Nuclear Safety

Decommissioning of a Uranium Reprocessing Pilot Plant
- practical experiences

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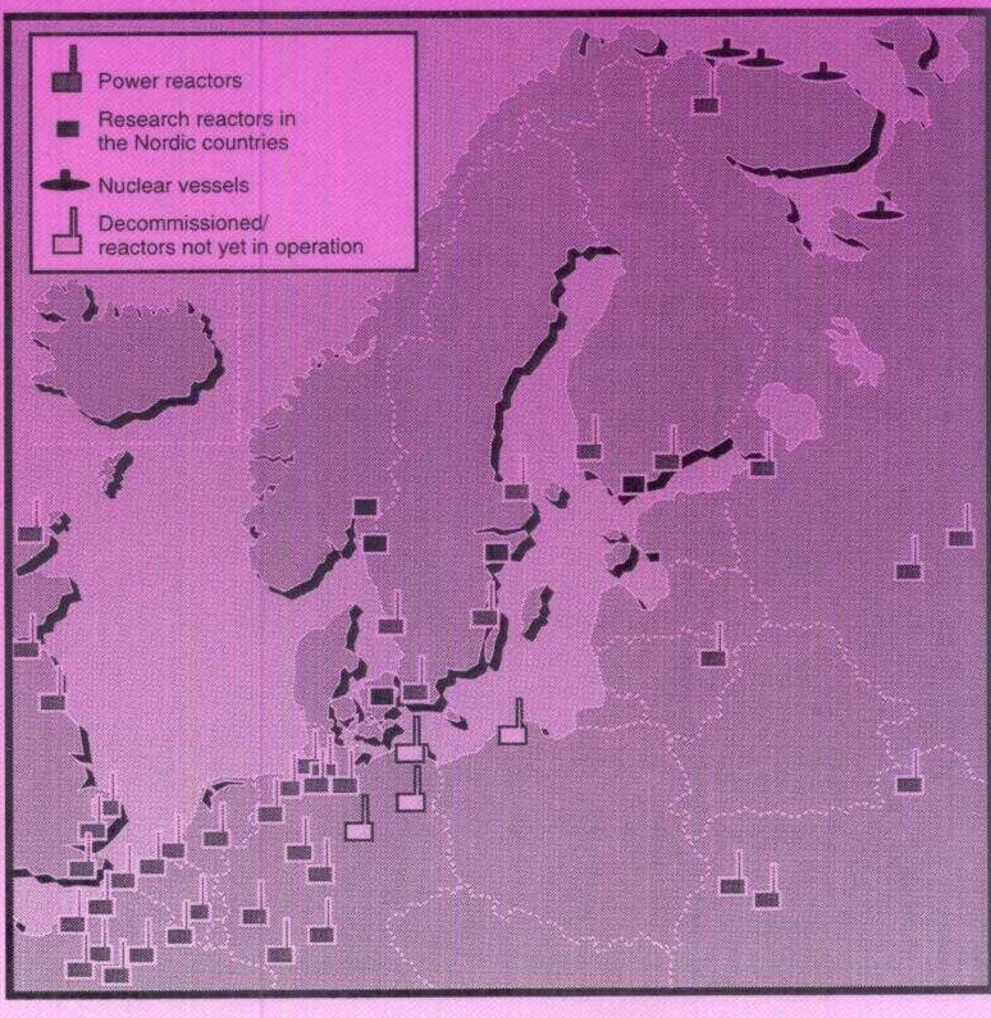

Decommissioning of a Uranium Reprocessing Pilot Plant

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- practical experiences

Final Report of the Nordic Nuclear Safety Research Project KAN-1.2

John Erling Lundby
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The Nordic Council of Ministers
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Abstract

Dismantling of the process equipment in the Uranium reprocessing pilot plant at Institutt for energiteknikk, Kjeller in Norway has been in progress during the last few years and is now nearly completed. The Kjeller pilot plant went into operation in 1961 and the emphasis was put on reprocessing of fuel elements from the research reactor JEEP I and experimental activities. After shut-down in 1968 a one year dismantling period took place in 1982 - 1983, and the work was resumed in 1989 and will be completed in 1994 - 1995. The main objective was to remove the essential part of remaining radioactive materials and equipment so as to permit reuse of the building for radwaste work.

In most cases internal decontamination of the process equipment was not profitable, even when its possible reuse as inactive material was considered. On the other hand, mechanical surface decontamination of shielding blocks shows a profitable result. The secondary amount of waste arisings is important when deciding whether decontamination or direct packing is favourable.

It is also important to pack the waste as tightly as possible and this has given a reduction to half the original calculated waste volume.

Key words:

- Chemical decontamination
- Decommissioning procedures
- Mechanical decontamination
- Packing of radwaste
- Protective clothing
- Tools for dismantling operations
- Uranium reprocessing pilot plant

Summary

A pilot plant for reprocessing of irradiated fuel was operated at Institutt for Atomenergi (IFA), now Institutt for energiteknikk (IFE), Kjeller/Norway, during the years 1961 - 1968. In this period about 1200 kg of uranium were processed, and plutonium and fission products separated by means of liquid-liquid extraction. The plant comprised a tube system of more than 6000 meters, and a total of 50 tanks, evaporators, and extraction columns.

Two words that repeatedly are used in this report may need some further explanation. They are contamination and decontamination. When radioactivity is spread on surfaces or has penetrated into the material, it is called contamination. If practical, the surfaces are cleaned from radioactivity, i.e. decontamination.

The plant was shut down and partly decontaminated in 1968, but decommissioning proper was not carried out until 1982, and then again during the period 1989 - 1993. The experience from decontamination and dismantling of the plant is reported by the decommissioning team that performed these operations. A reprocessing plant is contaminated by radioactive solutions, but due to the absence of neutrons, there is no activation of the construction material like in a nuclear reactor.

The purpose of the operations was to remove radioactive and contaminated material so that the building could be reused for radwaste work. This requires decommissioning to "stage 3" and "stage 2" according to IAEA nomenclature.

The main part of the radioactive deposits inside the process equipment were removed with chemical solutions during three consecutive decontamination steps after shut-down of the operation. Remaining liquid in the tubing is a source of contamination during dismantling operations. This can be dealt with by means of special tools. The next step was dismantling of process equipment. Before starting, safety procedures were issued, and alternative strategies for handling waste were conceived. For the dismantling phase, many tools needed to be specially adapted to the difficult cutting operations that must take place in narrow cells.

The total dose to the operating crew could be kept as low as 50 milliSv because most of the radioactive deposits had already been removed. It has been a major concern to prevent the intake and inhalation of radioactive deposits, especially alpha contaminants.

It is important to generate as small a waste volume as possible in the decommissioning process. For the major part of this installation it turned out that less waste is obtained by avoiding wet methods, since considerable secondary waste volumes would be generated. Several factors such as labor cost and the cost of intermediate and final waste disposal must be considered before deciding how far decontamination should be pursued, or whether direct packing of partly decontaminated equipment would be preferable. Melting of metal parts for recycling could have been an interesting alternative, but this was not pursued since no such installation is available in Norway. Measuring techniques permit to verify the interior of thin process tubing

typically used in radiochemical installations, but this requires tubes to be cut in adequate lengths.

In general, reuse of decontaminated metal turned out not to be profitable, keeping in mind the low scrap value of the metal and the complications encountered in obtaining clearance from radiological control. The volume of solid waste can be kept low by careful planning, reasonable cutting, and tight packing. Using boxes instead of drums for storage of the waste further reduces the volume. On the other hand, lead shielding blocks can be decontaminated for reuse as shielding material, using a dry process by means of mechanical milling.

The availability of members of the original operation crew has been a great help during the decommissioning operations, and without the knowledge of the operation crew the work would have been far more costly and complicated. One lesson learned is that conservation of all essential written information, drawings etc. is an obligation that must be recognised by plant management during the operational phase, and that strict control of this material is essential when decommissioning is delayed for a longer period.

Sammenfatning

Et pilot-anlegg for rensing av bestrålt uran var i drift ved Institutt for Atomenergi (IFA), nå Institutt for energiteknikk (IFE), på Kjeller i Norge i årene 1962 - 1968. 1200 kg uran fra JEEP-I reaktoren ble behandlet, og plutonium og fisjonsprodukter ble separert ved hjelp av væske-væske ekstraksjon. Anlegget hadde et røropplegg på ca. 6 km, 50 tanker og inndampere, ekstraksjonskolonner, faseseparatorer og diverse prøvetakingsstasjoner.

Da driften opphørte i 1968 ble anlegget delvis dekontaminert (renset), men demontering ble først igangsatt i 1982 og pågikk i ett år. Demontering ble gjenopptatt i 1989 og har pågått ut 1993. De praktiske, tekniske og sikkerhetsmessige erfaringer, pakking av avfallet, dekontaminering, avfallsbehandlig og økonomibetrakninger er beskrevet i denne rapporten. Hensikten med demonteringen var å fjerne radioaktivt forurenset materiale slik at bygningen kan gjenbrukes til behandling av radioaktivit avfall og tilknyttet virksomhet. Dette krevde en demontering og rensing til "trinn 2" og "trinn 3" etter IAEA's regelverk. Før start av selve demonteringen ble det utarbeidet sikkerhetsforskrifter og arbeidsreglementer, likeledes alternative strategier for behandling av det radioaktive avfallet som oppstår. Fremskaffelse og tilpasning av riktig verktøy til de forskjellige demonteringsoperasjoner er også en viktig del av forberedelsene selv om det må justeres og tilpasses underveis.

Radioaktiviteten som hadde festnet seg på innsiden av prosessutstyret ble så langt som mulig fjernet med kjemiske løsninger ved tre dekontamineringsprosesser etter driftsstans. Gjenstående væskerester i rørsystemene kan være opphav til kontaminering (uønsket spredning av radioaktivitet) under demonteringen, men det unngås ved bruk av spesielt tilpasset verktøy. Den totale dosebelastningen til rivingspersonellet er målt til 50 millisievert som er relativt beskjedent i en så omfattende jobb, og som skyldes den foretatte kjemiske dekontamineringen.

Det er viktig at avfallsmengdene holdes på et minimum og det er derfor lagt vekt på å pakke metallkonstruksjonene (rør, plater, stativer stålprofiler etc.) tettest mulig med prinsippet rør i rør. Bruk av firkantede kasser til pakking istedenfor tønner og en tettest mulig pakking har redusert det beregnede avfallsvolumet til omtrent det halve. Det viste seg at rengjøring av metalldeler ofte medførte større avfallsmengder enn volumet av selve gjenstanden, og det er derfor viktig at personellkostnader og lagringskostnader for avfallet blir nøye gjennomgått før en dekontaminering blir iverksatt. Den radiologiske kontrollen for å tillate metallskrapet frigitt til almen bruk kan være komplisert, dessuten er skrapverdien liten. Måleteknikk for å kontrollere radioaktivitet på innsiden av prosessrør med liten diameter er utprøvd, men det krever nedkapping av rørene i mindre lengder. Mekanisk dekontaminering av bly- og betong skjemingsblokker har gitt en lønnsom dekontaminering.

Deltakelse av personell som var med i oppbyggingen og driften av anlegget har vært av stor betydning under rivingsoperasjonen, og ville i motsatt tilfelle ha medført store ekstrakostnader og komplikasjoner. Det er viktig at skriftlig informasjon og konstruksjonstegninger oppbevares på en tilfredsstillende måte og at det delegeres ansvar for oppsyn med et nedlagt radioaktivt anlegg, spesielt hvis demonteringen blir skjøvet inn i fremtiden.

Acknowledgement

The project leader wishes to thank all persons who have been involved in the practical decommissioning operation as well as the Nordic research programme NKS/KAN-1.2 project, cfr. Appendix A. Especially I wish to thank Mr. Franz Marcus (Nordisk Kjernesikkerhetsforskning, Roskilde, Denmark) for good support during the editional phase of the final document.

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Last but not least I appreciate very much the work done by our secretary, Nina Wiig Holmedal, during the preparation of this document.

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Kjeller, 27. May 1994
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Project leader

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1 Introduction

The Norwegian-Dutch reprocessing pilot plant at Kjeller, Norway, (fig. 1) went into operation in 1961. The emphasis was on experimental processing of natural uranium fuel elements from the research reactor JEEP I, and testing of the "Purex" process, equipment, instrumentation and various flow-sheets, especially for Eurochemic in Mol, Belgium. Another objective was to obtain operational experience and know-how for the design of a full-scale plant. The Swedish "AB Atomenergi" completed an additional facility in 1964 with the intention to study a separation process using a silica gel column. The Norwegian-Dutch "Purex" part and the Swedish "Silex" part were connected in 1964 to increase the purification capacity. The plant is described in /1, 2/.

The plant was shut down and partly decontaminated in 1968. The dismantling was delayed due to economic reasons and re-started in 1982 for a one year period /3/. The work was resumed in 1988/1989 /4, 5/ and will be completed in 1994/1995.

The need to collect the experience from the decommissioning of the Kjeller reprocessing pilot plant was recognized in the Nordic research programme NKS 1990-1993. Here the project KAN-1.2 was carried out with the objective to document the decontamination and decommissioning experience and to draw conclusions on preferable decontamination practices. In order to achieve this, decommissioning operations and the related research programme were adjusted to each other.

Evaluations, recommendations and conclusions drawn in this report are based on the experience gained during practical dismantling work of this pilot plant and through laboratory tests. The best way to make the experience known in such an operation will be by photographing, and this documentation is therefore illustrated by a large number of pictures.

Figure 1 The Reprocessing Plant at Kjeller

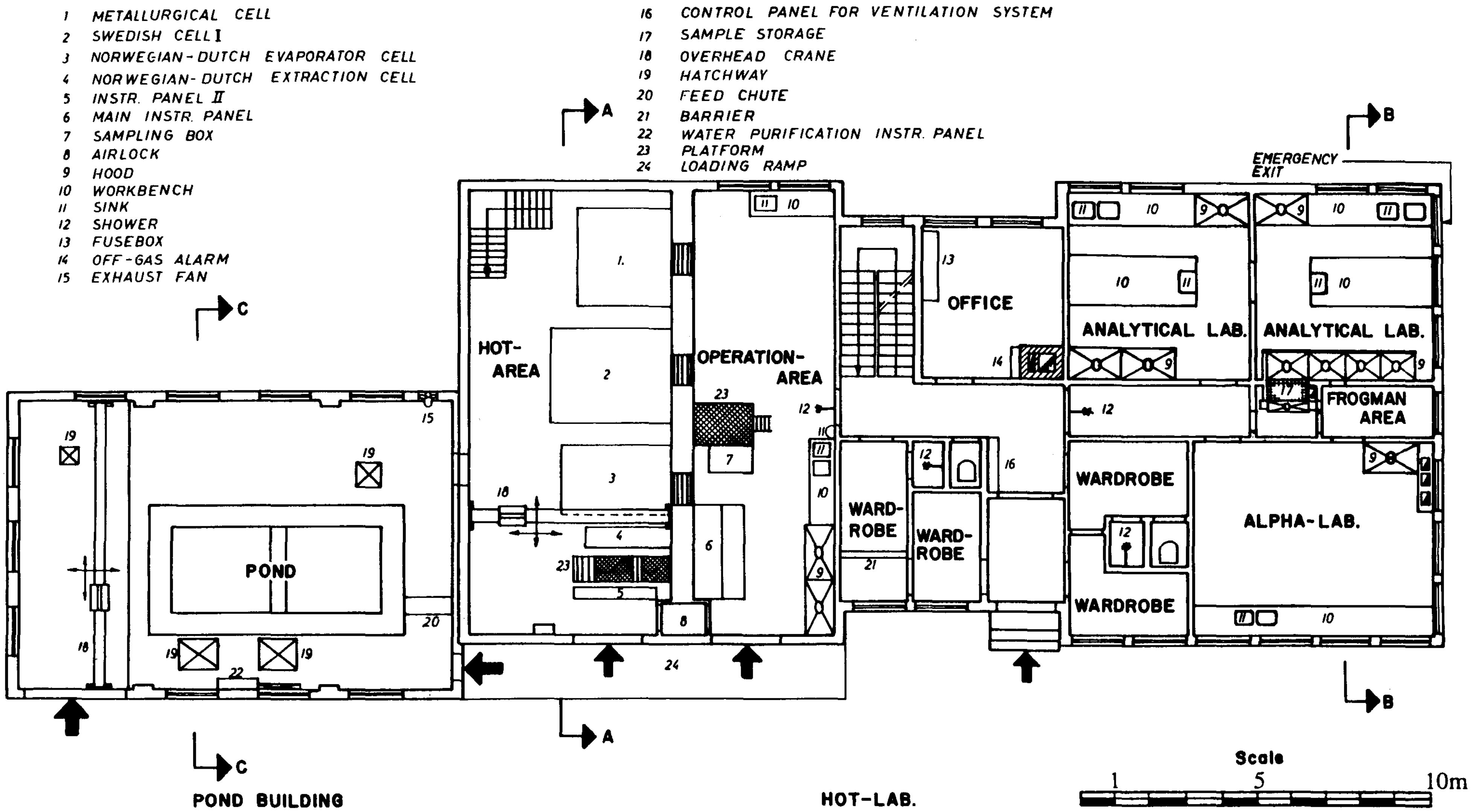


Figure 2 Reprocessing plant. Ground-floor plan

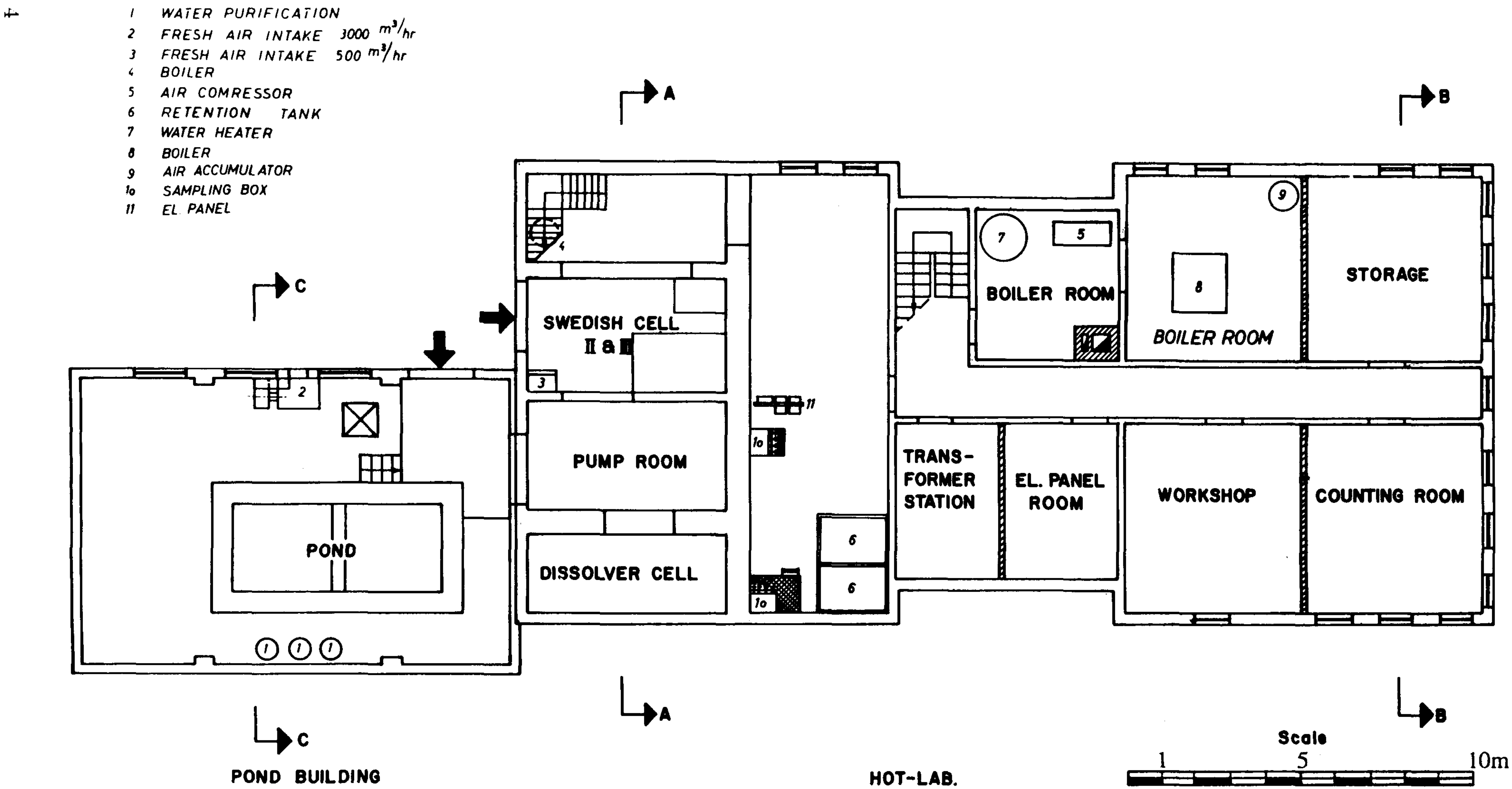


Figure 3 Reprocessing plant. Basement plan

Figure 4 An exposed cell

2 The Plant

The pilot reprocessing plant is shown in figure 1 as it was in 1968 after shut-down. The left cubical part was the Pond building where the aluminium canning was mechanically removed from the irradiated uranium elements. To the right of the pond was the Hot cells arrangement with extraction-, evaporation-, and purification cells on the ground-floor. In the basement were the dissolver cell, pumps to extraction columns, and purification cells. The right hand part of the building contained analytical laboratories, wardrobes, offices and auxiliary equipment. The lead and concrete shielded cells (cfr. figures 2, 3 and 4 on previous pages) were located in a two-storied building which was directly connected to the waste treatment plant.

2.1 Equipment

Equipment for dissolution of irradiated uranium elements and for subsequent extraction and evaporation was located in six concrete cells. There were a total of 47 vessels and evaporators, 9 extraction columns, and in addition phase separators and various sampling stations, filtres etc. Lead blocks were used to provide additional shielding. There were 6000 meters of process piping of stainless steel with an average diameter of 19 mm. All cells were enclosed in metal sheet housings and provided with "drip trays" of stainless steel in order to contain possible leakages and to protect the concrete from contamination.

2.2 Decontamination and radiation levels

After the shutdown in 1968 the plant had been drained for all radioactive solutions and then internally decontaminated using warm nitric acid and sodium hydroxide. From an all-over radiation level of about 20 mSv/h, the dose rate was brought down to 1-2 mSv/h or lower, measured at close distance from most of the process equipment at the "outer edges" of the plant /6/.

A further decontamination with oxalic acid/tartrate reduced the levels to 0.15 - 0.3 mSv/h.

In 1982 it was decided to start complete dismantling of the plant. The main objective was to remove the essential part of remaining radioactive materials and equipment so as to permit reuse of the building. The intended use of the building was for radwaste work.

A thorough survey of the radiation and contamination levels of all areas and components of the plant was then performed. The survey was made after the removal of all non-radioactive parts in order to obtain better access to the areas that contained the most radioactive components.

The dose rates measured were not significantly different from what had been found in 1968, but better access to active parts revealed dose rates up to about 10 mSv/h at some "hot spots".

The contamination levels were generally below detection limits on the floor, but on "drip trays" below process equipment, beta levels of up to 5000 Bq/cm^2 and alpha levels of up to 500 Bq/cm^2 were detected. The average activity was a factor of twenty lower.

3 Planning of decommissioning. Safety measures and radiation doses

3.1 Stages in decommissioning

The IAEA has defined three stages in decommissioning of research reactors/7/, and these have been adapted to the actual case.

STAGE 1 Storage with surveillance

During this stage, excess of radioactive/contaminated materials and non-essential systems are removed. Systems containing radioactive material shall be in a stable and sealed condition.

STAGE 2 Restricted site use

This stage involves a further decommissioning, without going to complete dismantling. It comprises areas that can be readily decontaminated down to levels of radioactivity below authorized limits for unrestricted use.

STAGE 3 Unrestricted site use

In this stage the decommissiong is completed, leading to the release for unrestricted use. All materials and structures in or on which radioactivity are present above authorized limits for unrestrictive access are removed to a storage or disposal facility.

3.2 Planning

The purpose of the decommissioning was to bring various parts of the pilot plant (cfr. figure 2 and 3 on page 3 and 4) to stages 2 and 3, respectively. Some areas were to be used for waste treatment operations, while others were to be brought to stage 3 for radioactive laboratory work and for non-radioactive work.

Dismantling of the plant was a new challenge to IFE although the Institute had gained some experience with the dismantling of research reactors. Visits to the Eurochemic plant in Mol and the Kernforschungszentrum in Karlsruhe gave information of great value in the planning of the work.

From a radiological point of view, the overroling aspect in preparing the dismantling work was to prevent the intake of radioactive materials, to keep the exposure as low as possible, and to avoid the spread of contamination to clean areas.

To achieve this goal in practice, detailed working instructions were issued. These included access to the building and plant areas, use of special wardrobes, change of clothing, wearing mandatory protection equipment, routine radiation protection monitoring, and specific procedures for the work including handling and dismantling of components.

The general ventilation of the dismantling areas was secured by using the original, but still intact ventilation system of the plant. In addition, spot ventilation was used where the risk of inhalation of airborne contaminants was assumed to be high.

The process cells and adjacent areas were relatively narrow and crowded by equipment. In order to reduce contamination of the nearby areas, it was decided to complete the disassembly of one cell or area before proceeding to the next.

Normally two persons at a time were to deal with the dismantling. No one was allowed to work alone.

3.3 Radiation protection monitoring

The radiation protection of the dismantling workers aimed at a) reducing the exposure to external radiation to the lowest practical level, and b) preventing the intake of radioactive materials in the body.

In addition to standard film dosimeters, TL-dosimeters were used for finger monitoring, but has shown to be of minor importance. Also direct reading dosimeters were worn for "personal use" during the work.

Air contamination was controlled by portable monitors for beta and plutonium activity. Only traces of activity have been recorded, and only during the first dismantling period.

3.4 Radiation doses

External exposure

The dose rate levels in the plant were generally so low that they did not present any special problems. As the work was proceeding there was close communication between the dismantling workers and the radiation protection staff. Practising on inactive components prior to dismantling has contributed positively to the actual low exposure records.

The table below shows the recorded doses from film dosimeters, expressed as *effective dose*, and expected dose from remaining work.

Decommissioning work (including waste treatment)	46 mSv
Remaining work	4 mSv
Total	50 mSv

It is difficult to correlate the received doses to specific work situations since they were not measured for that particular purpose. A total of ten persons have been involved in the actual decommissioning work for shorter or longer periods, see Appendix 1. The highest total dose received by one operator was 10 mSv.

Internal exposure

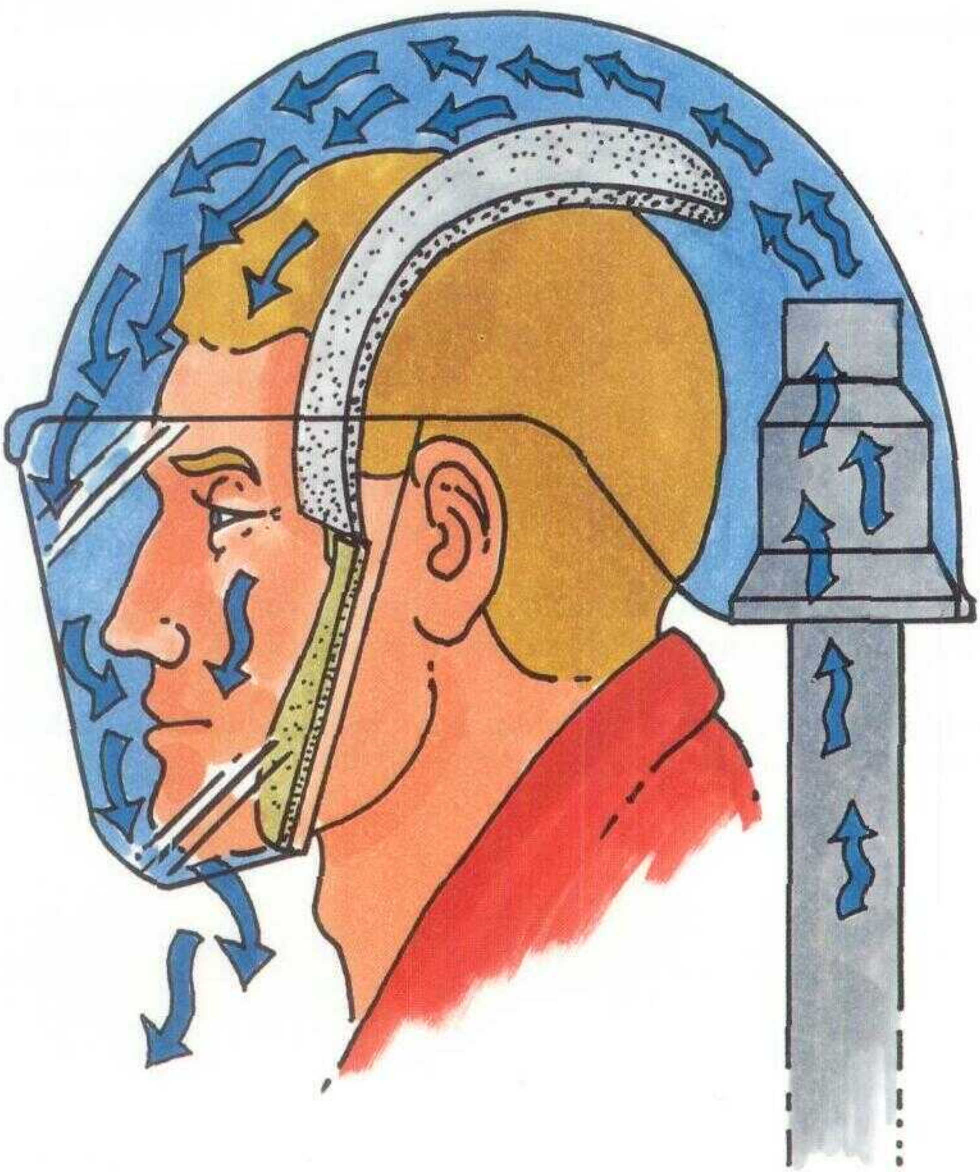
For the prevention of intake of radioactive materials, the inhalation risk has been of greatest concern, but also the ingestion risk has been taken into account. Ingestion was avoided by instructions for change of protective clothing, washing, and monitoring of skin (hand) contamination when leaving the active area.

In most operations the general ventilation system of the building was supplied with spot ventilation, and this was regarded as sufficient to control the inhalation risk. But in operations where the dust risk was assessed to be high, dust masks or air stream helmets (figure 5 on the next page) were used.

Intake of activity was routinely controlled every second month by wholebody monitoring and radiochemical analyses of urine samples.

The wholebody monitoring revealed only small amounts of 137-Cs. The resulted effected dose has been estimated to be below 0.1 mSv.

The urine analyses have primarily focussed on plutonium, but no samples have had concentrations above detection level ($\leq 1 \times 10^{-5}$ Bq/litre).



This protection helmet is used to avoid the inhalation of radioactivity. Pressurized air is led into the back of the helmet. The clean air is passed over the wearer's head and gently directed down over the face providing a refreshing flow of air to breathe. An advantage is that spectacles can be used without dewing.

Figure 5 Airstream Anti-Dust Helmet

4 Decommissioning procedures

4.1 General

The first step in a decommissioning operation is acceptance of all safety and protection procedures. Thereafter planning of the practical approach can take place. Several procedures have to be specified and some examples are given below.

Organization, responsibility and management must be clearly defined. A decommissioning procedure is a wholly practical and technical operation, and successful completion depends upon the presence of a qualified and well motivated work staff. In the early phase of the process the complete planning must be outlined. However, it is more or less impossible to foresee in detail the problems that will arise, and therefore the operation must allow improvising with respect to the original plans.

Wardrobes, protective clothings and control- and safety procedures must be ready beforehand, and the selection of tools is important. Anti-dust helmet and mandatory clothing worn by the operators are shown in figure 6 on the next page. Handling of material, active or inactive, must be prepared. The type of waste containers to be used will depend on packing methods and the possibility of cutting metallic components into smaller parts.

If severely contaminated metals are to be decontaminated, alternative methods should be investigated, since such surfaces may turn out to be difficult to clean. For dismantled parts that cannot be packed in situ, temporary storage areas must be arranged.

A convenient way to start decommissioning work is first to dismantle abundant inactive components, and thereafter approach areas/components with increasing radiation levels. Due to the risk of contamination it is of importance that dismantled parts are removed from the working zone as soon as possible. If more hot cells are to be dismantled, they should be completed one at a time.

The practical way to approach a hot cell is first to remove the outer shielding (normally concrete), which is shown in figure 7 on page 15. Thereafter the metal sheet housing has to be dismantled (se figure 8 on page 16) before the cell can be entered and the equipment removed. The principle for dismantling of the cell equipment is to start at the easiest accessible point and move forwards into the cell by cutting the pipework bit by bit, and subsequently to remove other items.

A decommissioning operation must be performed as a team work. In order to solve the various practical and technical problems encountered it is useful to engage the crew in group discussions. Hereby inovative suggestions are often brought forward. In the decommissioning project described here the knowledge of the operation crew has been of great importance, and the presence of members of the original plant staff was of great help. Without their assistance, the work would have been much more costly and troublesome. If decommissioning is delayed for a longer period, the availability of all written information, drawings etc. must be assured /8/.

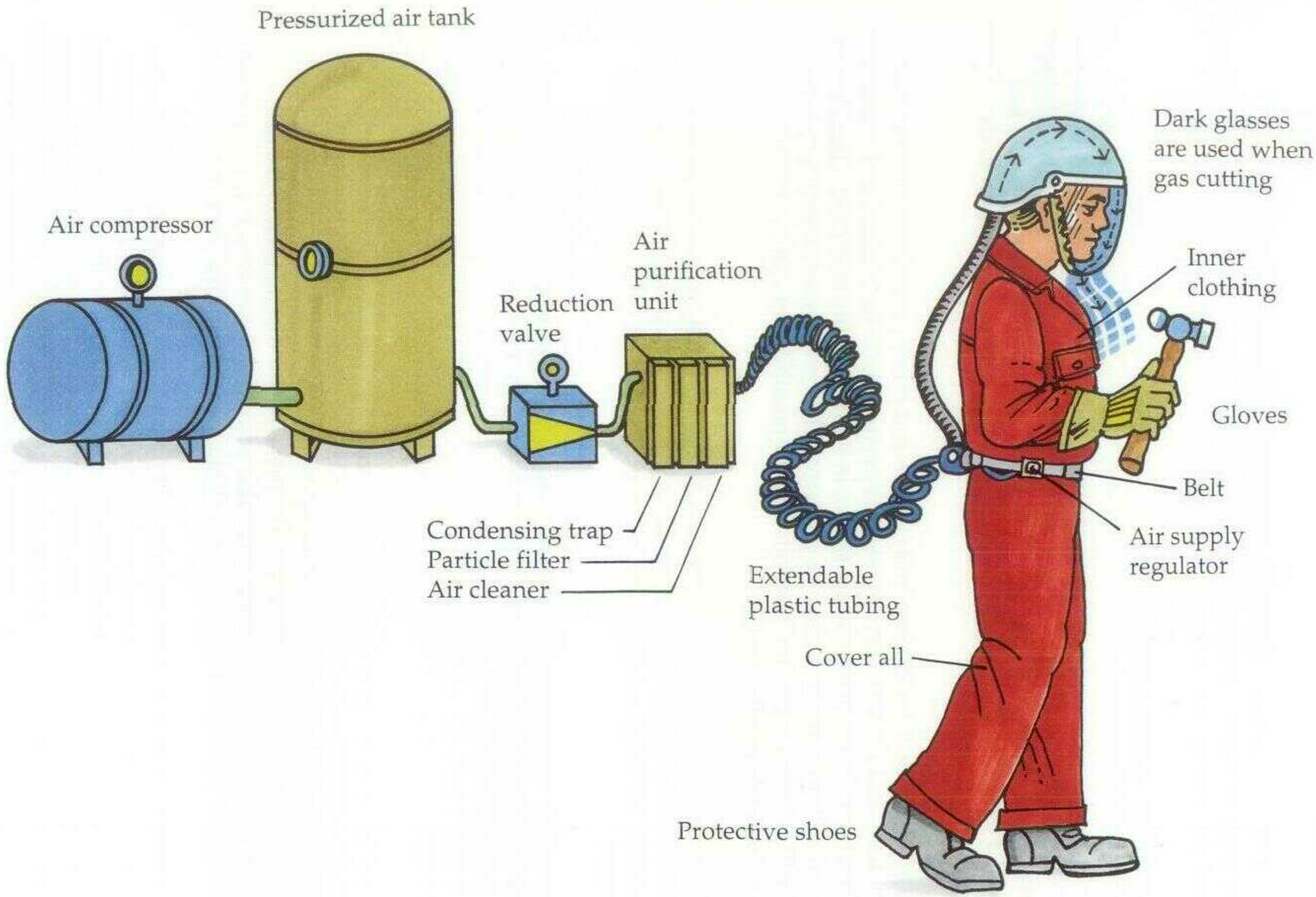


Figure 6 Anti-dust helmet and mandatory clothing worn by operator

Figure 7 Removal of concrete shielding blocks

Figure 8 Removal of metal sheet housing

Dismantling of process equipment and of shielded cells is a physically tough job. A good health condition of the operators is a necessity since lifting heavy components and difficult working positions occur frequently.

It is recommended:

- that instrumentation and ventilation equipment be kept in operation as long as possible
- that cutting, shearing and packing of active components be done inside the decommissioning area
- that spot ventilation be used to prevent the spread of dust
- that there is a strict definition of the working zones with respect to the degree of contamination possibilities to avoid cross-contamination
- to wash and clear the working area daily and to pack and remove the produced waste for further treatment.

4.2 Complications

Some construction features turned out to complicate decommissioning.

Joints in extraction and evaporation cells had been connected as screwed and flanged systems When dismantled, they showed that leakages of radioactive liquids had occurred. These had caused outside contamination of the process equipment so that it had to be handled carefully to avoid inhalation of alpha contaminants (uranium and plutonium). The majority of the joints in the "Silex" part were welded, and here only a few leakages were observed. Screwed or flanged joints are thus not suitable for components exposed to thermal gradients if they cannot be inspected daily.

Piston pumps used for pulsation of the extraction columns had caused high contamination in parts connected to the pumps and in the pump enclosure. In other parts of the plant all pumps for radioactive liquids were of the double membrane type and had no flanged joints except near the active dosage heads. This part was placed inside fitted boxes equipped with leakage alarms, and this construction caused much less contamination problems.

As mentioned in the following chapters, explosive drilling clamps were available to drain U-pipe constructions. Unexpectedly, other parts of the pipe lines could also contain liquids, so that cutting would result in a spurt. Additional awareness of this phenomenon is mandatory.

5 Special tools

The tools described here are shown at the end of the chapter, see pages 23 - 46.

Whenever practical, standard commercially available equipment and tools can be used for decommissioning. Thus, where industrial safety aspects are of less concern, conventional tools are used, such as

jigsaw, for cutting sheet steel and pipe lines
nibbler, for cutting sheet steel
bolt cutters, for cutting electric cables, pipelines, etc.

Work with standard tools within temporary containment systems can be difficult and potentially hazardous. Also, modifications may have to be made to enable tools to be operated safely and efficiently by workers wearing protective clothing /9/. A range of tools can be adjusted including /10/ cutting tools where sections of the cutting part would normally be unprotected ("hands-off" tools), dismantling tools, lifting aids, etc. Some of these are described below.

5.1 Tool for removal of concrete blocks

5.1.1 Riveting punch/chisel hammer

Concrete shielding blocks joined together by grout can be removed by using a strong chisel hammer with flat chisel, as shown in figures 9 and 10. The riveting punches/chisel hammers are air operated.

The inner housing of a hot cell is normally constructed of sheet steel fastened to a framework. The sheet steel may be welded or joined by riveting. For removal of rivets a riveting punch/chisel hammer is very effective. This tool is shown in figures 11 and 12.

5.2 Drainage of U-pipes

5.2.1 Explosive drilling clamp

Even after several years of forced ventilation of the pipe lines, liquids were found in the bottom of U-pipe constructions. To remove the excess liquid before dismantling two methods can be used:

- Drainage by an explosive drilling clamp
- Emptying by suction (vacuum)

The two alternatives are illustrated in figure 13 a and 13 b, and the princip shown in practice in figure 14.

The removed liquids can be a mixture of process- and decontamination fluids, and the chemical composition is therefore somewhat unspecified, but the amount is relatively small. They can be solidified using cement with additives.

5.3 Devices for cutting of pipes, framework and sheet steel

5.3.1 Clamp-cut device

When alpha-activity is present in process piping, there may be a risk of inhalation during dismantling. A clamp-cut tool was modified in order to lock the pipe ends. The method was difficult to use by hands alone because the equipment was too heavy. A counter balance could be used, but amongst tightly packed process equipment that was less practical. The clamp-cut knife is shown in figures 15, 16, 17 and 18. It has a pneumatic/hydraulic drive. The maximal diameter that can be cut is 21 mm.

5.3.2 Hydraulic cable cutter and blowing wedge

As the name indicates, this tool is developed for cutting electric cables, but it is also well fitted for cutting steel pipes with a diameter up to 50 mm. This cutter works much quicker than the one previously mentioned, but it does not close the end section of the pipe. For this reason it is used for cutting low-contaminated pipework such as condensate lines, steam lines, exhaust lines, lines for decontamination systems, etc.

An advantage of using these hydraulic cutters compared to the plasma arc cutter that is described later, is that no steel chips or slag is formed during cutting. For both of these cutters, extended work space is required around the pipe lines to be dismantled, and the cable cutter is opened and closed by a movable part that must be operated from the front side before cutting. If the area is too narrow, a hydraulic blowing wedge may be used to make the access more convenient. The hydraulic cutter is shown in figures 19 and 20, and the blowing wedge in figure 21.

5.3.3 Hydraulic shear

This tool is originally conceived as a rescue shear to free people that are trapped in car accidents. An advantage of this shear compared with the cutters mentioned above is that it can be operated with access from one side only.

The hydraulic shear cuts through stainless steel pipes with a diameter up to 100 mm depending upon the thickness of the material. The shear is heavy and must be operated by means of a counter balance. Actual situations where use of this shear is practical are shown in figures 22 and 23. Slag and steel chips are not formed during cutting.

5.3.4 Angle grinder

Angle grinders of different sizes have been used to a great extent in cases where spread of dust and radioactive contamination could be disregarded. The angle grinder is practical for removal of radioactive spots in sheet steel and for cutting metal-profiles and inactive pipe lines. An example of such an operation is shown in figure 24. Precautions must be used to avoid inhalation of dust and to reduce noise when cutting.

5.3.5 Electric saws

Portable as well as stationary circle saws have been used and examples from these operations are shown in figures 25 and 26. 1/2" pipe lines can be cut in 20 seconds by the mobile saw. Metal chips are easily collected below the working place in wet absorbing paper or plastic bags.

The stationary circle saw is placed in a glove box and is used for cutting highly alpha-contaminated items, in our case the extraction columns. The saw has been used for cutting double pipe lines with diameters up to 65 mm, square profiles of 55 x 55 mm and flat iron of 70 x 45 mm. The saw is cooled by a fluid whereby spread of airborne contamination is avoided.

5.3.6 Plasma arc cutting

Most electric conducting metals and alloys can be cut by the plasma arc. In the actual case, experience was obtained from cutting stainless steel, carbon steel and aluminum. Air has been used both as plasma gas and cooling gas.

The plasma arc is suitable for sectioning of unpainted metal sheets and channel sections that normally are the constructive parts of a hot cell. Up to 10 mm thick steel can be cut without problems, and it is reported /11/ that up to 7.5 cm stainless steel and 13.8 cm carbon steel have been cut.

It is important to protect operators against inhalation of the toxic nitrous gases and slag dust that is formed when cutting in open air. Spot ventilation must be used for removal of the gases produced (cfr. figure 27). Cutting aluminium produces less smoke than cutting steel. The principle of a plasma arc cutting operation is shown in figure 28 on page 41.

Plasma arc cutting is normally quicker than using the arc saw or angel grinder. When cutting painted metal, much smoke is produced. Cutting of steel constructions up to 2 mm thickness gives sharp and smooth cuts, but above this thickness the cutting edge is quite rough. This makes later decontamination work more difficult or even impossible. The high temperature makes radioactivity "stick" to the metal.

5.3.7 Bayonet saw

This saw is used for cutting thicker profiles and when it is necessary to fasten the tool in existing equipment. It is electrically driven. Stainless steel pipe lines up to 50 mm and profiles up to 10 mm thickness have been cut, while it is able to cut up to 100 mm pipe lines.

An example of removal of framework of a hot cell with a bayonet saw is shown in figures 29, 30 and 31.

Since this saw is equipped with a blade moving forwards and backwards, one may approach the cutting area more conveniently than with a circular saw that needs larger space in front of the saw blade. With the bayonet saw, very tight and compact constructions can be reached, too.

Figure 9 Chisel hammer for removal of concrete shielding blocks

Figure 10 A chisel hammer

Figure 11 Removal of rivets from a sheet steel housing

Figure 12 Close-up of a riveting punch

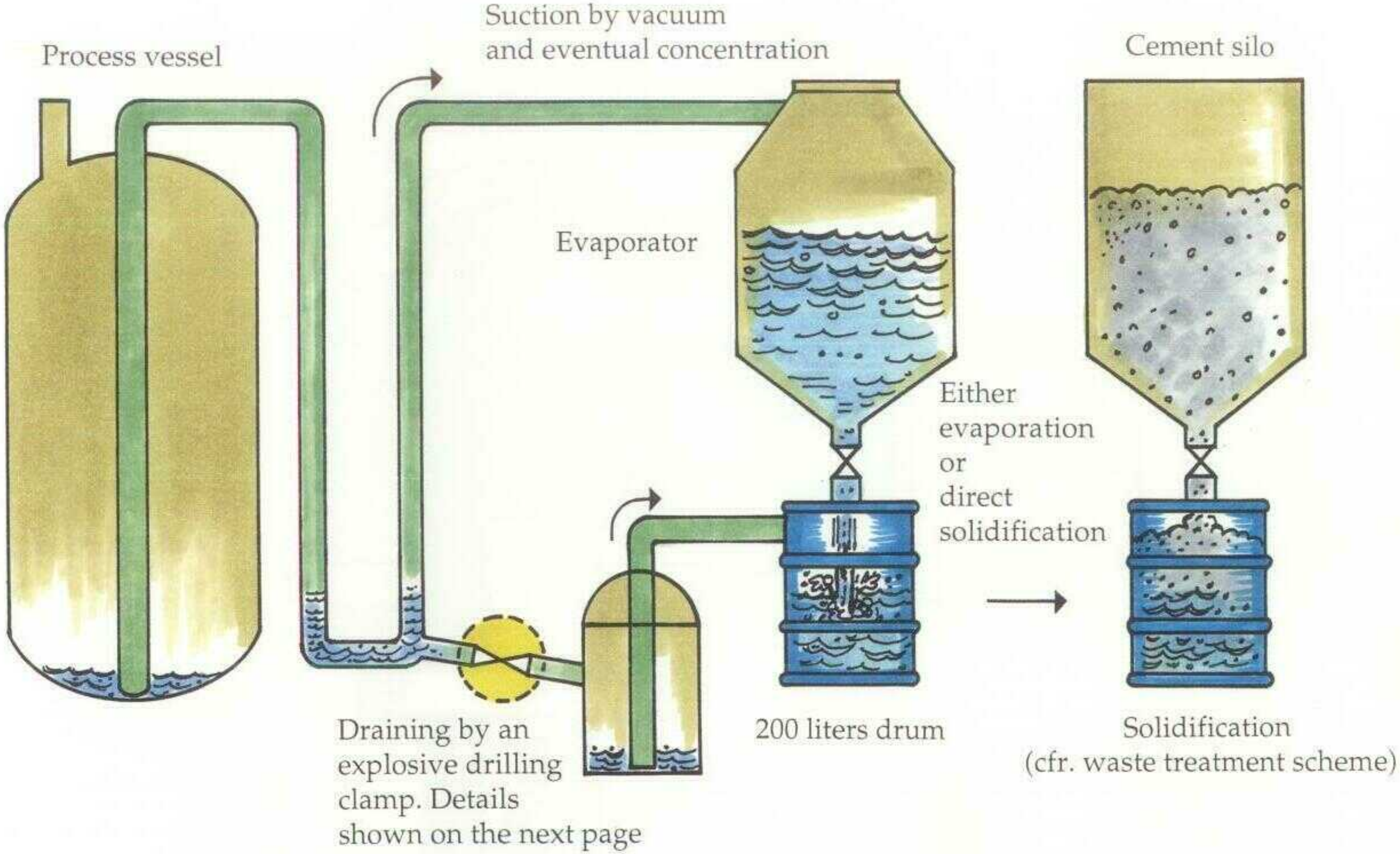


Figure 13 a Removal of excess liquid from U-pipe contructions
The principle of an explosive drilling clamp is shown on the next page

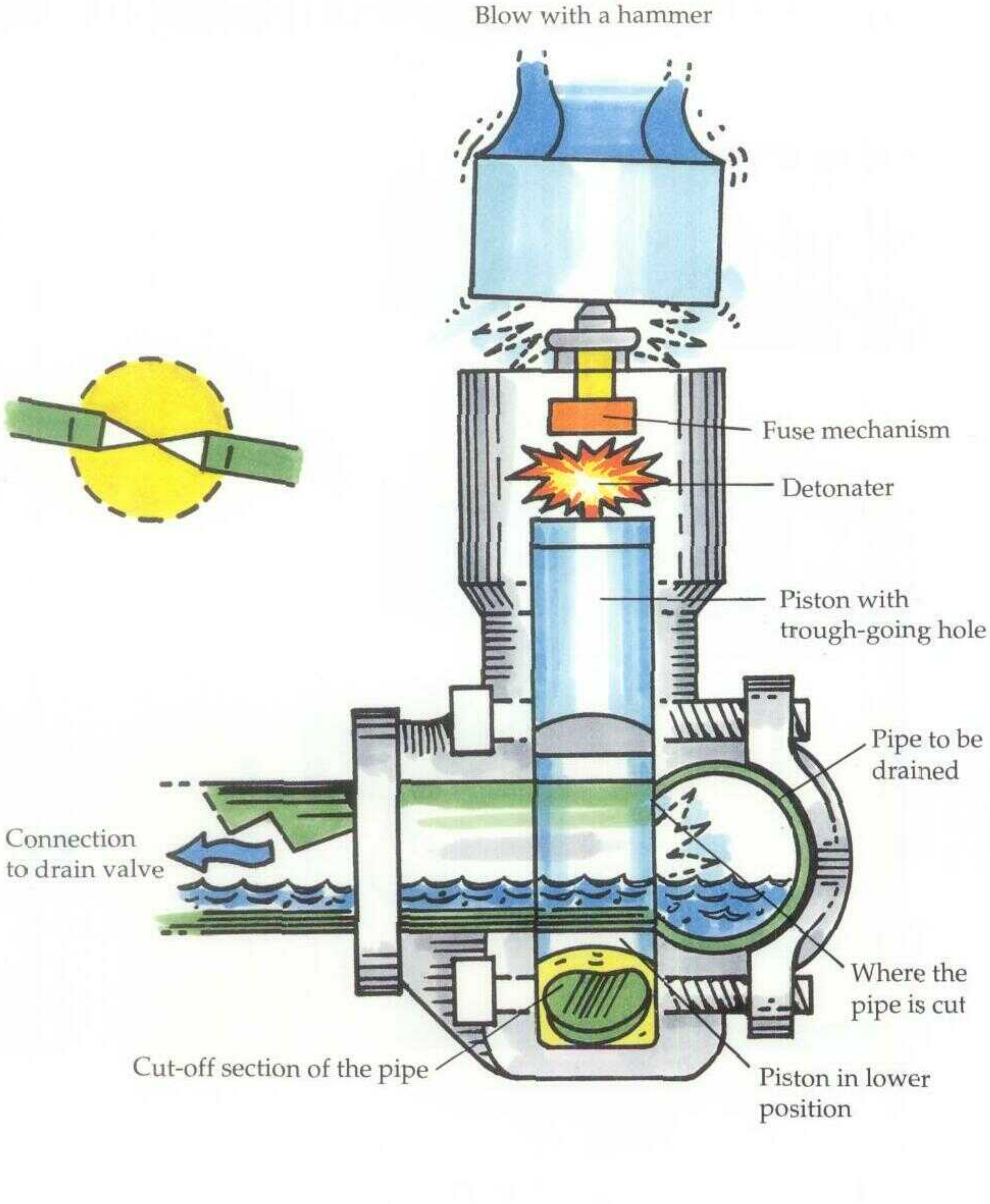


Figure 13 b The principle of an explosive drilling clamp

Figure 14 The use of an explosive drilling clamp. Note the drained liquid

Figure 15 The clamp-cut tool. Observe the knives and that the clamp-cut of the pipe just has started. Continues on figure 16

Figure 16 Cutting of a pipe in progress

Figure 17 The pipe is cut and the pipe ends locked

Figure 18 Cutting of contaminated pipes

Figure 19 Cutting with a hydraulic cable cutter

Figure 20 Close-up of the hydraulic cable cutter

Figure 21 A blowing wedge

Figure 22 Cutting with a hydraulic shear

Figure 23 Close-up of the hydraulic shear

Figure 24 Cutting of inactive pipe lines with angle grinder

Figure 25 Portable circle saw

Figure 26 Stationary circle saw

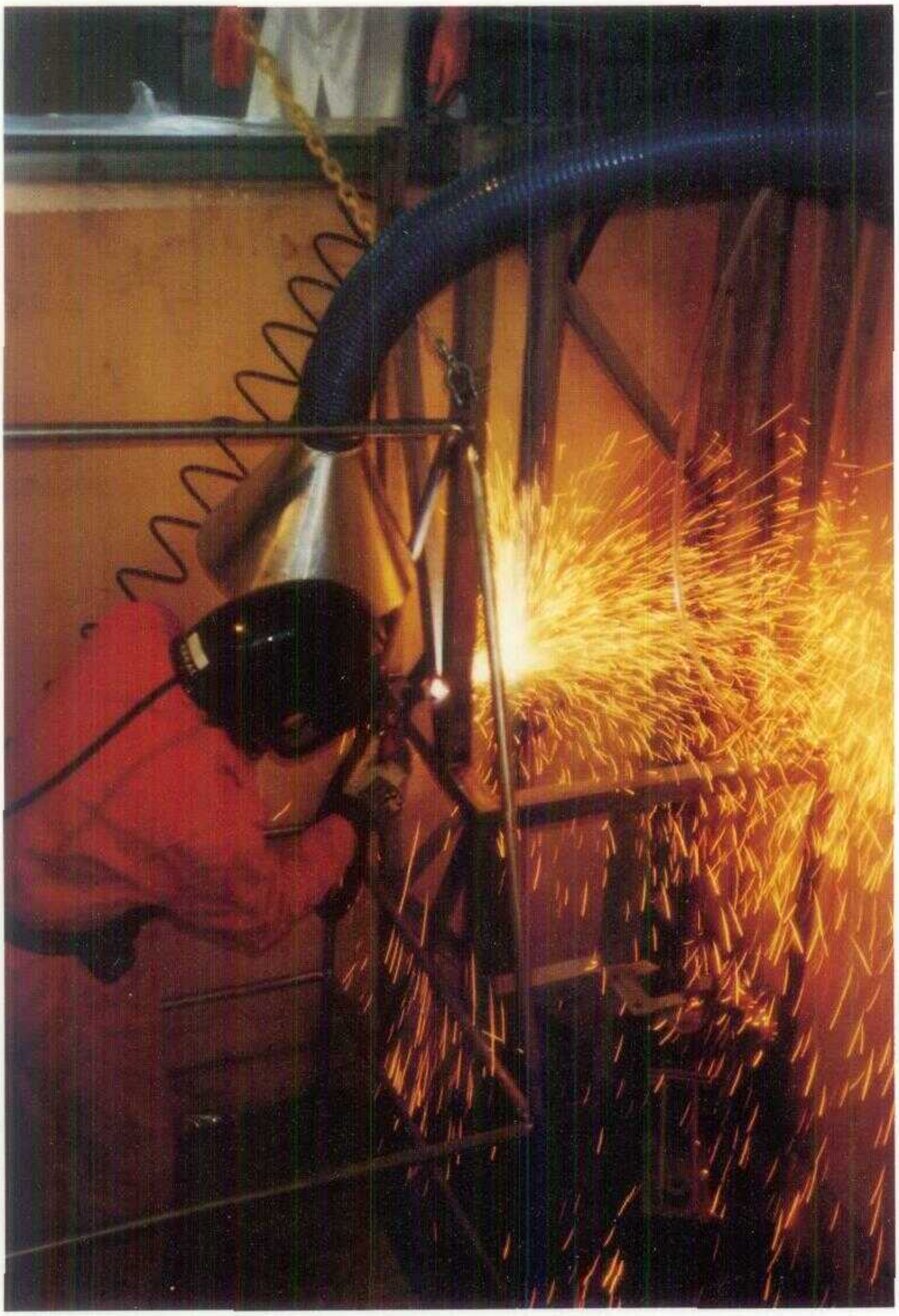


Figure 27 Plasma arc cutting. Removal of the equipment for decanning of the uranium elements

Figure 28 The principle of a plasma arc cutting operation

Figure 29 Cutting of framework construction with a bayonet saw. Cutting has started

Figure 30 Cutting with a bayonet saw. Cutting goes on

Figure 31 Cutting with a bayonet saw. Cutting completed

6 Choice of decontamination methods

6.1 Introduction

The illustrations described in this chapter are shown at the end, pp. 52 - 56.

In the course of a complicated decommissioning sequence, decisions have to be taken at several stages, depending on the outcome of the previous step. Optimation of subsequent steps is thus a recurrent task. Several aspects have to be considered. For example, dismantling by use of cutting tools that make rough and sharp edges (especially plasma arc cutting) requires a more complicated decontamination procedure.

The 50 vessels, evaporators, and extraction columns had several inlet and outlet lines in addition to instrumentation lines. Reuse of the equipment for other purposes was not regarded as possible. Due to the very compact construction, the piping system had to be cut into short pieces. No practical reuse of the pipe ends was possible.

The plant had been decontaminated by chemicals and the radiation level lowered by a factor of 100, to an average of 0.2 mSv/h. Many of the short-lived nuclides had decayed.

Under these circumstances, further decontamination of the process equipment to avoid that the material is treated as radioactive waste had to be evaluated. In this connection, a main objective was to generate as small waste volumes as possible. Only the scrap value of the equipment was interesting for comparison with the cost of decontamination and waste handling.

Melting of metal parts for recycling was not considered as an economical alternative. This is due to the relatively small size of the plant in conjunction with the fact that no melting plant for radioactive material is available in Norway. Also, the complication with obtaining a licence for recycling must be taken into account.

6.2 Decontamination or disposal as waste

In this section various calculations are presented that indicate whether it would be cost efficient to decontaminate piping systems, vessels, and shielding blocks.

6.2.1 Unprofitable decontamination: decontamination compared with cutting and packing

6.2.1.1 Piping systems

The 6000 meters of contaminated pipe lines had an average of 16.5 mm in outer diameter and a wall thickness of 2.5 mm. The weight is approximately 1 kg/m, that means 6000 kg totally. The scrap value for stainless steel is NOK 3/kg, giving a total of NOK 18 000.

If the pipes are molten and sold to a steel factory, the most realistic price is the scrap value. On the other hand, stainless steel as a raw material resource represents a somewhat higher value.

The economic comparisons indicate that, since decontamination would require considerable efforts and costs, direct packing as waste could be achieved for one quarter of that cost. The total decontamination cost including chemicals, operational cost, waste handling and disposal are calculated to NOK 500 000.

This is an example of unprofitable decomissioning, where high packing tightness of steel components can be obtained, and where secondary waste volumes would have exeeded the volume of the item to be cleaned. The cost estimate is shown in Appendix C.

Summary:

Scrap value	NOK 18 000
Decontamination	NOK 500 000
Direct packing	NOK 150 000

6.2.1.2 Vessels

40 vessels might have been decontaminated, but due to the complicated inlet and outlet connections, it was not possible anyhow to reuse them either for radioactive or non-radioactive purposes.

With an average volume of 200 l, wall thickness 4 mm and a weight of 80 kg, the scrap value of all the vessels is NOK 10 000.

Two vessels were decontaminated manually. The cost is listed in the summary below. Decontamination by high pressure water flushing was a possible alternative, but the investment cost would have been high. In addition, treatment, solidification, and final disposal cost would arise.

It turned out that placing vessels inside other vessels was the most economic method, about half the cost of manual cleaning. Space between the vessels can be filled with other waste items (see figure 32). This packing system results in eight packages of 1 m^3 each, and the cost estimate is shown in Appendix D. Segmenting methods applicable to tanks and pressure vessels are listed in /12/.

Summary:

Scrap value	NOK 10 000
Manual cleaning	NOK 150 000
High pressure flushing	NOK 320 000
Vessel inside vessel	NOK 70 000

6.2.2 Profitable decontamination: shielding blocks

6.2.2.1 Lead shielding blocks

Lead shielding blocks that are contaminated represent a considerable value and can be reused after mechanical surface treatment (milling). A typical lead block has the size 10 x 10 x 5 cm and a value of NOK 300. 1000 blocks (out of a total of 3000) were contaminated, and their value was NOK 300 000.

An average thickness of 0.25 mm of the surface was removed, and when the lead chips are molten, they give a volume of 12 litres waste. The investment cost for the installation was NOK 40 000 including a milling machine. The net reuse value for the 1000 lead blocks was thus NOK 165 000. They can be reused for shielding purposes. The milling machine and the milling operation is shown in the figures 33 and 34, and a summary is given in Appendix E.

6.2.2.2 Concrete shielding blocks

The cells were shielded with concrete blocks. Some 550 blocks were somewhat contaminated. 350 of them were reused for a shielding wall (25 m^2) in the waste treatment plant. For this purpose, the permitted contamination level was 2 Bq/cm^2 α- and 20 Bq/cm^2 β/γ-radioactivity. Maximum radiation level was set to 10 $\mu Sv/h$. The blocks were coated with two layers of paint. The saved waste disposal costs are calculated to NOK 50 000.

Radioactive material had normally penetrated the outer 1-2 mm (up to 5 mm), and two methods were used for removal: chiseling, and chemical attack by 3 molar nitric acid + 2% hydrofluoric acid. The acid makes the surface "boil", and after 10 minutes the contamination can be wiped off with absorbing paper. Treatment of 200 blocks (1800 litres) resulted in 100 litres of waste. The working hours and waste treatment cost is NOK 15 000, and the reuse value of the blocks is estimated to NOK 50 pr. block, i.e. that a total of NOK 10 000 is saved. A summary is given in Appendix F. The cost for packing and storage of 1800 litres as radwaste is estimated to NOK 50 000.

6.3 Chemical decontamination

6.3.1 Surfaces

All structural work of steel, located close to the hot cells such as frame work, steel sheets and steel sections must be handled as potentially contaminated. Likewise service- and auxiliary equipment and steel constructions such as sampling stations, staircases, landings and staircase railings in the operational area may have to be treated as contaminated, even if the aim is to obtain clearance from being radwaste.

Both stainless steel and carbon steel, often painted with a two component hardening paint, can be decontaminated by:

- pickling with corrosive agents (unpainted surfaces)
- paint removers
- water abrasive blasting (using glass beads)

or a combination of these methods.

The success of such treatments will vary from case to case, since the handling is very individual, depending on the degree of adhesion of radioactive material to the components.

Parts of the aluminium structural work have been decontaminated to a level, sufficient for clearance of radiological control, by using 2 % sodium hydroxide for one minute at $60^{O}C$.

In most cases it is possible to decontaminate metal parts to the exemption level by using different chemicals and time consuming operations, but the costs and the secondary waste volume produced and the final treatment should be born in mind. If more secondary waste than the volume of the original part is produced, then decontamination is unprofitable. One example: A square meter steel sheet with a thickness of 2 mm has the volume of 2 litres. It is not possible to decontaminate this to exempt level without exceeding a final waste volume of 2 litres.

If there is a risk of radioactive dust, the surface of components to be removed should be moistened and wiped before dismantling. Spraying with water, detergents or nitric acid (for stainless steel constructions) is useful. Smooth and accessible stainless steel surfaces were normally decontaminated by manual wash with 3 molar nitric acid, with or without 2 - 4 % hydrofluoric acid, depending on the degree of contamination. The addition of hydrofluoric acid is very effective. A drawback is, however, that the waste have to be neutralized to the corrosive action.

6.3.2. Process equipment

As mentioned in section (2.2) the plant equipment was decontaminated three times after shutdown to lower the radiation level so as to ease access for further work. Warm nitric acid, sodium hydroxide and oxalic acid/tartrate reduced the over-all radiation with a factor of 100 from 2 mSv/h to 0,2 mSv/h. The plant had many up- and down going pipe lines (U-pipes) that made a complete emptying impossible, cfr. figure 4 on page 5.

In situ decontamination to an exemption level of the process equipment was not possible in practice, and due to the crowded construction the pipe lines had to be cut into short pieces (on average 1 meter). As shown above, decontamination of pipe lines and vessels turned out to be unprofitable. This is not necessarily true in other cases with less complicated and more similarly shaped plant arrangements, and where contamination levels are different.

As an experiment, in order to try a total decontamination, smaller pieces were treated for 6 hours at 80^0C (cfr. figure 35 and 36) with forced circulation, using 3 molar nitric acid. The inside remaining activity level was 2.6 Bq/cm^2 β/γ and a factor of ten lower for α activity. Addition of 3 % hydrofluoric acid to 3 molar nitric acid brings the inside activity level down to 0.6 Bq/cm^2 β/γ (background level), but due to the corrosive effect, problems with concentration of larger volumes of liquid waste before the solidification step must be taken into account. In practice, decontamination of piping must be done in another way with longer pieces and by forced flow of the decontamination solution.

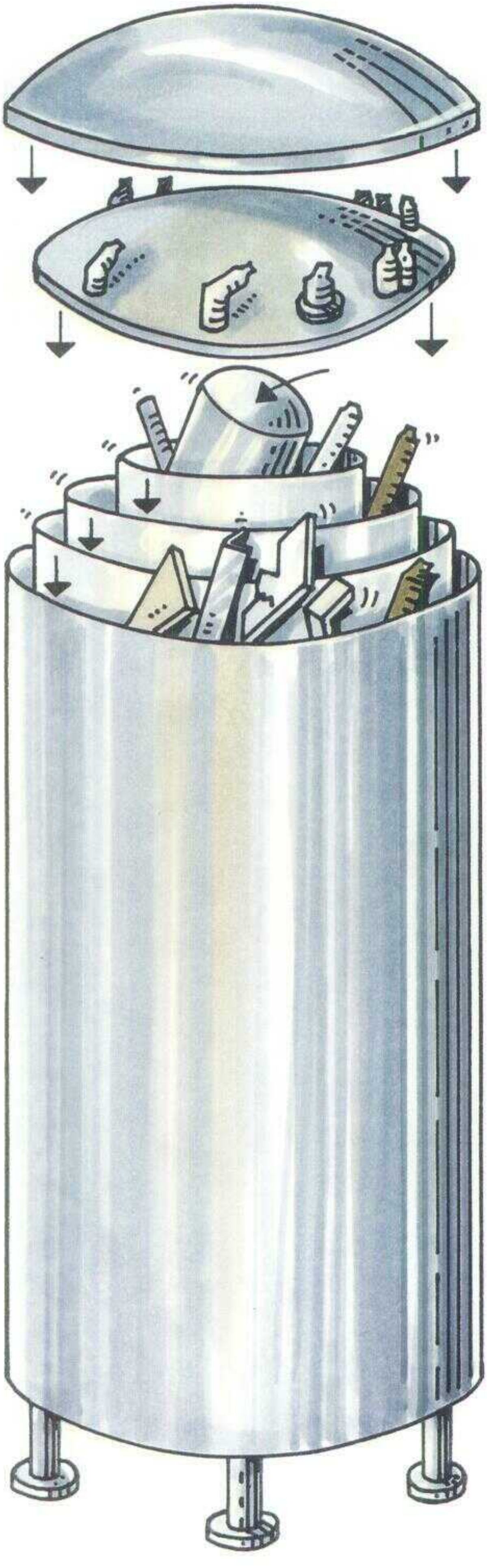


Figure 32 Vessels inside vessels

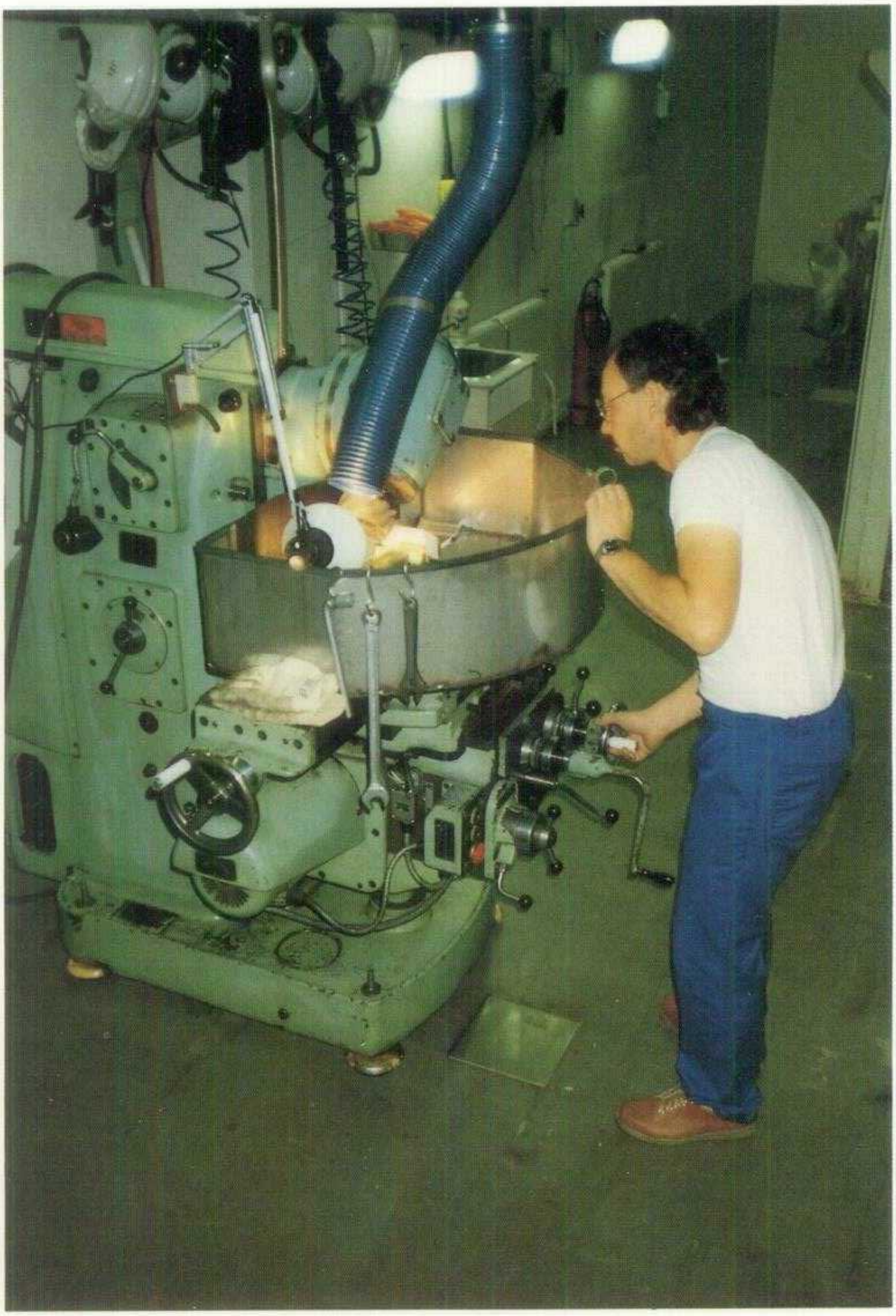


Figure 33 The milling machine

Figure 34 Close-up of the milling. The lead shielding block is painted and it can be seen that the upper part to the left is milled

Figure 35 Decontamination of short steel pipe pieces inside soxhlet columns. The soxhlet principle is like a redestillation in such a way that "fresh" liquid is continuously added to the object

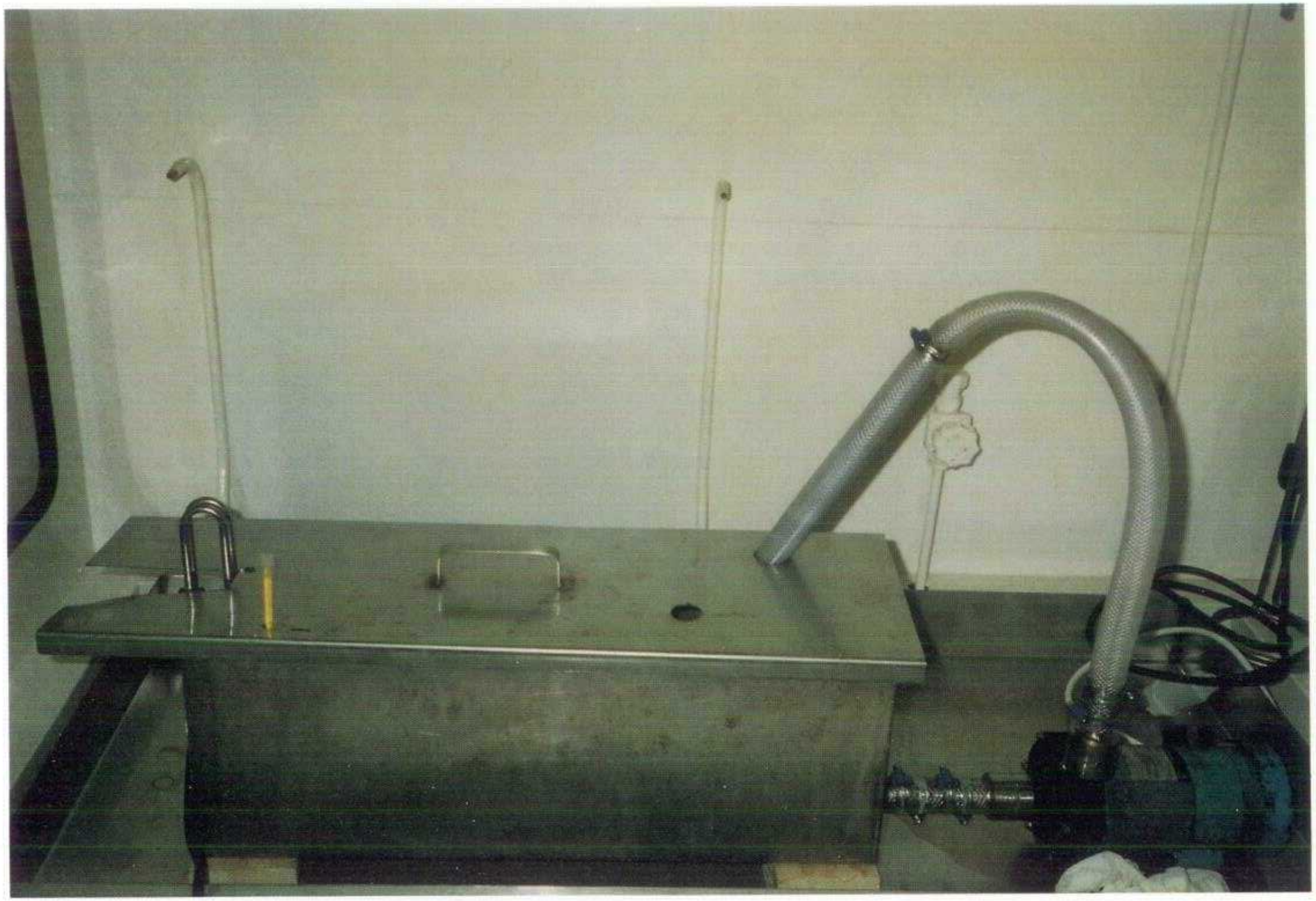


Figure 36 Decontamination with forced circulation. A piece of a steel pipe is placed in the down-going part of the plastic tube

7 Measurement of surface contamination

7.1 General

The figures described are shown at the end of the chapter, pp. 59 - 62.

The goal of the decontamination operations was to remove radioactive deposits from surfaces so as to either allow clearance from regulatory control or to optimise waste management. The operations are followed closely by measurement of the remaining surface contamination.

The accuracy of measurements becomes more critical as the contamination levels decrease. Control of dismantled parts in view of clearance is often a difficult task. Thus, sheet steel, frame constructions and accessories may have rough edges after removal, especially when plasma arc cutting is used, which make them more difficult to measure. Some pieces of equipment must be opened by cutting them into small pieces in order to be controlled. If the metal had been sent to a melting plant, the situation would have been different. In such a case, measurements can be made on a homogenous sample. Concrete shielding blocks have a porous surface and radioactivity may have penetrated. Dirt upon the surface may for instance stop the detection of α-radioactivity that must be checked near to the surfaces. Special difficulties arise when measurements have to be performed inside narrow steel piping.

In the case dealt with here, a portable monitor with a photomultiplyer probe, type DP2, could be used for measurements and for exempt control of surfaces (see figure 37). The measuring area is 50 cm^2 and the efficiency is 10% for alpha as for beta/ gamma activity.

For unrestrictive reuse the metal scrap shall be free from any radioactivity, and for restrictive reuse inside active working areas the limitation is for α-activity $\leq$ 0.4 Bq/cm^2 and for β/γ-activity $\leq$ 4 Bq/cm^2 /13/. The general levels at IFE to allow clearance for reuse of decontaminated materials have been lowered by a factor of two in order to account for the uncertainties in measuring the activity levels of surfaces.

The control during the decommissioning was performed by the irradiation protection group that has a long experience in measuring technique, also while the plant was in operation. They were well acquinted with the history of the actual parts to be measured. This is helpful when it comes to decide whether these items should be handled as radioactive waste, or whether they can be subject to exemption from radiological control. There is no general rule regarding the choice of measurement techniques. Different methods are available to control the contamination of surfaces. Their choice depends on the characteristics of individual dismantled parts, and on the possibility to perform measurements in close contact.

7.2 Internal control of narrow steel piping

The control measurements inside steel piping were performed using a micro-probe GM-detector, mounted to a 1 m long insulated steel rod and connected to a detector at the other end, see figures 38, 39 and 40. With this equipment, measurements can be made inside pipe lines with a diameter down to 16 mm and lengths up to two meters by inserting the probe from both sides. The goal of constructing this instrument was to make possible an inside control of narrow steel pipes for eventual clearance as non-restrictive material.

With the equipment developed it is possible to detect contamination levels that approach the natural background /14/.

Figure 37 Surface control of decontaminated stainless sheet steel and framework

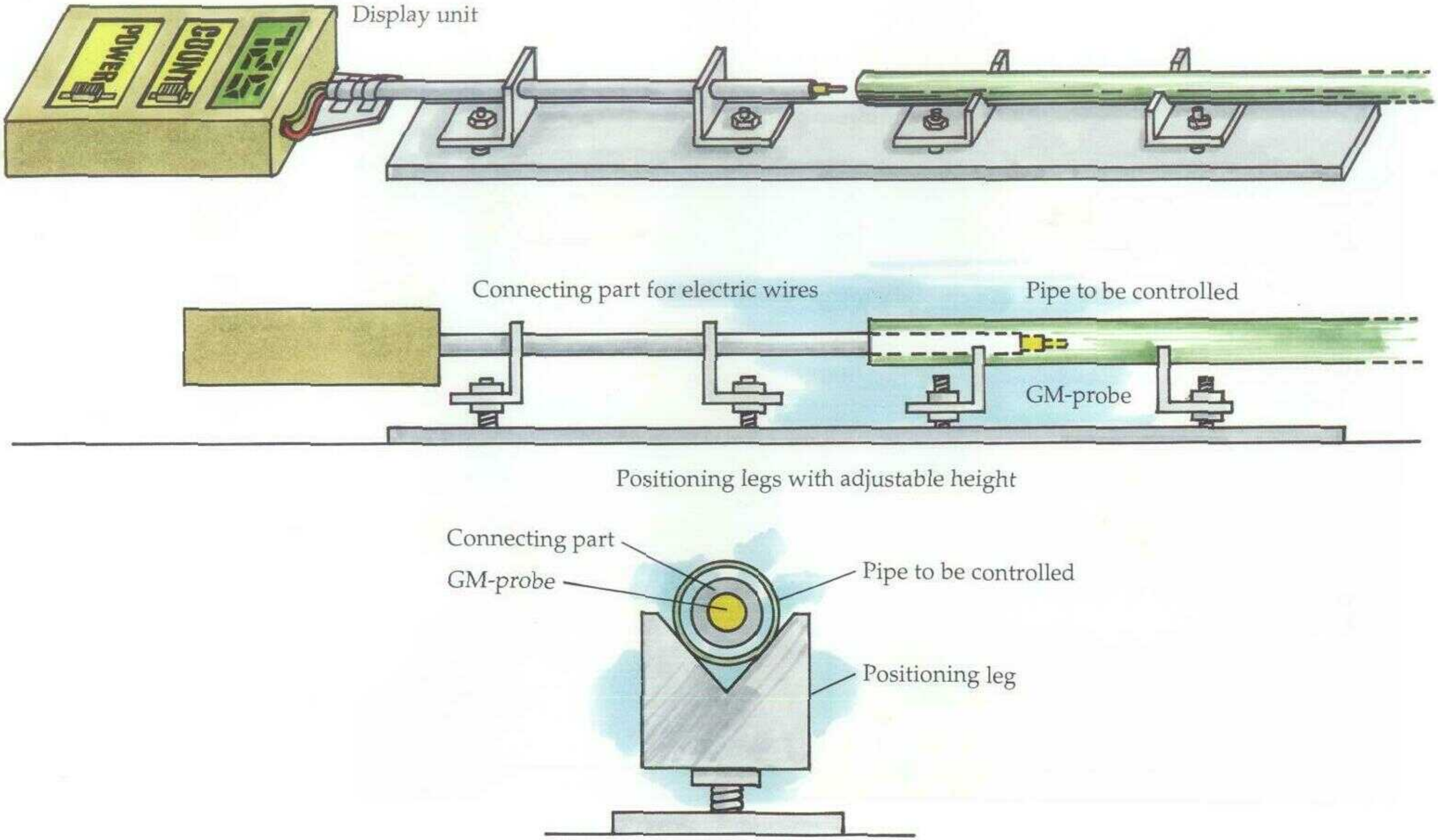


Figure 38 The principle of radioactivity control inside narrow steel pipes

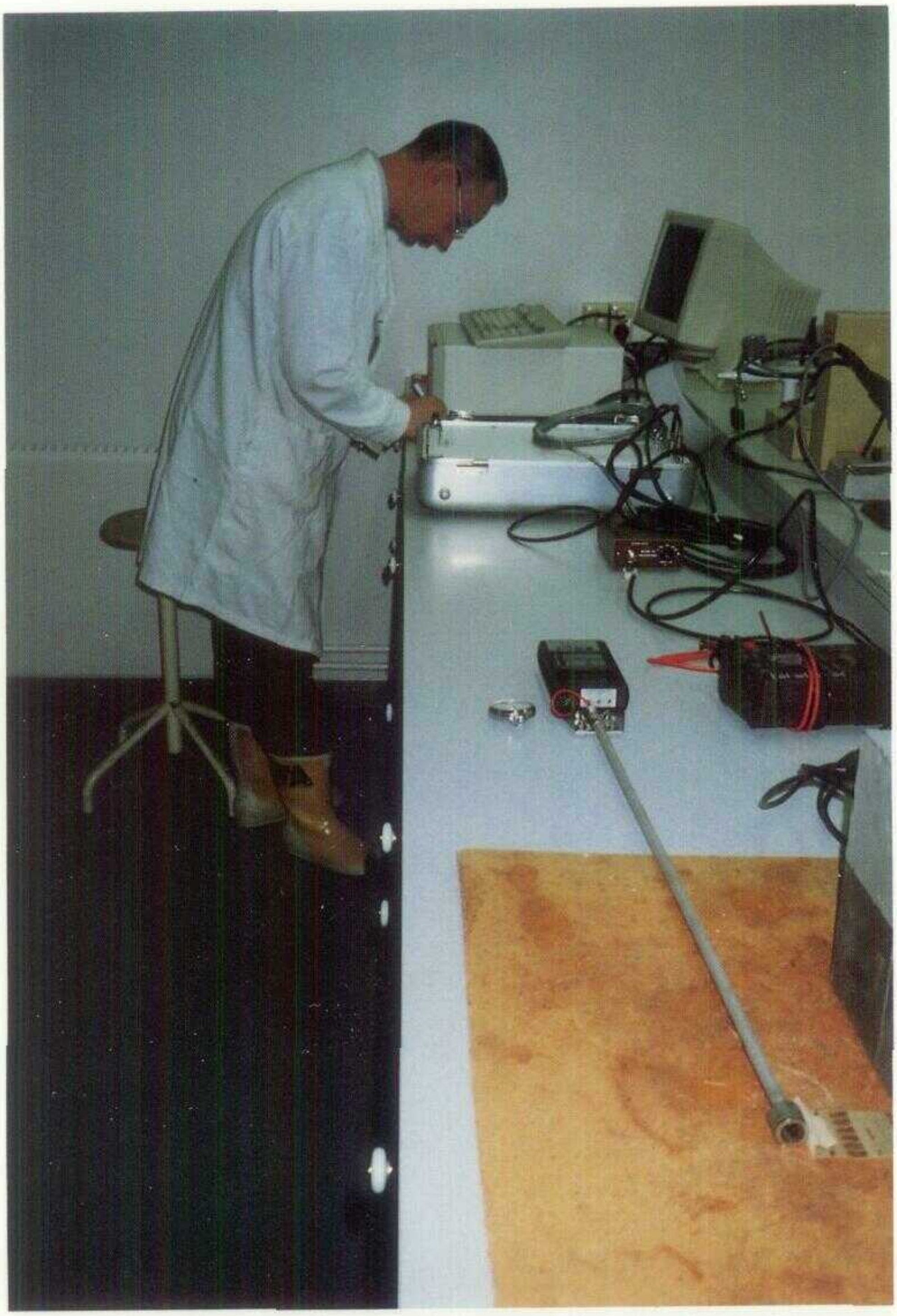


Figure 39 Calibration of the micro probe detector

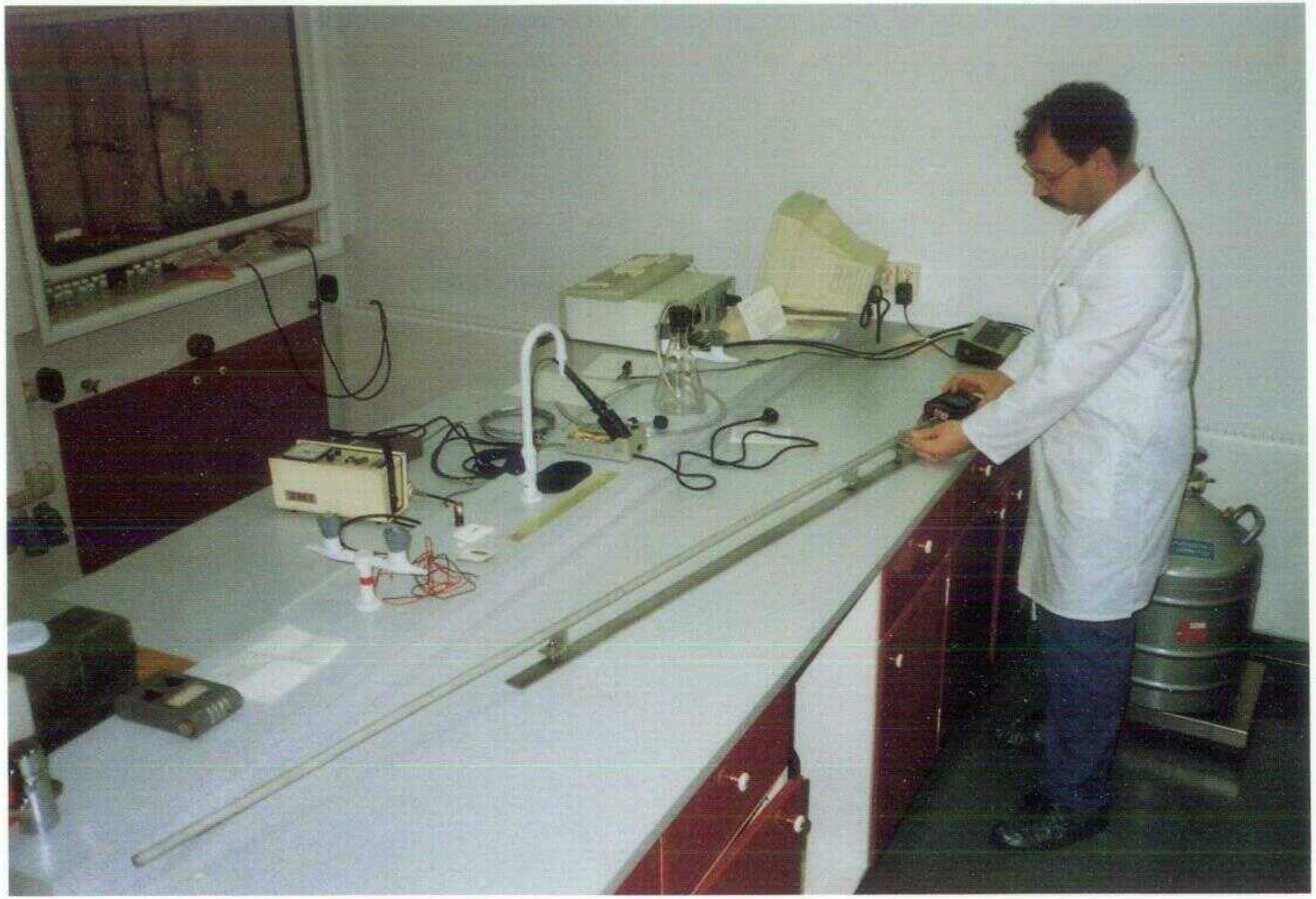


Figure 40 Inside control of a 2 m long steel pipe

8 Waste treatment

8.1 General

Waste management is a major cost factor in decommissioning. Once a decommissioning strategy has been decided, e.g. whether to arrive at stage 1, stage 2 or stage 3, a main objective is to arrive at the lowest possible overall cost, and this mostly implies as small waste volumes as possible. This can be achieved by detailed planning of the dismantling process. The choice of either decontamination with the view of clearance or direct packing can be difficult because the secondary waste may very quickly exceed the volume of the dismantled parts.

Even where pipelines or other process equipment can be decontaminated (cfr. section 6), the most reasonable solution often turns out to be direct packing. This is especially the case if tight packing can be achieved with components placed inside each other like in the MATRECHKA ("The Russian doll") system.

8.2 Methods

Absorbent paper, plastics, textiles, rags etc. used for outside cleaning of low-contaminated equipment were shredded and therafter compressed inside concrete shielded drums. They can also be incinerated. Floor-covering and mixed items can be handled in the same manner. Spot contaminated floor plates, framework, and sheet steel are cleaned by manual rubbing or wet blasting, using glass beads. If this is unsuccesful, the spots can be removed using a cutting blowpipe. The metal scrap is cast into drums or stainless steel boxes as shown in figures 41 and 42 on pages 66 and 67.

Remaining liquids from process equipment were transferred to 200 l drums lined with polyethylene, and thereafter solidified by the addition of cement and additives. For compacted waste the original volume was reduced to 15 %, and for burnable waste to 2 - 3 %. For liquid waste that had to be solidified without any concentration, the volume increased by a factor of 1.6. A principal scheme of the waste treatment at the institute is shown in figure 43 on page 68.

8.3 Choice of containers

In the early stages of the decommissioning described here, nearly all of the waste was collected in shielded drums as shown in figure 41. Thus, in the beginning, standard 210 l drums were used as the outer container for most of the waste. At that time only smaller parts had been dismantled.

It soon turned out that the 210 l mild steel drums were not satisfactory as the only container. A better performance was expected of a 110 l drum placed inside a 210 l drum with 5 cm of concrete in between (see figure 41). This type is mostly used for compression of paper, plastic, rags, brushes, protective clothes etc.

In some cases there were observed corrosive liquids inside dismantled pipework, and therefore the use of a 210 l stainless steel drum as a waste container was also evaluated.

The 210/110 l drums were later replaced by stainless steel boxes, with the following dimensions: lenght x depth x width = 120 x 80 x 80 cm. They were placed on a 10 cm high U-profile for easy lifting (see figure 42).

The price for various containers is shown below, cfr. figure 44 on page 69.

Prices for radwaste containers

Container type	Material	Material thickness,	Price
110 l drum	Mild steel, SS 1142	1.0 mm	NOK 150
210 l drum	Mild steel, SS 1142	1.0 mm	NOK 250
110 l drum inside 220 l	Mild steel, SS 1142	1.0/1.0 mm	NOK 600
210 l drum	Stainless steel, SS 2343	1.5 mm	NOK 3 600
860 l box	Stainless steel, SS 2343	2.0 mm	NOK 23 000

The choice of containers does not only depend on their cost, but also on the cost of operation and on intermediate storage and final disposal. In the project reported here, the temporary storage cost at IFE is NOK 2 300 per drum and the cost of final disposal (rock depository) /15/ is assumed to be NOK 3 000/m^3 (NOK 2000/m^3 for rock repository and NOK 1 000/m^3 for transporting). One working hour is arbitrarily set at NOK 300 (internal cost).

It is also necessary to compare how much pipework and how many smaller items can be packed into the different drums and containers available.

It is possible to pack 245 m of pipework (172 kg) and smaller items of an average dimension of 16.5 x 2.5 mm inside a 110 l drum (se figure 41). A box can be filled with 2200 m of pipework and smaller items (figure 42). The utilization of the volume inside the container can be expressed in two ways, either using the net volume of the pipe material, or using the outer volume actually occupied by the pipes.

Calculations show that the 860 l stainless steel box has the lowest storage space requirement for a given amount of solid waste. The same amount of solid material filled into 210 l drums would require 1.7 times this storage volume, and if using 220/110 l drums, 3.3 times the volume would be needed.

The use of larger containers also means less cutting work. The average cutting lengths for the three types of containers are 400, 500 and 1190 m, respectively.

Summing up the container cost, the cost of cutting/packing, and the costs of temporary and final disposal, gives:

Container type	Container cost NOK	Cutting packing NOK	Temporary storage NOK	Final * disposal NOK	Total NOK	% more expensive
210/110 l	5 400	72 000	20 700	8 640	106 740	91
210 l st.st.	16 200	57 600	10 350	4 320	88 470	58
860 l st.st.	23 000	24 000	6 216	2 592	55 808	

* /15/

This evaluation is based on a case where straight and flat parts can be packed relatively tight together with piping, and the cost estimate is shown in Appendix G. The packing tightness depends in general on:

- the shape of the items
- whether parts can be put into parts (The MATRECHKA principle)
- whether cutting into smaller pieces can give a tighter packing.

Figure 41 Drum packed with steel pipes and other metallic objects

Figure 42 Steel box for radwaste objects

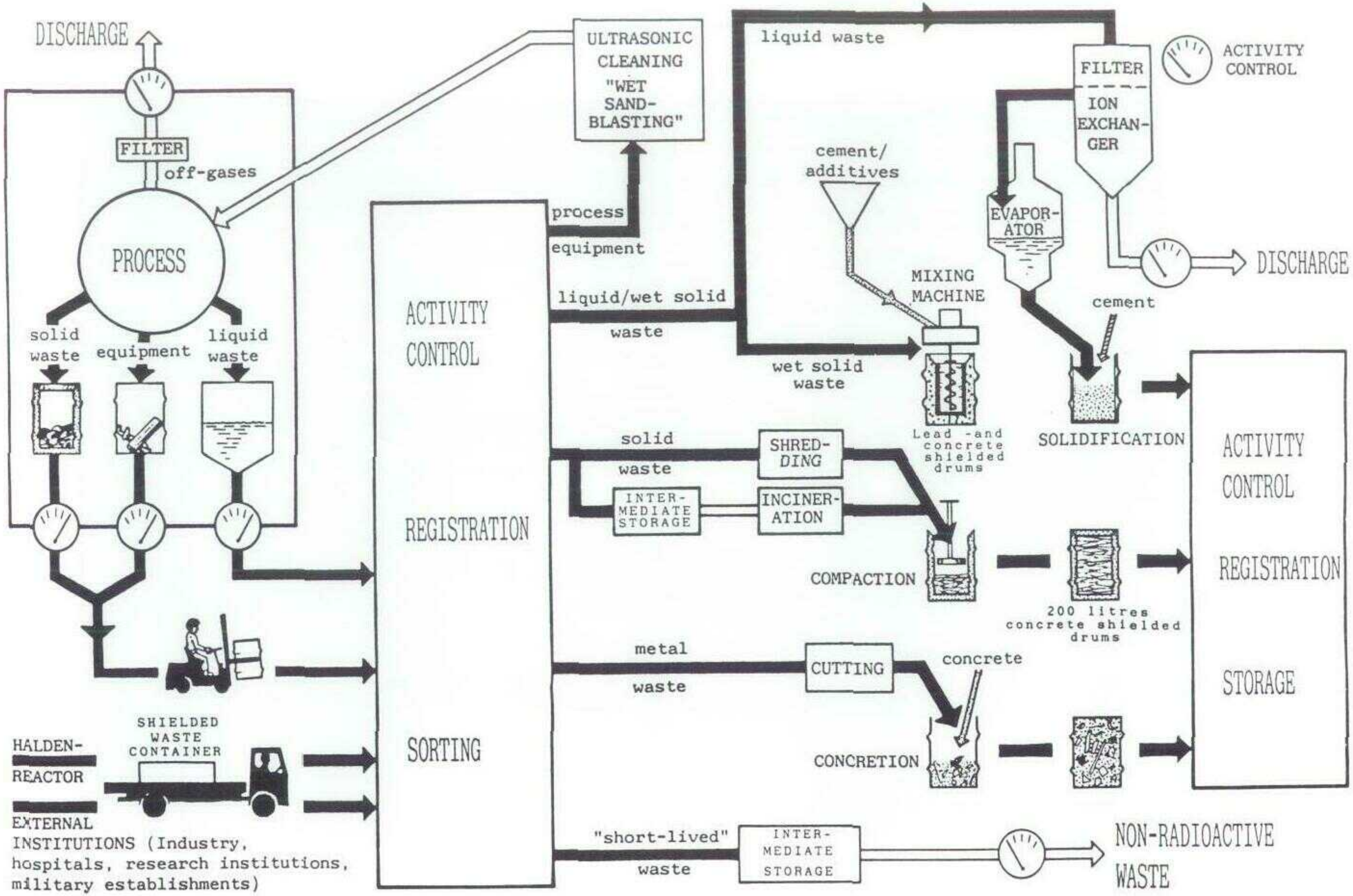


Figure 43 Treatment and storage of radioactive wastes at Institutt for energiteknikk

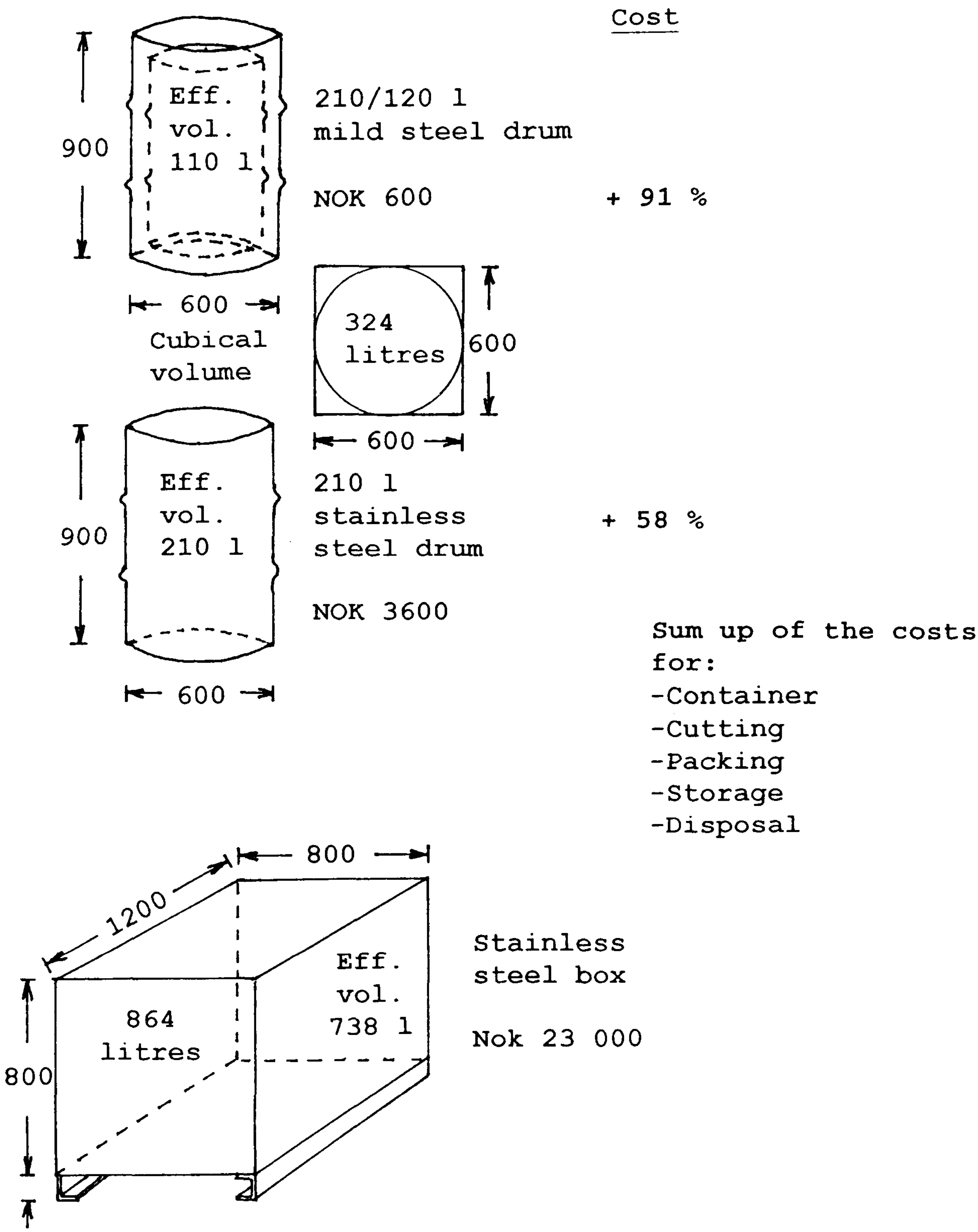


Figure 44 Radwaste containers

9 Further use of buildings and objects

9.1 General

The plant has been decommissioned to stage 2 and stage 3 level, and the major part of the building will be reused for waste treatment operations.

One of the analytical laboratories is completely renewed to stage 3. The other one is renewed to stage 2 for continued radioactive analytical work. The alpha-laboratory is renewed to stage 3 for non-radioactive work.

The operation area is so far decommissioned to stage 2 but will be brought to stage 3 for non-radioactive operations. Future plans for the "hot" area is reuse and rebuilding of a decontamination cell and a hot cell for radwaste work. The area will be decommissioned to stage 2 level. The pond building with its mechanical decanning equipment is renewed to stage 3, and here solidification equipment is installed for preparing of waste containers. Parts of the ponds are used for intermediate storage of industrial radiation sources, and the dismantling-, decontamination-, and rehabilitation operations are shown on pp. 73 - 83. The waste volume is 1.1 m^3, included packing 1.5m^3. Retrieved volume of the two pond parts is 65 m^3.

Other cells in the basement, as well as the pump room, will be decommissioned to stage 2 and 3 and reused as storage for shielding components and auxiliary equipment in connection with radwaste work. The dissolver cell will so far be kept as a "mausoleum" since it only occupies a small building volume. The pond basement section is decommissioned to stage 2; it contains three 2 m^3 waste vessels that have been emptied and will be kept for future waste operations. Ventilation, heating, electrical systems as well as monitoring equipment are updated to specified standards.

9.2 Reusable objects

Certain dismantled parts can be reused after decontamination, following control, and approval of the responsible authorities. Below some examples from this project are listed.

Non-contaminated parts	Possible reuse
Instrumentation	Teaching/Instruction/Experiments
Lead shielding blocks	Shielding material
Concrete shielding blocks	Shielding material/Building material
Vessels	Chemical processes
Pumps	Chemical processes
Steel pipe-lines	Scrap
Other steel parts (ventilation ducts, steel sheets, racks, framework)	Scrap

Contaminated parts	Decontamination methods	Possible reuse
Lead shielding blocks	Milling or Chemical	Shielding material
Concrete shielding blocks	Chiseling Chemical	Shielding material Building material
Vessels	Brushing High pressure flushing Chemical	Melting/Scrap/Reuse
Pumps	Brushing High Pressure flushing (Chemical)	Chemical processes
Stainless and mild steel parts (sampling stations, ventilation ducts, racks, steel plates, framework)	Brushing High Pressure flusning (Chemical)	Scrap

The reuse value of objects and materials from this project is estimated to be NOK 1.5 - 2 million. This can be compared to the total decommisssioning cost of NOK 6 million.

Figure 45 *The decanning of the fuel element was performed mechanically. The operation involved separation of the twin rods by means of a chisel, removal of the end sections of the rods by means of a cutting disk, and removal of the canning by pressing the rods through a knife assembly. The decanning equipment was mounted on a tower construction located in a corner of the pond, and the operations were conducted from a platform on this tower.*

Figure 46 After several years we met the pond in this state

Figure 47 Removal of the decanning tower contruction by means of plasma arc cutting. Note the spot ventilation

Figure 48 Removal of the decanning tower construction is nearly completed

Figure 49 Cleansing of the pond bottom

Figure 50 Excess water in the bottom slurry was removed by means of a 2 KW heating cable

Figure 51 The slurry was solidified by the addition of cement and vermiculite inside a 110 l drum placed in a 210 l drum

Figure 52 Water flushing of the epoxy lined concrete walls

Figure 53 Manual cleansing

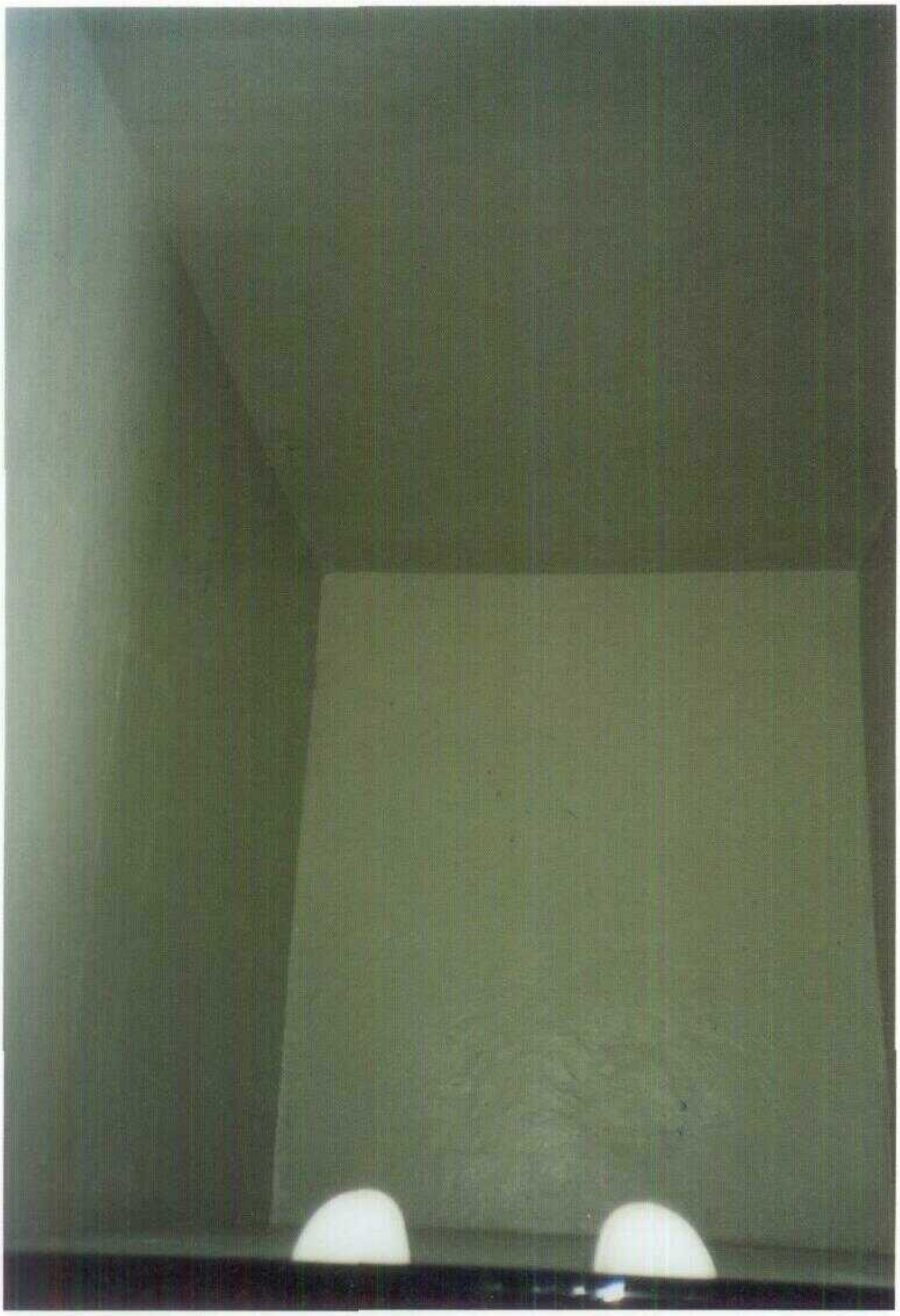


Figure 54 The pond is rehabilitated. Cfr. figure 46 and note the shoe-tips and that the picture is taken in the same position

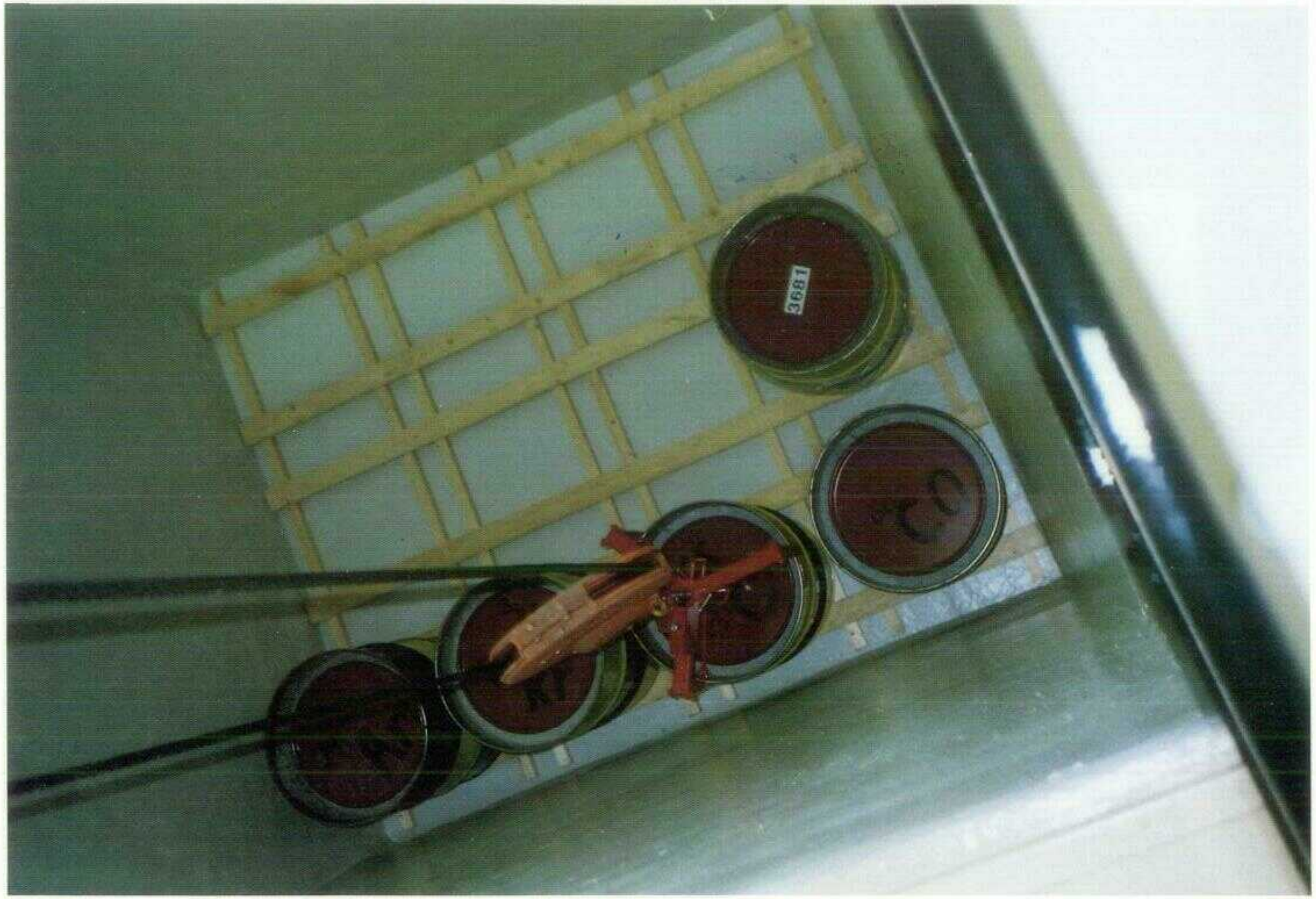


Figure 55 *One of the two pond parts is reused as a intermediate storage for obsolete industrial radiation sources*

10 Discussion of costs

The total decommissioning cost is approximately NOK 6 million, including investment in tools of NOK 0.6 million and a similar amount for waste treatment. The cost of final disposal is calculated to NOK 0.1 million /14/. Rehabilitation of the building is not included. The value of reusable components mentioned in section 9 is estimated to NOK 1.5 - 2 million.

The investment cost of the plant was approximately NOK 42 million (1992 kroner) and the operating cost approximately NOK 80 million including waste treatment and decommissioning. The total cost of the project is thus NOK 122 million.

The decommissioning cost amounts to 14 % of the investment and 5 % of the total project costs.

The ratio between labor cost, tools cost, and waste treatment during decommissioning is 8:1:1.

The value of components, if reused, amounts to 1.4 % of the project cost.

The total labour involved adds up to 10-12 person years. 70-80 % of the decommissioning time is used for the practical dismantling work, 10-15 % for treatment of waste, and 10-15 % for safety and management.

11 Work and social conditions

Dismantling work, by its proper nature, will often be seen by the operating crew as a demoralising, destructive task. The physical work is mostly tough, complicated and time consuming. Such a job will generally require twice the working hours compared with more conventional tasks.

On the negative side is also that the plant is now of no practical interest. Furthermore, the decommissioning may continously give rise to technical and practical problems, and in addition radioactive waste is generated.

A positive argumentation against this negative opinion must be set up. Plant management must manifest its interest in the project, attach importance to the work, contribute positively through encouragement of the involved persons, and express appreciation of results.

It must be stressed that the practical and technical experience can be useful in other situations and therefore will be positive. It can also be argued that the work represents a duty towards future generations, and that it may save resources, e.g. if the buildings can be reused for other purposes.

Management should give the decommissioning crew a great deal of responsibility, let them contribute to the development of better working routines, e.g. through practical tests that can lead to less complicated methods, and by letting them make their own evaluations. It should make sure that the proper tools are made available.

If there is a possibility of rotation with other jobs, the decommissioning task may appear more interesting.

A practical point is that there must be well prepared plans for the handling of all kinds of decontamination waste. Otherwise, since the main interest concerns the dismantling work, the waste treatment may become of secondary interest to the dismantling crew. This could result in "easy" solutions in cases where packing of waste is difficult to decide upon, or where direct waste handling requires difficult preparations. Without giving priority to waste removal, it will mostly take a long period until the parts are brought out again from an intermediate storage and handled in a final manner.

Figure 56 The main crew
From the left: John Erling Lundby, Bent Øverhagen, Oddvar Bjerke and Kjell Frydenlund. Here we are visting the famous jumping hill Holmenkollen in Oslo during summertime.

12 Conclusions and recommendations

From the decommissioning of a small reprocessing plant, some general conclusions can be drawn.

The role of plant management is decisive in creating the right basis for a succesful decommissioning operation. Firstly, sufficient funds should be put aside from the outset of any project of this kind. Secondly, management must attach importance to the work by showing positive encouragement of the crew. The decommissioning operation itself may otherwise be regarded as a negative task which may discourage operators. Motivation of the crew is thus an issue for management.

High flexibility of operating teams should be strived for by combining different skills, including experience from work in active areas and mechanical abilities.

In the course of the decommissioning work, it is important frequently to re-examine the planned steps. In discussions with the team, genuine solutions generated by its members can be obtained.

Strict housekeeping and permanent radiological surveillance help to maintain a high working moral. Transportable, automatic radiation monitors are available to control radiation fields where operations take place. Daily washing of the working area will contribute to avoid spread of contamination. Dismantled parts should be removed from working areas for further treatment, either for decontamination or for direct packing as radioactive waste. Tools to be used for dismantling can be adapted so as to facilitate operations in narrow spaces.

Before each decontamination step, the generation of secondary waste, and the total cost, should be ascertained in a realistic way. The value of metallic scrap for reuse in commercial products may be low compared to the operating cost and the secondary waste treatment costs. There is also an inherent difficulty in proving that scrap metal is below limits that permit clearance from radiological control. Special instrumentation is needed to measure low surface activities within thin process pipes.

In many cases it may turn out that secondary waste volumes will exceed the volume of the original object to be decommissioned. In the present case, comparison of direct packaging with decontamination, and the use of boxes instead of drums, reduced the waste volume to half the original estimate.

Delayed reprocessing can be a preferred option, when advantage can be taken from the decay of short-lived nuclides. Delayed decommissioning requires availability and updating of all relevant information about the plant, including drawings, operating instructions, etc. On the other hand, availability of members of the original operating crew will facilitate decommissioning to a great extent. Thus, the reduced doses to the operating crew that can be obtained by delaying operations must be weighed against the disadvantages.

After termination of operations of the plant it is important to maintain a staff which is given responsibility to take care of safety, inventory, the building, and first of all the archives. During the period up to the start of decontamination and dismantling, it is important to avoid uncontrolled situations with respect to removal of equipment and the risk of contamination.

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Appendix A

The management and operating crew involved in decommissioning of the Uranium Reprocessing Pilot Plant and persons who joined the Nordic research project KAN-1.2.

Educational degree:
M.Sci. = University or Technical High Scool
Engineer = Technical college grade
Other specifications = Skilled or unskilled workers

The decommissioning of the uranium reprocessing pilot plant is managed by the Radioactive Waste Section (Head, **John Erling Lundby**, chemical engineer . He participated in the operation of the actual plant for two years. More than 30 years of experience in radioactive waste operation and related work). The section is part of the Health- and Safety Department (Head, **Gordon C. Christensen**, M. Sci. in nuclear chemistry). A few members of the original operating crew were still available, and the following persons have been involved:

Kjell Frydenlund. Chemical engineer. Member of the construction crew of the Swedish Silex part. Operating manager of the same plant and with long experience regarding construction and running of chemical-technical plants. Has done a great part of the practical dismantling work.

Erik Karlsen. Mechanical engineer. Participated for more than one year in the intermediate, and probably the most complicated decommissioning period. Long experience in radioactive Hot-cell work.

Bent Øverhagen. Mechanic. Experience in radioactive waste treatment and has managed the dismantling work in the latest period.

Oddvar Bjerke. Technician. Long experience as radioactive waste treatment operator. Participated in the decommissioning work in periodes and with the waste treatment of dismantled parts.

Øistein Nordhelle. Plant operator. Experience as tinman before radioactive waste treatment work. Joined the decommissioning work in periodes.

Geir Solberg. Electrical engineer. Radiation protection engineer since 1988. Participated in the experimental laboratory work, especially the instrumentation.

Gunnar Hannestad. M.Sci. in chemistry. Several years of development and research work with chemical and radiation analysis, uranium and plutonium purification and related projects. Participated in the experimental laboratory work.

Kjell Neset. M.Sci. in chemistry. Several years of development and research work with chemical and radiation analysis, nuclear reactor chemistry, and chemical-technical projects. Participated in the experimental laboratory work.

The Radiation Protection Section (Head, **Eivind Stedje**, M. Sci. in Physics, several years of experience in radiation protection work) has continously followed the decommissioning work and health physics control as described in chapter 3.

During the first decommissioning period in 1982 - 1983 the work was managed by the Chemistry Department (Head, **Bjørn Gaudernack**, M.Sci. in chemistry), and the following persons assisted:

Kjell Frydenlund, see above
Olav Moi,chemical engineer
Finn Helgesen, mechanic
Leif Karlsen, mechanic

Appendix B

Translation English - Norwegian

Angle grinder	=	vinkelsliper
Arc saw	=	sirkel (bue) sag
Blowing wedge	=	sprengkile
Chisel	=	meisle
Chisel hammer	=	meiselhammer
Chiseling	=	meisling
Cutting blowpipe	=	skjære-brenner
Explosive drilling clamp	=	anboringsklammer
Flat chisel	=	flatmeisel
Hardening	=	herde
Jigsaw	=	vippesag
Landings	=	dørkplater
Lead chips	=	blyspon
Lead shots	=	blyhagl
Mill	=	frese
Milling	=	fresing
Milling machine	=	fres, fresemaskin
Nibbler	=	platesaks/nibbler
Pickle	=	beise
Pickled pipe	=	beiset rør
Pickling	=	beising
Plasma arc cutter	=	plasmaskjærer
Riveting punch	=	naglekutter
Roll	=	valse
Shear	=	større saks for klipping av metall
Staircase railings	=	trappe-rekkverk
Pipe cutter	=	rørkutter
Turntable	=	dreieskive
Water abrasive blasting	=	våtblåsing med slipemiddel

Appendix C

Piping systems, decontamination compared with cutting and packing

The 6000 meters of contaminated pipe lines had an average of 16.5 mm in outer diameter and a wall thickness of 2.5 mm. The weight is approximately 1 kg/m, that means 6000 kg totally. The scrap value for stainless steel is NOK 3/kg with a total of NOK 18 000.

If melting and selling to a steel factory the most realistic price is the scrap value. On the other hand, stainless steel as a raw material resource represents a value of NOK

10 - 20/kg and a total of	NOK 90 000
Three waste containers are saved:	NOK 69 000
Final disposal cost:	<u>NOK 5 160</u>
Available for decontamination:	<u>NOK 154 160</u>

The decontamination costs are estimated as follows:

Chemicals and equipment (NOK 25 x 2000 l)	NOK 50 000
Preparative arrangements (4 manmonths)	NOK 168 000
Decontamination (4 manmonths, 100 m pipes/day)	NOK 168 000
Melting costs (NOK 15 x 6000 m)	NOK 90 000
Treatment of chemicals (evaporation, neutralization and solidification of 500 l in 4 drums)	NOK 24 000
Final disposal cost	<u>NOK 3 000</u>
Total decontamination costs	<u>NOK 503 000</u> ≈ 500 000

Cutting costs for tight and reasonable packing is estimated to 2 men in 5 hours/day in 8 days, i.e. 80 hours for filling approximately 2000 m steel pipes in one box (see section 8.3)

Cutting and packing of 6000 m steel pipes (NOK 300 x 80 x 3)	NOK 72 000
3 waste boxes	NOK 69 000
Final disposal	<u>NOK 5 160</u>
	<u>NOK 146 160</u> ≈ 150 000

<u>Summary:</u>

Scrap value	NOK 18 000	
Decontamination	NOK 423 280	(441 280 - scrap value)
Direct packing	NOK 146 160	

Appendix D

Vessels and vessels inside vessels

Number of vessels = 40
Average volume 200 l
Wall thickness 4 mm
Weight 80 kg

Scrap value: NOK 3 x 80 x 40 = NOK 9 600 ≈ 10 000.

Two vessels were decontaminated manually and including preparative work and control the time comsumption is 10 h for each, i.e. a working cost of NOK 300 x 10 x 40 = NOK 120 000 and accumulated waste, NOK 40 000.

Decontamination by high pressure water flushing will be tried, but the investment cost is high, NOK 300 000. Anticipated working hours will be considerably reduced to one hour pr. vessel, 40 hours totally, i.e. NOK 300 x 40 =NOK 12 000. In addition treatment, solidification and final disposal cost which is estimated to NOK 10 000 will arise. Total high pressure costs = 322 000.

To place vessels inside other vessels will result in 8 packages with an outer cubical volume of approximately 1 m^3. Space between the vessels can be filled with other items of radwaste.

Time for opening vessels, cutting away extending parts and closing the outer vessel etc. is estimated to eight hours pr. vessel, i.e. 320 hrs.

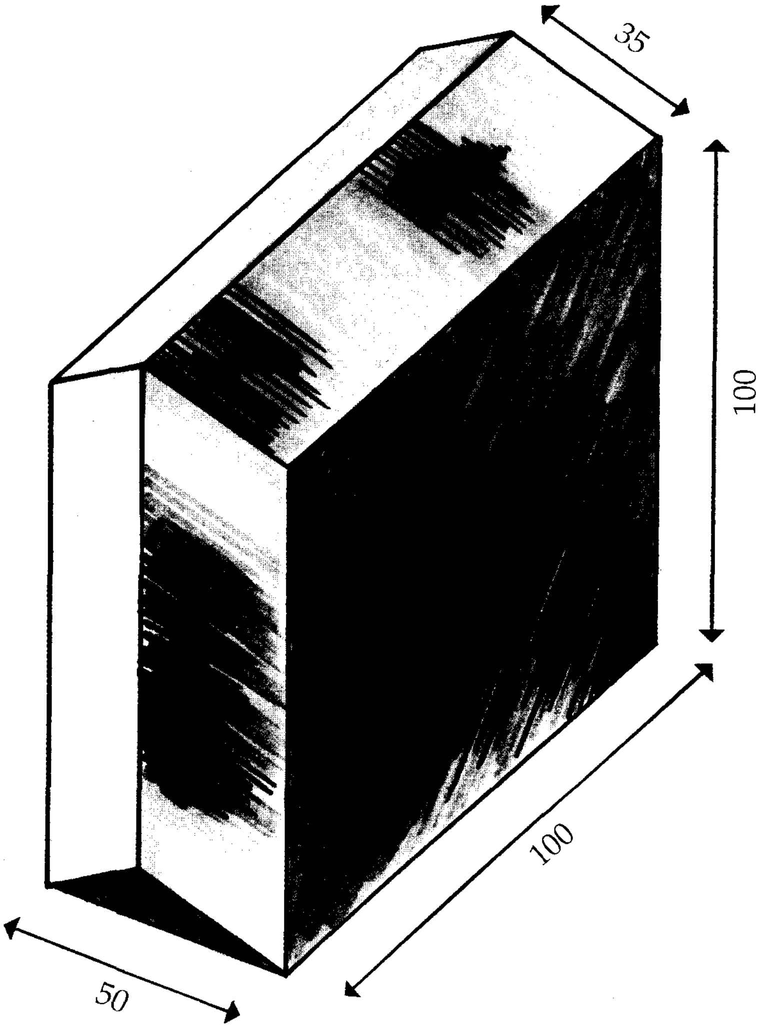
Working costs: NOK 300 x 160=	NOK 48 000	
Final disposal cost NOK 2000 x 8:	<u>NOK 24 000</u>	
	<u>NOK 72 000</u>	≈ 70 000

<u>Summary</u>:

Scrap value	NOK 10 000	
Manual cleaning (for release)	NOK 150 000	(160 000 - scrap value)
High pressure flushing	NOK 322 000	≈ 320 000
Vessels inside vessels	NOK 72 000	≈ 70 000

Appendix E

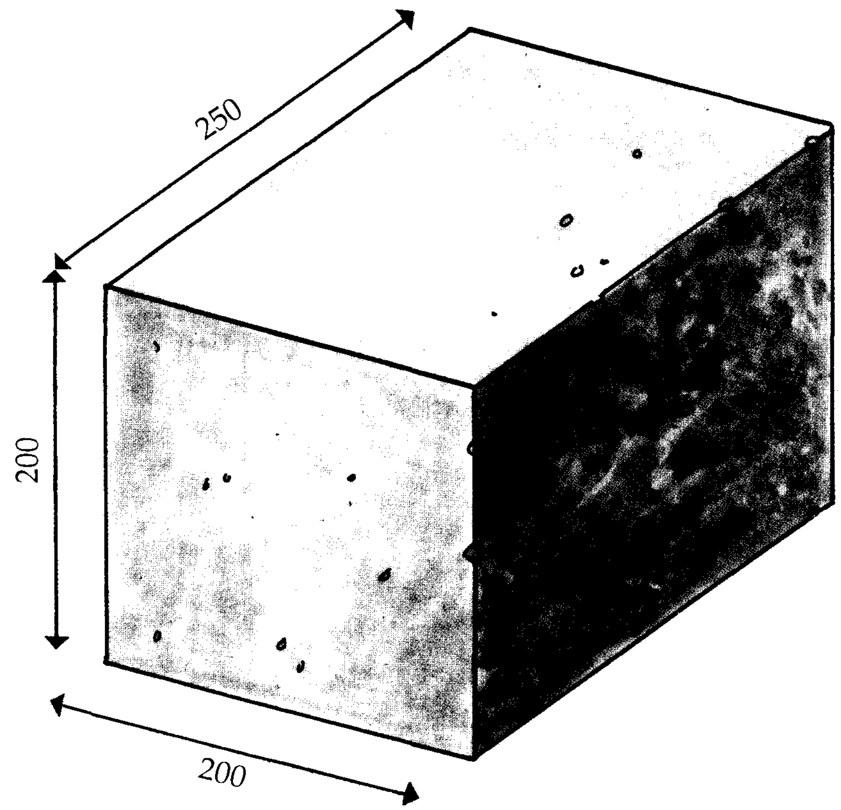
Decontamination of lead shielding blocks



Number contaminated:	1000
Decontamination method:	Mechanical milling (chemical rinsing)
Contamination level:	$\alpha \leq 10$ Bq/cm^2
	$\beta/\gamma \leq 200$ Bq/cm^2
Radiation level:	≤ 5 µSv/h
Average thickness of removed surface layer:	0.25 mm
Removed lead from 1000 blocks:	12 litres, i.e. 2.4 % of total weight
Value of 1000 blocks:	NOK 300 000
Investment and working costs:	NOK 135 000
Net. saved:	NOK 165 000

Appendix F

Decontamination of concrete shielding blocks



Number contaminated:	200 (+ 350 reused in a shielding wall)
Decontamination method:	Chiseling (and chemical rinsing)
Contamination level:	$\alpha \leq 5$ Bq/cm^2 $\beta/\gamma \leq 100$ Bq/cm^2
Radiation level:	≤ 5 µSv/h
Average thickness of removed surface layer:	1.5 mm (spots of 5 mm)
Removed concrete from 200 blocks:	30 litres, i.e. 5 % of total weight, in average two sides contaminated
Packing and storage of 200 blocks (2 m^3) is estimated to:	NOK 50 000
Decontamination, waste treatment is estimated to:	NOK 15 000
Value of 200 blocks:	NOK 10 000
Net. saved:	NOK 45 000

Appendix G

Boxes versus drums

At a early stage in the decommissioning 200 l drums were used as a standard outer container. At that time only smaller parts had been dismantled. It was later changed to stainless steel boxes, lenght x dept x width = 120 x 80 x 80 cm, on a 10 cm high U-profile for lifting (see figure 42).

Prices for radwaste containers

Container type	Material	Material thickness,	Price
110 l drum	Mild steel, SS 1142	1.0 mm	NOK 150
210 l drum	Mild steel, SS 1142	1.0 mm	NOK 250
110 l drum inside 220 l	Mild steel, SS 1142	1.0/1.0 mm	NOK 600
210 l drum	Stainless steel, SS 2343	1.5 mm	NOK 3 600
860 l box	Stainless steel, SS 2343	2.0/3.0 mm	NOK 23 000

Stainless steel was used because corrosive liquids was observed inside some dismantled pipework.

The 210 l mild steel drum as the only container for enclosing the waste was not satisfactory. A better performance is expected of a 110 l drum placed inside a 210 l with 5 cm concrete in between (see figure 41). This type is mostly used for compression of paper, plastic, rags, brushes, protective clothes etc. The cost of using a 210 l stainles steel drum is also evaluated in the table.

Effective volume required for storage

	Storage volume	Effective volume
110 l inside 210 l drum	320 *	110 litres
210 stainless steel drum	320 *	210 litres
860 l stainless steel box	864	738 litres

* The square volume around the 210 l drum is 320 litres.

It is necessary with:
6.7 drums of the type 210/110 compared to 1 box (738 : 110 = 6.7)
3.5 drums of the type 210 l stainless steel compared to 1 box (738 : 210 = 3.5)

Comparable costs are then:

6.7 drums, type 210/110	4 000 NOK
3.5 drums, 210 stainless steel	12 600 "
1 box, stainless steel	23 000 "

Effective utilization of drums/boxes

It is possible to pack 172 kg/245 m pipework and smaller items of an average dimension of 16.5 x 2.5 mm inside the 110 l drum (see figure 41). A box (figure 42) can be filled with 2200 m of pipework and smaller items. The utilization of the effective volume can be calculated in two ways, either the net material volume of the pipes or the outer volume. Based on the net material the utilization is:

210/110 drum = 10 volume % *
210 st.st. drum = 21 "
860 st.st. box = 26 "

* Calculated on outer drum, 210 l. Based on 110 l it is 20 %.

If the calculation is based on the outer volume of the pipes the utilization is:

210/110 drum = 23 volume % *
210 st.st. drum = 47 "
860 st.st. box = 60 "

* Calculation based on 210 l. If 110 l is used the value is 45 %.

The ratio between the effective utilization is the same whether the calculation is based on net or gross volume:

210/110 : 210 : 860 = 1 : 2 : 2.6

In a box it can be packed: $\frac{738 \cdot 60}{100} = 442$ l stainless steel pipes

To pack 442 l in 210 drums it is necessary with 4.5 drums

$$\left[\frac{210 \cdot 47 \cdot X}{100} = 442, \text{ where } X = 4.5\right]$$

The storage volume for 4.5 drums is 320 l x 4.5 = 1440 l. Using the drum type 210/110 it is necessary with

$$\frac{110 \cdot 45 \cdot X}{100} = 442, \text{ where } X = 9, \text{ i.e. 9 drums.}$$

The storage volume is 320 · 9 = 2880 l. Adjusted for effectiv utilization and storage place requirements the ratio is:

210/110 : 210 : 860 = 3.3 : 1.7 : 1

Waste cont. type	Container cost	Temporary storage place	Total
9 pcs. 210/110 l	NOK 5 400	NOK 20 700	NOK 26 100
4.5 pcs. 210 l st.st.	NOK 16 200	NOK 10 350	NOK 26 550
1 pc. box st.st.	NOK 23 000	NOK 6 216 *	NOK 29 216

* Temporary storage cost is NOK 2 300 pr. drum. (calculated internal cost)
NOK (2 300 · 9/3.33) = NOK 6216.

$\frac{320 \cdot 9}{864}$ = 3.33 = The ratio between the required storage place for 9 drums resp. 1 box

Working hours

The use of larger containers means less cutting work, and the average cutting lengths for the three types of containers are 400, 500 and 1190 mm that makes the ratio of the number of cuts, i.e. 3 : 2.4 : 1.

The average cutting and packing hours for pipes and smaller items is estimated as 80 hrs. pr. box, i.e. NOK 300 · 80 = NOK 24 000. Adjusted for working hours it will cost NOK 24 000 · 2.4 = NOK 57 600 to fill an equal amount in 210 l drums, and NOK 24 000 · 3 = NOK 72 000 in 210/110 l drums.

Summing up the container - cutting/packing - temporary storage - and final disposal costs gives:

Container type	Container cost NOK	Cutting packing NOK	Temporary storage NOK	Final * disposal NOK	Total NOK	% more expensive
210/110 l	5 400	72 000	20 700	8 640	106 740	91
210 l st.st.	16 200	57 600	10 350	4 320	88 470	58
860 l st.st.	23 000	24 000	6 216	2 592	55 808	

* The final disposal cost is assumed to be NOK 2 000/m^3 /15/ and NOK 1 000/m^3 for transporting.

Appendix H

Sum up the Decommissioning

Estimated waste volume at start:

150 - 200 drums (210 liters) with an outer square volume of 320 liters.	56 m^3

Accumulated waste including storage containers:

• Number of drums =	$32 \cdot 0{,}32 =$	10,2 m^3	
• Number of boxes =	$10 \cdot 0{,}864 =$	8,6 m^3	
• Estimated volume = of vessels	$8 \cdot 1 =$	<u>8,0 m^3</u>	27 m^3

Hot-cells volume (including decanning pond)	180 m^3
Retrieved building volume	1100 m^3

- The reduction of the final waste volume to approximately the half is caused by the use of boxes instead of drums for metallic waste, and the stress of tight and resonable packing.
- Later in the decommisssioning operation we were also more restrictive with respect to time consuming decontamination steps that may cause larger volumes of secondary waste than the waste objects themselves.

Decommissioning of a Uranium Reprocessing Pilot Plant

- practical experiences

During a few years in the 1960ies a pilot plant was operated in Norway, by a Norwegian and a Swedish team. The chemical process involved radioactive material that was dissolved in various solutions. This report describes the steps that followed once the plant had been emptied and provisionally cleaned, in order to dismantle the equipment so that the buildings can be re-used for other purposes. Solid and liquid radioactive waste is generated in this decommissioning procedure, and valuable information has been obtained about tools to be used and about handling the radioactive waste.

The Nordic Committee for Nuclear Safety Research - NKS
organizes pluriannual joint research programmes. The aim is to achieve a better understanding in the Nordic countries of the factors influencing the safety of nuclear installations. The programme also permits involvement in new developments in nuclear safety, radiation protection, and emergency provisions. The three first programmes, from 1977 to 1989, were partly financed by the Nordic Council of Ministers.

The 1990 - 93 Programme
Comprises four areas:

* Emergency preparedness (The BER-Programme)
* Waste and decommissioning (The KAN-Programme)
* Radioecology (The RAD-Programme)
* Reactor safety (The SIK-Programme)

The programme is managed - and financed - by a consortium comprising the Danish Emergency Management Agency, the Finnish Ministry of Trade and Industry, Iceland's National Institute of Radiation Protection, the Norwegian Radiation Protection Authority, and the Swedish Nuclear Power Inspectorate. Additional financing is offered by the IVO and TVO power companies, Finland, as well as by the following Swedish organizations: KSU, OKG, SKN, SRV, Vattenfall, Sydkraft, SKB.

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