Dismantlement of the Amsterdam 700 MeV Linear Electron Accelerator MEA, Electron Storage Ring AmPS and the Experimental Halls.

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INTRODUCTION.

On January 1, 1999 the electron scattering experiments with the 700 MeV linear accelerator were terminated. As no new accelerator facility is envisaged the accelerator and the experimental set-ups have to be dismantled and removed in order to terminate the licence to operate a nuclear facility. The removal of the facility has to be executed in accordance with a plan approved by the Dutch ministry of Housing, Spatial Planning and the Environment (ministry VROM).

The plan submitted by NIKHEF was never officially approved, as there were no official regulations covering the issue. The Inspectorate of the ministry VROM was informed regularly.

After an official clearance of the former irradiation vaults by the ministry VROM it was intended to let the buildings to commercial companies.

OVERVIEW OF THE FACILITY.

An overview of the facility is shown in figures 1 and 2. The 200 m accelerator MEA produces 700 MeV electrons, which are injected into the 210 m electron storage ring AmPS. The facility encompasses the beam switchyard AFBU, the electron scattering hall EMIN, the former pion-muon facility PIMU, and former low-energy irradiation facilities for chemistry and physics. The accelerator, the beam switchyard and the storage ring are located underground.

The accelerator and the experimental facilities were used for approximately 20 years for nuclear physics research. In 1990 the electron storage and stretcher ring was constructed.

Up to December 1998 electrons were extracted from the ring to provide a 5 μA electron current with a duty

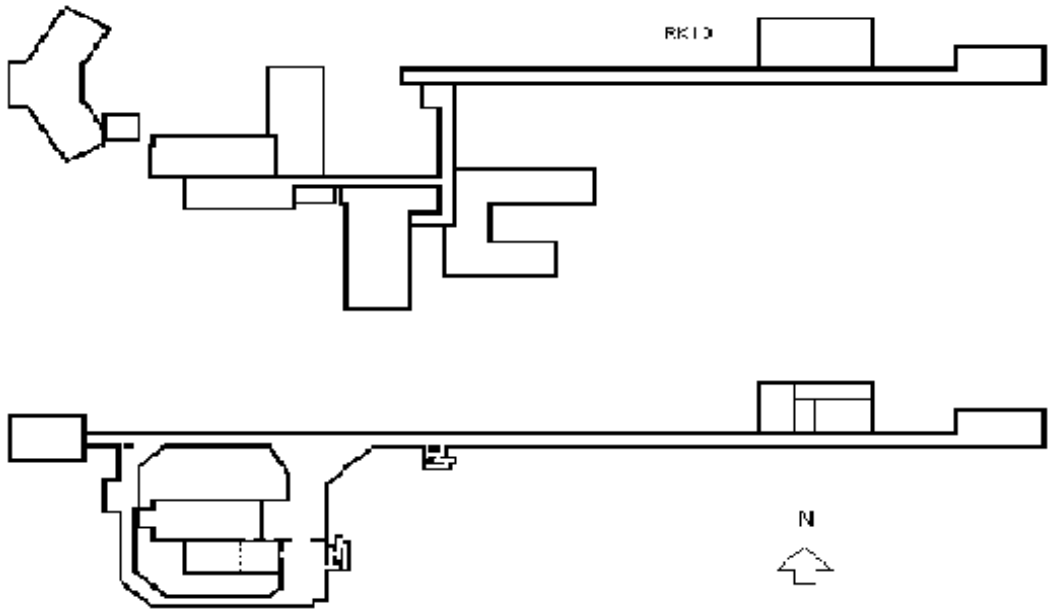

Figure 1. Plan of the accelerator buildings. Upper part: above ground level, containing power supplies; lower part: underground structures containing the accelerator, the beam switch yard and the experimental areas.

cycle of about 80 % for electron scattering experiments. From 1998 on only experiments with a stored electron beam with polarised electrons and internal targets were performed.

STARTING PRINCIPLES.

The facility has to be dismantled on a short time schedule, as the licence does not allow NIKHEF to store radioactive materials for a long time. Further, reuse of components is useful only if they are available now.

Re-use by other laboratories is preferred over recycling; recycling is preferred over storage as chemical waste or as radioactive waste.

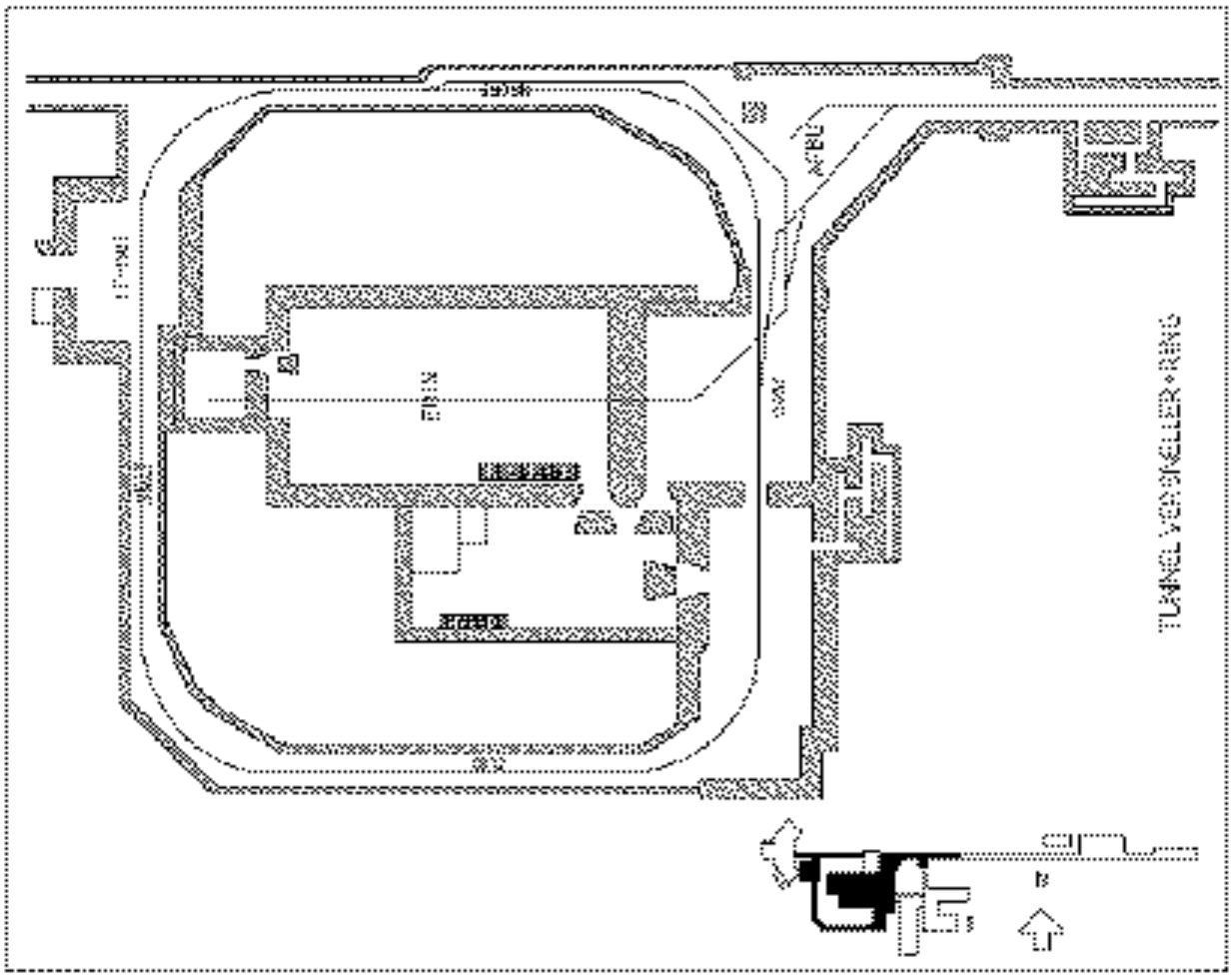

Figure 2. Plan of the beams in the beam switch yard, the storage ring and the experimental areas.

CHARACTERISATION AND MEASUREMENT OF THE INDUCED ACTIVITY.

The activation of accelerator structures and of concrete shielding is well studied (1, 2, 3, and 4). For this accelerator the prominent isotopes with half-lives longer than 60 days are given in table 1.

Table 1. Prominent activation products in the accelerator structures and the concrete shielding walls.

	isotopes	Half-lives
stainless steel	^{56}Co, ^{57}Co, ^{58}Co, ^{60}Co ^{54}Mn, ^{55}Fe, 84 d	77 d, 282 d, 71 d, 5.27 y 312 d, 2.7 y, 84 d
copper	^{57}Co, ^{58}Co, ^{60}Co, ^{54}Mn	282 d, 71 d, 5.27 y, 312 d
aluminium	^{22}Na	2. 6 y
concrete	^{152}Eu, ^{154}Eu	13.3 y, 8.6 y
lead	^{207}Bi	2.1 y

An ISO standard for the determination of the activity in solid materials intended for recycling is published (5).

For the determination of the radioactive content a calibrated portable germanium detector (86 cm^3, Oxford Instruments, Target, iSPEC plus analyser) is used for in-situ measurements. Small samples are measured with a 40 cm^3 germanium detector in a calibrated geometry.

As the activation of the material is highly inhomogeneous, the activity in large objects has to be estimated by means of the computer program MicroShield 5®. Gamma dose rates are measured with a 1” x 2” NaI detector (Target, FieldSPEC).

REMOVAL OF THE ACCELERATOR, STORAGE RING AND BEAM SWITCHYARD TO JINR, DUBNA, RUSSIA.

The accelerator and the storage ring will be reused as components of a new synchrotron light source by the Joint Institute for Nuclear Research (JINR) in Dubna, Russia.

Before the dismantlement of the facility started, a comprehensive database of all components was set up. For each component the database contains the description, the function, the position, a unique number, the dose rate on the surface and at 30 cm and an electronic picture showing the number.

Apart from some parts of the ring injection system all components could be transported as exempted material or as LSA II or LSA III material. The accelerator sections could be transported as inactive material. The only slightly activated components of the accelerator are the section collimators. These can be removed easily to facilitate the transport.

The transport was performed by a Russian subsidiary of a Dutch transport company. It required about 60 transports of about 20 tonnes each. It was completed in 2000.

The transport of the activated ring components and the ring injection magnets required transport licences for Germany, Poland, Belarus and Russia.

REMOVAL OF SLIGHTLY RADIOACTIVE COMPONENTS AS METAL-SCRAP.

Considerable amounts of slightly activated copper, steel and aluminium have to be removed. In the Netherlands there were at that time no reference values for the clearance of activated materials.

In the literature there are a number of values for the activity concentration below which the material can be recycled without further regulatory control (6, 7, and 8). However, for large structures like magnets, which are only locally activated it is unclear whether averaging is allowed.

The Swiss definition of clearance was considered (4). Activated materials are separated into 5 categories: inactive material, material with a dose rate of 0 to 0. 1 μSv h^{-1} at 0. 1 m distance, of 0. 1 to 10 μSv h^{-1}, of 10 to 100 μSv h^{-1}, and > 100 μSv h^{-1}.

Factors to convert dose rate to an estimated activity concentration were determined for various materials, masses and geometries.

To be considered inactive, the activity concentration should be < 3 Bq g^{-1} for ^{22}Na and < 1 Bq g^{-1} for ^{60}Co, and the dose rate at 0. 1 m distance should be < 0. 1 μSv h^{-1}. Unfortunately for large items even lower activity concentrations than 1 Bq g^{-1} are required to meet the second criterion.

All these considerations were of little use: no scrap metal company accepted material that activated the alarm level of the radiation detector at the entrance of the scrap yard. Experiments showed that an activity of 0, 5 Bq g^{-1} ^{22}Na or ^{60}Co averaged over a load of 6 to 10 tonnes could easily be detected.

Thus only the electron scattering set up, containing about 400 tonnes of scrap metal and 350 tonnes of concrete shielding could be disposed of as reusable materials.

About 31 tons of lead used for shielding the energy defining slit and the beam dumps could be recycled. The lead was not activated, but the steel internal frames contained measurable amounts of ^{60}Co.

Separation was done by melting under supervision of NIKHEF and the ministry VROM in a commercial lead processing factory. The steel components could be easily removed, as they floated on the molten lead.

The materials which could be deposited as chemical waste were packed in 15 m^3 reinforced plastic containers usually used for the disposal of asbestos (figure 3, 4).

Figure 3. Contents of a partly filled asbestos disposal bag.

Figure 4. Final deposition of activated materials as chemical waste.

REFERENCE VALUES.
At the time material was considered radioactive when the activity concentration was > 100 Bq g^{-1}. From this it was decided that all material with an activity concentration > 50 Bq should be disposed of as radioactive waste.
Due to the inhomogeneous distribution of the activity and the large variety of objects the separation between radioactive and non-radioactive objects had to be done using a dose-rate meter and the measured or calculated conversion factors mentioned above.
All other materials in which activity could be detected were to be disposed of as chemical waste.

ACTIVATED COMPONENTS.
Four aluminium dumps, the stainless steel energy defining slits and one pion production target were activated to dose rate levels > 1 mSv h^{-1} at 0. 1 m from the surface. Activity concentrations were in the order of 10^5 Bq g^{-1}.
To dismantle these components and prepare them for transport to the Central Organisation for the Storage of Radioactive Waste (COVRA), NIKHEF was assisted by a group of COVRA technicians. All other activated parts were collected in steel containers of 0, 5 m^3. for transportation.
After transportation to COVRA these objects were disseminated and put in standard 100 l COVRA drums for further processing.
Some water-cooled components still contained water residues. The maximum concentration of ^{22}Na amounted 0, 6 Bq g^{-1}. Most of the water could be released as non-radioactive.

RADIOLOGICAL PROTECTION PROGRAM.
As a large number of Russian guests are involved in the dismantling and packing of the facility a radiation protection program was set up. As a result of a stringent beam management system the radiation levels are generally low. However, the controlled access to the accelerator area and the stringent ban on the removal of any uncontrolled item from the area were maintained.
On arrival there was a brief instruction about the Dutch regulations, about the rules of conduct in the accelerator area and about the operation of the various dose and dose rate meters. An interpreter was present to ascertain the correct interpretation of the information. For checking the dose rates FAG FH 40F2 meters were used. Regular TL dosimeters were used to measure the accumulated dose, for operations where some exposure could occur Siemens Plessey EPD's were issued. The readings of the TL dosimeters were communicated to the Russian radiation protection officer and to the workers.

BUILDINGS.
In view of the presence of a mayor node of Internet at NIKHEF the buildings were of interest for companies involved in computer network technology.
The 200 meter gallery originally housing the power supplies of the accelerator is let to a British company involved in internet activities. Although no electron beam ever was present in that part of the building, a complete radiological survey was made by NNC Ltd before the decision was made.
When in a later stage also the use of the underground tunnel was considered, again a radiological survey was made. Before that, NIKHEF had to construct a masonry wall to close the access to the former low-energy experimental areas and NIKHEF had removed some 25 cm activated concrete to a depth of 30 cm at a spot

where the electron beam had activated the wall. The gamma dose rate at this position was raised 0. 066 μGy.h^{-1} compared with the background of 0. 121 μGy.h^{-1}. For an occupation of 2000 hours a year this converts to an additional effective dose of 115 μSv.h^{-1}. As this was not supposed to be rented by the company it still was an obstacle. In the mean time the market for these activities collapsed, and the negotiations were terminated.

In order to revoke the nuclear licence a radiological survey has to be made.
All structures that are activated are located underground. Thus, unless the buildings are demolished, access is controlled.
There are a number of clearance values for buildings and for building rubble (table 2). The only official value now is the clearance level from the Dutch Radiation Protection act.

Table 2. Various clearance levels for buildings and building rubble.

	Dutch clearance level	Various clearance levels recommended by art 31 experts, European Union						
	all materials	Report 89 Scrap metal		Report 113 buildings and building rubble			Report 122 all materials	
	Bq/g	Bq/g		Bq/g	Bq/cm^2		Bq/g	
			rounded			rounded		rounded
Na-22	10			0.1	3.5	10	0.13	0.1
Co-60	1	0.6	1	0.1	2.9	1	0.099	0.1
Eu-152	10			0.1	6.2	10	0.21	0.1

The walls of the beam dumps for the pion target area and for the electron scattering hall are activated to a measurable extend, about 9 Bq g^{-1} ^{60}Co for the steel shielding of the pion target, and about 5 Bq g^{-1} ^{152}Eu for the electron beam dump area. The entrance to the pion target area is locked, and the access from the beam switch yard is controlled. The electron beam dump area is closed with a 2m thick concrete door, which is sealed at the inside and the outside to prevent water from leaking into the other halls in case groundwater should leak in. In addition a masonry wall is constructed to close the recess leading to the area. This wall also shields the minor activation of the concrete around the former beam line.
In the other bunkers 29 samples of the concrete are taken to a depth of about 30 cm. The positions were based on information about the beam properties, and on measurement of the dose rate.
Only in one position the activity was about 1 Bq g^{-1}, ^{60}Co, ^{22}Na and ^{152}Eu combined. In 10 positions in the beam switch yard the activity per gram and the activity integrated over 30 cm is larger that the values recommended by the European Union (9).
In nine concrete samples there was a chunk of reinforcement steel. One sample contained 6 Bq g^{-1}, the other samples contained less than 1 Bq g^{-1}, the Dutch clearance level for ^{60}Co.
NIKHEF is working on an application for a new nuclear licence.

Costs.
Costs that could be traced directly to the decommissioning are given in table 3.

Table 3. Decommissioning costs

	costs
radioactive waste	€ 195000
chemical waste	€ 2600
additional NIKHEF personnel	€ 23000
support by COVRA	€ 25000
removal of the electron scattering setup	€ 70000

CONCLUSIONS
The reuse of a major part of the facility saved NIKHEF considerable means: manpower for dismantling and the expenses for deposition as chemical waste.
Outside companies are only interested in the use of the buildings if there are no measurable increments in the radiation fields due to activation. They simply do not wish any discussion with worried employees about the subject. The observation that the radiation field due to natural radioactivity of concrete is considerably more does not carry weight.

There are no firm criteria for the clearance of buildings. As long as the buildings are used and controlled by NIKHEF that is no problem.

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