation
MAX I	1986–2015	29
MAX II	1996–2015	19
MAX III	2007–2015	8

A survey of the historical (normal and abnormal) operation that could affect the radiological characterization was performed.

The mean electron power lost in the different parts of MAX-lab accelerators during normal operation is summarized in TABLE II, which indicates that the induced activity present in the MAX II and MAX III areas were significantly less than in the Linac, MAX I and the nuclear physics areas. This was compared to the results of the included surface dose rate measurements, and the results were in good agreement, thus it helped justifying the applied risk assessment.

TABLE II. An estimation of mean electron power lost in the MAX-lab areas for the different operational modes.

Mode	Recirculator (W)	Linac (W)	MAX I (W)	MAX II (W)	MAX III (W)	Nuclear Physics (W)	FEL (W)
MAX I		0.012	0.012				
MAX II	0.014	0.0017		0.01		0.0017	
MAX III	0.028	0.0034			0.021	0.0034	
Nuclear Physics		1.8	0.92			0.92	
FEL	0.0012	0.00012				0.00012	0.001
Sum	0.043	1.8	0.93	0.01	0.021	0.93	0.001

The survey identified four different historical abnormal events that could have affected the radiological characterisation. TABLE III shows estimates of the mean electron power lost in the storage rings during these events.

TABLE III. An estimation of mean electron power delivered to the MAX II and MAX III storage rings for abnormal operations for MAX-lab .

	Area	Year	Duration	Mean Power (W)
Abnormal 1	MAX II	2005	1 y	0.042
Abnormal 2	MAX II	2006	1 y	0.042
Abnormal 3	MAX III	2006	1 y	0.24
Abnormal 4	MAX III	2007	0.5 y	0.34

Radiological classification

Since ionizing radiation was produced at MAX-lab when the accelerators were in operation, and with different levels in different areas, the facility was divided into three radiological classification areas

- Controlled area (high radiation area).
- Protected area (increased radiation levels may be present).
- Normal areas.

After termination of the operation only activation in material, that had already been induced, had to be taken into account during decommissioning. The facility contained no measurable surface contamination. Classification of surfaces at MAX-lab based on its radiological classification during operation is summarized in TABLE IV.

TABLE IV. Classification of surfaces at MAX-lab based on its radiological classification during operation.

Radiological classification	Approx. size (m^2)
Controlled area	1 550
Protected area	6 700
Normal area	100

METHODS

Regulatory framework

The two main Swedish applicable acts related to ionizing radiation and radioactivity is the Radiation Protection Act [1] and the Nuclear Act [2]. The radiation protection provisions are contained in the Radiation Protection Act. The purpose of this Act is to protect humans, animals and the environment from harmful effects of radiation. The law applies to both ionizing and non-ionizing radiation. The Nuclear Act is applicable to nuclear operation and nuclear facilities. MAX-lab is not regarded as such a facility.

Clearance is not explicitly handled in these Acts, but is handled in the Swedish Radiation Safety Authority (SSM) regulation SSMFS 2011:2 [3].

The clearance limits in the Swedish regulation are in line with the EU proposal for new radiation safety directive, also known as Basic Safety Standard (BSS) [4]. The BSS mentions that disposal, recycling or reuse of radioactive substances or material containing radioactivity shall comply with clearance limits determined by the national competent authority.

The Swedish clearance levels are, to a large degree harmonized with the EU RP 113 [5] and RP 122 (part 1) [6], but exemptions exist for some nuclides (both higher and lower levels). When rooms and buildings have been cleared, the building rubble is cleared as well. The Swedish clearance levels for material differ somewhat compared to the clearance levels for building rubble in RP 113.

The prerequisites and basic concepts for the clearance process are given in regulation SSMFS 2011:2 [3]. The measured activity is compared to the clearance levels in the Swedish regulations on clearance SSMFS 2011:2, and the melted metal will after treatment be compared to RP 89 [7].

The formal clearance process differs depending on object type and on clearance type (end state). Conditions, requirements, assessments, actions, decision making, and end state differs depending on if material, room or facility, or land shall be subject for clearance.

Radiological survey

The purpose of the radiological characterisation of the MAX-lab facility was to obtain information about the radiological status of material and rooms, including an assessment of the nuclide inventory and the amount of radiological waste expected during the dismantling.

The radiological characterisation contained pulse and dose rate measurements, as well as nuclide specific analysis of the activity content of material samples. Since loose contamination was not present[1] at MAX-lab, smear test samples were not taken on waste components other than during initial checks (to verify). Cooling water samples were also taken to check for activity.

The measurement types were chosen for each section to optimize the needs during dismantling, waste management and clearance. The measurement types used are

- Dose rate (dismantling, waste management and clearance)
- Scintillation (waste management)
- Smear tests (if applicable for waste management)
- Co-60 measurements (clearance of Low risk material or surfaces)
- Nuclide specific measurements (clearance of Risk material or surfaces)

The measurement results were documented in the database SVALA.

[1] Even though activated metal components were segmented during decommissioning, the amount of loose contamination that could be caused was not significant, as confirmed by surface examination during the radiological survey.

Samples were taken from MAX-lab (metallic parts from the rings, concrete drill core or wall filling material grab samples) and sent to the Studsvik site for nuclide specific measurements.

The radiological characterisation resulted in nuclide vectors for concrete, stainless steel and wall filling material that has been used for the material and facility clearance, either by measuring the main nuclide Co-60 and applying the vector for the remaining gamma emitting nuclides, or by measuring all nuclides in the vector.

QA and Object Tracking

Initial risk assessment and all characterisation measurement results were documented systematically in the database SVALA, so that individual measurement results can be linked to a certain object in a certain section.

A naming convention was used for all objects and rooms included in the characterisation, using unique IDs printed on barcodes placed on the objects in the facility. The IDs were entered in to SVALA-.

In SVALA tracing of waste handling and clearance is integrated for objects included in the characterisation and decommissioning. All measured results from the Radiometric Laboratory, Canberra Colibri and Canberra HPGe-equipment were automatically transferred and included in SVALA. Other project specific documents such as photos, drawings or relevant facility history documents were stored in SVALA.

To avoid clearance of rooms, buildings and land based on false information, it is important to have a well-structured, traceable and scientifically based characterisation and dismantling process.

The requirements of quality assurance and documentation for radiological characterisation and clearance work, is mainly motivated in order to avoid erroneous clearance. In a project, the requirements can have different origin, such as:

- Reduce costs by rational information handling
- Fulfil future requirements by securing the lifetime of the data.

Quality assurance for radiological characterisation, dismantling and clearance work of rooms, buildings, and land is related to both securing the project results (clearance) and that the path to clearance is effective and traceable.

Risk based Approach

A risk based categorisation system was developed [8] to simplify clearance of material, rooms and facilities. For decommissioning the following categories are used:

- Extremely Low Risk
- Low Risk
- Risk

- (Sections/Contamination) Above Clearance Limit

For MAX-lab the last category was divided into two:

- Sections Above Clearance Limit (clearance possible after decay storage)
- Sections not Subject for Clearance (decay storage not applicable)

The room risk categories are seen in TABLE V, and the material risk categorisation is seen in TABLE VI. Fig. 2 illustrates different risk category areas used for walls with filling material. The activation depth was estimated to be about 40 cm in concrete and wall filling material.

TABLE V. Room risk categories at MAX-lab.

Room risk category	**Number of rooms**	**Floor area, m^2**
Extremely Low Risk	157	6 800
Low Risk	5	800
Risk	3	750
Above Clearance Limit	0	0
Not Subject for Clearance	0	0

TABLE VI. Categorisation of metal material risk at MAX-lab.

Material risk category	**Number of rooms**
Extremely Low Risk	157
Low Risk	2
Risk	3
Above Clearance Limit	3
Not Subject for Clearance	0

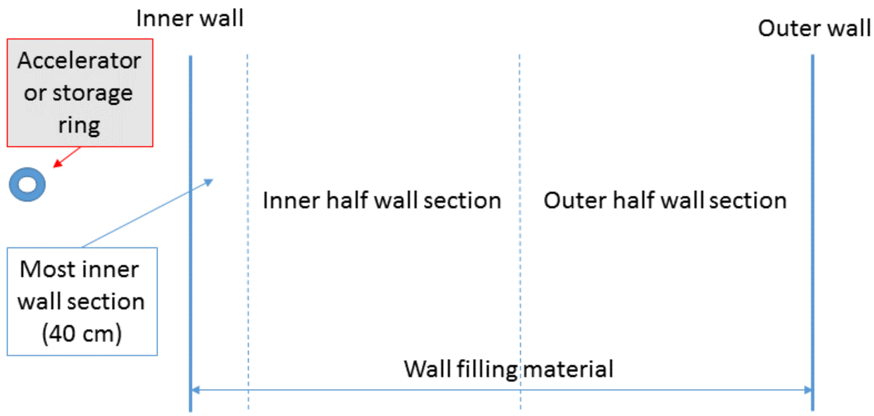

Fig. 2. Naming of wall sections with filling material at MAX-lab, used for material risk category separation in a clearance perspective.

Each room were divided in five general areas with different risk categories, an example is shown in TABLE VII. The risk categories were in some cases revised after assessing radiological survey results.

TABLE VII. Example of risk categories for rooms and material used for dismantling and decommissioning.

	Room ID (description) / Risk categories*			
Areas	A	B	C	D
Vacuum system - in general	OCL	LR	OCL	LR
Next to vacuum system - in general	OCL	LR	OCL	LR
Other material incl. stands	R	LR	R	LR
Room surface closest to accelerator	R	LR	R	LR
Other room surfaces	LR	ELR	R	ELR

*) OCL = Over clearance limit; R = Risk; LR = Low risk; ELR = Extremely low risk, A: M0320B (Injector); B: M0320C (Nucl. Phys. Entrance); C: M0340B (Nucl. Phys. Beam line); D: M0340C (Nucl. Phys. Experiment area)

Dismantling

Safety was the most important factor during the decommissioning and had the highest priority during all activities.

During the decommissioning at MAX-lab the revised risk categories, as in the example in TABLE VII, were used to guide the dismantling. Metallic and some other waste types was packed and shipped to the Studsvik site for clearance measurements or waste treatment. Concrete blocks and wall filling material were handled locally at MAX-lab, including clearance.

Depending on the risk category, the dismantling was somewhat different. Formal clearance was needed for material and room surfaces with risk categories Low Risk and Risk. Agreed risk categories was marked in each room before dismantling started.

Only one risk category was packed in each package. Waste categories were segregated as far as possible in each package. Waste categories were e.g.:

- Carbon steel
- Stainless steel
- Aluminium
- Cable
- Electronics
- Incinerable
- Copper

Waste for melting was shipped ready for melting, i.e., closed rooms were opened and inspected, fluids and gaskets were removed.

Packages for clearance measurements had a target total weight of 990 kg (due to clearance regulation requirements). A photo of each package was attached in SVALA.

All waste, i.e., material for clearance measurements or treatment and packages have a unique ID and were registered in SVALA on a daily basis, as well as all package movements and transports to or from MAX-lab. The unique ID was printed as barcodes and placed on waste or on packages.

Measurements for Clearance of Material (On- and Off-site)

Clearance at MAX-lab was needed for material and rooms within controlled area with judged risk category Low Risk and Risk. Clearance was performed for concrete blocks, wall filling material, and rooms in the facility.

Metallic and other material from controlled area with assessed risk category Low Risk and Risk were sent to the Studsvik site for clearance measurements.

Two methods were used for the clearance measurements at MAX-lab, one for material and one for rooms and objects with odd geometries.

A measurement station for primarily Low Risk material (concrete blocks and wall filling material) was used where NaI probes were connected to a Canberra Colibri device. Co-60 activity was measured, where after a nuclide vector (for concrete or wall filling material) was applied. Calculation of Co-60 activity in concrete and wall filling material was performed by converting the measured pulse rate in the instrument to gamma ray emission rate in the energy interval of 1000 keV to 1400 keV from the measured object. This was considered to result in a conservative measure (overestimate) of the Co-60 content.

Clearance measurements of room surfaces and objects with odd geometries were performed with HPGe-equipment, allowing nuclide specific measurements or MDA determination for all nuclides in the applicable nuclide vector. A surface layer activity model was used for the geometrical modelling and interpretation of the collected data from the HPGe-equipment.

By measuring the Co-60 activity and applying the nuclide vector (concrete or wall filling material) the clearance ratio was calculated. Clearance was allowed if clearance ratio including uncertainty was below 1.

According to clearance regulation, a written control program for clearance of material, rooms, buildings, and land, shall be notified to SSM before the clearance control starts. The control program describes methods and scope of the measurements, samplings and analyses, lists staff competence requirement and contains information about quality assurance, internal audit, and documented results.

Waste Treatment

Treatment of waste material that has been sent to the Studsvik site has been treated during 2016 and will continue under 2017, with the aim of material clearance directly after treatment or after certain decay storage.

Measurements for Clearance of Facility

Clearance of concrete block walls, rooms and facility were compared with two sets of tabulated data in the regulation. Concrete block walls were measured for clearance as material for free use, and the rooms themselves were measured for clearance as facility for free use.

The surfaces in a room could have different risk categories, but a single surface normally had one risk category. Clearance measurements of surfaces and objects with odd geometries were performed with HPGe-equipment. All IDs that were measured were registered in SVALA beforehand.

Two methods were used for the evaluation of the room surface clearance measurements.

Firstly:

Dose to person spending time in the facility is setting the boundary for clearance. This is related to the gamma flux from the material constituting the room surfaces. For reporting of measurement data for clearance a model is therefore used where gamma flux will be lower for activity spread in the material (as in the case of activation) compared to activity bound to or near the surface layer (surface contamination, possibly covered with paint). The clearance measurements were firstly judged against clearance limits for facility for free use.

Secondly:

A room surface found to have been activated to hold an activity per area unit shall still be possible to clear as material for free use (with the activation profile used at MAX-lab [9]), and as a consequence the material could then be used to build a corresponding wall. The clearance measurement was therefore also judged against clearance limits for material for free use. For this comparison, the surface model (room surfaces) was converted in to a volume model (mass specific) more relevant for material.

With the mass specific model a check was performed for each ID against clearance limits for material. Calculations were also done in order for comparison to four scenarios in RP 114 [10]. The scenarios are for clearance of buildings for continuous use as a non-nuclear facility and are

1. External gamma dose
2. Inhalation dose
3. Dose from secondary ingestion
4. Skin dose.
5.

MAX-lab approves the clearance of material from MAX-lab. However SSM approves the clearance of the rooms and building. Approval of the clearance application is needed from SSM before MAX-lab can hand over the facility for free use to the landlord.

Results

Fig. 3 summarizes the flow of material from different risk categories. Decommissioning of normal and protected areas (Extremely Low Risk) at MAX-lab resulted in large quantities of material, handled by an external company (other contractor). Studsvik handled 430 metric tons of Low Risk and Risk material for clearance locally at MAX-lab, and 133 metric tons were sent to the Studsvik site. The Low Level Waste (95 metric tons) were also sent to the Studsvik site for treatment. A small amount (less than two metric tons) needs to be sent for disposal at the national final repository site SFR.

Time schedule

The decommissioning at MAX-lab started with an inventory, data base setup and a radiological survey (Jan. – July 2015). Preparation for decommissioning was performed mostly from remote office during Aug. – Dec. 2015. Studsvik staff was located at MAX-lab from Dec. 2015 until June 2016. The control program for clearance at MAX-lab was sent to SSM in January 2016. An application for the approval of the clearance of the facility was sent to SSM in October 2016.

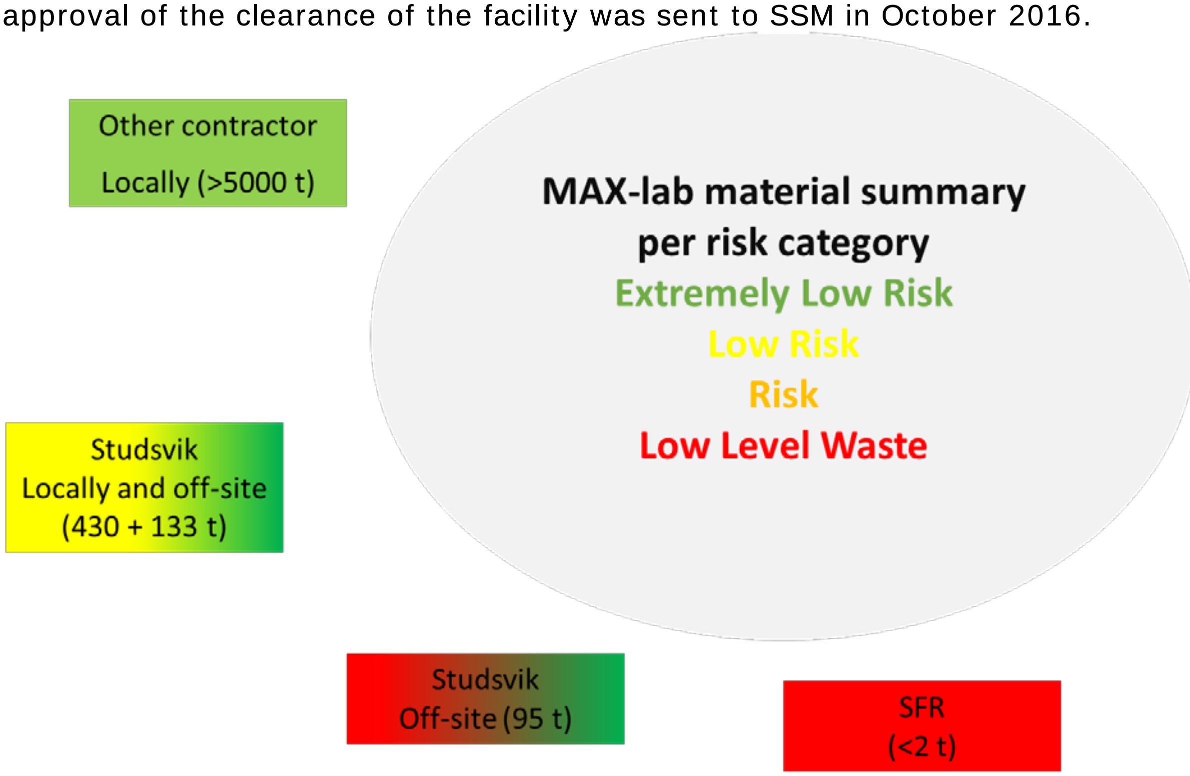

Fig. 3. Risk category material summary from the MAX-lab decommissioning.

DISCUSSION

QA and Object Tracking

The database SVALA was used on a daily basis to follow the actual process of dismantling and moving of objects. Photos and other documents were uploaded daily in SVALA. Project instructions were updated during the project to match how the actual work was performed.

All objects included in SVALA from the radiological characterisation and dismantling shall have a traceable exit, which can be one of the following:

1. Dismantled, measured and cleared at MAX-lab.
2. Dismantled, packed and shipped to the Studsvik site.
3. Moved to other controlled area under supervision of MAX-lab.
4. Re-categorised to Extremely Low Risk, i.e., no need to trace exit or clearance.

The implemented QA system and the documentation setup worked well. Shortfalls were discovered and mitigated. Lessons learned will be helpful in the continuous improvement process. The package photos and the structured handling of the information have proven to be valuable when assessing measurements and other database information.

Risk based approach

The used risk based approach saved time and money for the decommissioning project, since the effort needed could be optimized for each risk category.

Measurements

A combination of local and off-site measurements for material clearance was optimal for the project, minimizing shipment and allowing material flow out of the facility on a daily basis.

Waste treatment

Waste with category Low Level Waste and material (other than concrete blocks and wall filling) for clearance measurements was sent to the Studsvik site during the dismantling period.

Clearance of material and facility

Smaller sections (total area about 40 m^2) of floor/ceiling in two rooms, with activity above the clearance limits were removed from its original position in the facility, leaving only rooms at MAX-lab ready for clearance for free use. Any additional measurements are not to be performed on the remaining room surfaces, it is assessed that existing data is enough to ensure that activity levels are below the clearance limits. Instead the removed sections were shipped to the Studsvik site for new measurements / decay storage before clearance as material for free use.

Nuclide specific measurements with HPGe-equipment reported measured values or calculated MDA for all nuclides in the used vector. Most of the Low Risk packages should be subject for clearance, with a few exceptions. The clearance quota calculation is conservative for many packages since the MDA-portion is larger than from measured activity.

For each of the measurement locations, the clearance quota have been calculated in several ways (measured activity, MDA and total for facility for free use and for material for free use). An uncertainty (representative of reported Co-60 measurements) was added to the measured activity values.

The clearance of concrete blocks and wall filling material generally worked very well, allowing flow of material out of the building on a daily basis. Measured packages could normally be reported for clearance the following day, the data evaluation followed a routine where assessment was compiled using an Excel script and Canberra Colibri data files.

Comparison with RP 114

The following RP 114 [10] cases were considered to justify the clearance of MAX-lab and in order to compare to clearance levels in SSMFS 2011:2:

1. External gamma dose
2. Inhalation dose
3. Dose from secondary ingestion
4. Skin dose.

The comparison is made for each of the nuclides in the concrete nuclide vector, and relative the re-use scenarios for buildings. External gamma dose is the worst case for each of the included nuclides. The calculation show that several measured locations will have an annual dose in the range of 10 µSv. Single measurement locations can have clearance quota less than 1 and dose contribution slightly exceeding 10 µSv per year (but not exceeding 20 µSv per year) (this is related to the round off of the clearance values and does not raise any concerns).

CONCLUSIONS

Decommissioning and facility clearance has been performed for the MAX-lab facility, using the concept, techniques, and equipment described in [11].

Activity above the background level has been measured on concrete surfaces in several facility locations. Activity levels under as well as over the clearance level, for buildings for re-use have been measured. The measured activity levels are in line with the operating history of the MAX-lab facility. A few concrete floor / ceiling sections have been removed from its original position in the facility. The remaining facility contains activity below the clearance level.

Material, radioactive or potentially radioactive, has been sent to the Studsvik site for treatment. In some of this material, radioactivity significantly above the clearance levels have been measured. The results of the measurements are generally in accordance with expectations, taken the facility operating history into account.

All the material sent to the Studsvik site has or will be treated as radioactive waste until, where applicable, clearance measurements have confirmed that the clearance criteria have been met.

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