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Project for the handling and storage of vitrified high-level waste

Saint Gobain Techniques Nouvelles Oct 1977

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PROJECT FOR THE HANDLING AND STORAGE OF VITRIFIED HIGH-LEVEL WASTE

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5. SAFETY ANALYSIS

I. INTRODUCTION

1.1. The disposal of high level wastes

The high level wastes (HLW) originating from the reprocessing of spent fuels contain 99.9 % of the fission products, a maximum content of 1 % of the uranium and plutonium present in the spent fuels, and most of the other transuranic elements (1).

These wastes will be solidified in the reprocessing plant of La Hague giving an homogeneous borosilicate glass of a very low leachability. The HLW corresponding to one ton of uranium reprocessed are finally enclosed in a glass block of 150 liters. The composition of these HLW, hence their radioactivity and their heat release depends on the burn-up of the fuels. The related figures will be higher for PWR fuels which can be irradiated up to 33.000 MWd/t, than for BWR fuels whose burn-up is limited to 28.000 MWd/t. Our calculations are based on PWR fuels in order to be conservative (see Annex 1).

The glass blocks enclosed in a sealed container made of refractory stainless steel will be cooled in the reprocessing plant for the first years (up to 10 years), till their heat release will be lower than 7.6 watts/liter, i.e. 1140 watts/canister.

The glass containers will then be shipped to Sweden at a rate of 300 canisters/year, after 1990. The shielded casks to be used for this transportation will be very similar to the casks presently used for spent fuels transportation.

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(1) This content of 1 % is a conservative figure. Actually, the losses recovered in the HLW of the reprocessing plant are in the range of 0.5 % for U and Pu. Basically the safety problem of the disposal of HLW is the same for both cases.

The best way to dispose of these vitrified wastes is to bury them permanently underground. Furthermore, the cristalline bedrock in Sweden offers favorable geological conditions.

The glass containers will be deposited in pits accessible by tunnels drilled at 500 m below ground surface. The density of storage will depend on the heat release of the canister, and on the heat conductivity of granite and of the different materials inserted between the granite and the canisters. The glass is subject to devitrification when its temperature is higher than 600°C. It crystallizes, becomes brittle, and its leachability increases though remaining in a good range.

It is therefore advisable to keep the maximum temperature of the glass at the center line of the container below 500°C. This is normally achieved in the cooling ponds in La Hague, and in the shipping casks. If the canisters were to be disposed of immediately after reception in Sweden, i.e. after 10 years maximum of cooling, the temperature rise in the final storage would greatly limit the density of storage in the granite, and also the corrosion effects on the final packing would be enhanced.

In order to realize the best conditions of storage, it is preferable to put the glass containers in an interim storage for at least an additional period of 30 years. This storage will be cooled by forced air, and possibly by natural convection. After this total period of 40 years of cooling, the maximum heat release will be :

3.42 watts/liter of glass

or 513 watts/container

This heat release will allow a density of storage of one container per 100 m2.

The potential health hazard of the HLW varies greatly along the time. If we consider the decay curves of the HLW we see that the decrease of activity (and correlatively of heat release) is relatively fast during the first 600 years. This corresponds to the decay of the fission products whose activity is :

312.000 Ci β/ton of uranium (i.e. per canister) after 10 years

32 Ci β/ton of uranium after 600 years

The remaining activity, due to the actinides (uranium and transuranic elements) decrease very slowly :

3.130 Ci α/ton of uranium after 10 years

135 Ci α/ton of uranium after 600 years

Beyond this time, the activity of actinides is predominant.

Taking these facts into account, the strategy of the final storage will be the following :

1/ We shall provide the best isolation possible of the glass container by means of an encapsulation during the first 600 years in order to avoid any leaching of the fission products, constituted mainly by cesium and strontium.

2/ After this period, the health hazard will be reduced by a factor of 10.000. The release of the radioisotopes to the environment will remain limited by :

- Leachability of Pu appears to be somewhat lower than for the fission products (Cs/Sr) after long period of leaching. Leachability of Am is lower than for Pu.

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- the diffusion of the actinides into the ground in the rock;

- the space between the container and the rock will be filled with a material having a low permeability and some ion exchange capacity.

Thus the rock, the encapsulation and the low leachability of the glass and the filling material constitute the four barriers provided against the migration of radioactive nuclides to the biosphere.

1.2. Basic concept

According to the hereabove considerations, the main steps toward the final disposal of the vitrified HLW will be the following :

1.2.1. Transportation

The glass containers will be shipped from the reprocessing plant of La Hague to Sweden in shielded casks similar to those presently used for spent fuels. For example, the NTL 12 cask used for transportation of 12 PWR fuel elements with a heat release of 120 KW can be used for transportation of 15 glass containers with a maximum heat release of 17 KW The γ shielding is more than enough. The neutron shielding will also be sufficient.

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1.2.2. Intermediate storage

This storage will be built 30 meters under ground, for physical protection, and will allow an additional cooling of at least 30 years. Its capacity will be in a first step of 3000 containers, extensible to 6000 containers.

The transportation casks brought by trucks will be discharged in a special cell. After monitoring the containers will be stored in vertical pits cooled by forced air. This type of storage will be quite similar to the storage to be put in operation in early 1978 in Marcoule. All safety measures will be taken to maintain the necessary ventilation. In case of power failure of long duration (some days) natural convection will maintain the glass below a maximum temperature of 500°C.

The design of the whole facility will comply with the regulations in force in nuclear installations.

1.2.3. Encapsulation

After the additional 30 years cooling, the glass containers will be put into a titanium canister prior to final disposal. This enveloppe (thickness 6 mm) will have an excellent resistance to corrosion by ground water.

Between the titanium canister and the glass container, a filling of 10 cm of lead will be poured for the following purposes :

- Mechanical strength to avoid the deformation of the canister under a water pressure of 50 bars.

- Additional protection against corrosion.

- Attenuation of the γ flux to minimize the radiolysis of ground water to a level, which will not be damageable for the titanium enveloppe.

This containering is performed in a special hot cell at the outlet of the intermediate storage.

The canisters are then transferred into the final repository in a shielded cask .This cask is lowered to the mine through a material shaft by a drum hoist. This shaft is connected to the intermediate storage by an underground gallery.

1.2.4. Final repository

- The final repository will be located at a single level 500 meters below the rock surface (as an alternative a location at 1000 m depth could also be considered).

- The tunneling system will have 41 tunnels, each with a length of 1 km, with a c/c distance of 25 meters and will then cover an area of 1 km x 1 km.

- The canisters will be placed in vertical holes with a diameter of 1 meter and a depth of 5 meters with a c/c distance of 4 meters. One canister will be placed in each hole. Backfilling of the holes will be made with a filling material having a good ion-exchange property (bentonite + quartz sand). This material will have a thickness of 20 cm. It will also prevent any damage to the canister from a possible tectonic movement.
- The holes will be drilled into the rock from the floor of tunnels having a width of 3.5 meters and a height of 3.5 meters.

- The repository will have four vertical shafts for communication and ventilation.

- Placing of canisters will begin at one end of the repository and proceed towards the other. Backfilling of the tunnels and the shafts will be made when all canisters have been placed, thus 30 years after the first canister has been placed.

- Until then the ventilation of the entire tunneling system will be maintained. This ventilation will be designed in accordance with the Mines Safety Regulations, taking into account the additional heat flux of the stored canisters.

  Nuclear specifications will only apply to shielding against radiations (γ and neutron).

- Retrievability of the canisters before backfilling of the tunnels, has not been considered as an target. However it will remain possible.

II. PROPERTIES OF THE HLW

2.1. Composition

We are assuming the HLW are coming from the reprocessing of PWR fuel elements,

with a burn-up of 33.000 MWd/ton of U
a specific power of 30 MW/ton of U

which is the most pessimistic case.

Moreover, we suppose the reprocessing occurs 10 years after discharge of the reactor, which is an upper limit. In this case, the content of americium and its decay product will build-up in the spent fuels.

The detailed composition of the HLW is given in Annex 1 . These HLW contain all the fission products, 1 % of uranium and plutonium present in the spent fuels, most of the other transuranic elements, and some metallic impurities from the process.

After solidification in the glass, the HLW content can be splitted as follows, per ton of uranium :

Fission products	(as oxides)	:	35,75 kg
Actinides	"	:	10,5
Metallic impurities	"	:	2,25
(Al, Cr, Fe, Ni, Cr, Si, Na)			
	Total		58,5 kg/ton of U

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2.2. Activities

With the same assumptions, the activities of the HLW are given in Annex 2. (This annex shows the spectrum of γ curies which is used for the shielding calculations).

- 10 years after discharge of the reactor, the activity will be the following :

Fission products	:	312.000 Ci β/ton of U
Actinides	:	3.130 Ci α/t
Total	:	315.130 Ci/t

- 40 years after discharge :

Fission products	:	143.000 Ci β/t
Actinides	:	1.930 Ci α/t
Total	:	144.930 Ci/t

2.3. Heat flux

The heat flux will be :

- 10 years after discharge :

Fission products	:	1030 W/t
Actinides	:	108 W/t
Total	:	1138 W/t

- 40 years after discharge :

Fission products	:	447 W/t
Actinides	:	66 W/t
Total	:	513 W/t

The curve of the heat flux along time is given in Annex 3.

2.4. Glass composition

The average glass composition will be the following :

SiO_2	:	60 %	
Na_2O	:	10 %	
B_2O_3	:	16 %	
HLW (oxides)	:	14 %	(including transuranium elements and metallic impurities)
Total		100	

This corresponds to a concentration of 150 liters of glass per ton of uranium, which volume will be poured in single container.

2.5. Glass container

The glass canister is made of refractory stainless-steel (type Z 15 CN 24-12 : chrome 23-24 %, nickel 12-13 %, carbon 0.15 %)

The main dimensions are :

Diameter	:	400 mm
Overall height	:	1500 mm
Opening diameter	:	200 mm
Thickness - body	:	3 mm
- head	:	4 mm
Useful volume	:	150 liters

The cover is automatically welded in hot cell with a plasma torch. The stainless-steel material has a good resistance to water or in air even at temperatures of 300°C - 400°C. This resistance will be very limited in saline water.

2.6. Glass properties

The glass block is homogeneous, isotropic and without porosity.

- Fusion temperature : about 1150°C
- Crystallization temperature : above 600°C
- Density : 2.8 g/cm3
- Thermal conductivity : 1.2 W/m x °C
- Leachability by water at 25°C :
  - for fission products : 10^{-6} to 10^{-8} g/cm2 x day (higher figure for cesium , lower figure for ruthenium)
  - for actinides : 10^{-7} to 10^{-9} g/cm2 x day (higher figure for plutonium, lower figure for americium)

The leachability increases with the temperature. It is 10 times higher at 70°C.

The stability to radiation is very good. After irradiation up to 10^{11} rads, there is no energy build-up in the glass and the leachability is the same.

The incorporation of α emitters at high concentrations, simulating in one year the actual dose integrated in 1000 years gave the same results.

Bibliography : "La Vitrification en France des Solutions de Produits de Fission" by R. BONNIAUD (CEA-MARCOULE), Nuclear Technology Vol. 34, Aug. 77, pp. 449-460.

III. INTERMEDIATE STORAGE AND ENCAPSULATION

3.1. General Description of Facilities

This installation has the function of :

- receiving the NTL 12 transport casks containing the containers of vitrified HLW coming from the reprocessing plant;
- unloading the containers contained in the transport casks;
- transferring the containers to an intermediate storage for activity decay;
- transferring the containers, after decay, from the intermediate storage to a encapsulating cell where they will be put into titanium-lead canisters, before final storage.

It comprises :

- A cask receiving hall, in which the container transport cask arrives on its road trailer.
- A cask monitoring room, in which the internal activity of the cask is monitored before the containers are unloaded.
- An unloading cell, in which the following operations are carried out :
  - the unloading of the cask;
  - the provisional storage of the containers contained in the cask;
  - their evacuation to the temporary storage.

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- A recanning cell for damaged containers, in which the damaged and contaminating containers are put into tight containers before being removed to the temporary storage.

- An intervention cell, which permits : the transfer of equipment in the cells, its maintenance, its decontamination and conditioning in the event of its being evacuated outside the installation.

- A temporary storage, in which the containers are stored for the time necessary for their activity decay and temperature decrease before they are stored definitively.

- An encapsulation cell, in which, after temporary storage, the containers are conditioned before being put into their final storage pits.

3.2. Transport Cask

The containers coming from the reprocessing plant are transported in a shielded cask, type NTL 12, in conformity with the prescriptions of the latest safety regulations of the IAEA for radioactive material transportation.

The conception of the packaging is of the type "all in" comprising between the stainless steel containment vessel and the outer shell :

- a lead gamma shielding;
- a solid neutron shielding;
- a fireproof shielding.

Inside the tight containment vessel, the cooling is ensured by natural convection between the needles and allows the thermal transfer towards the cavity walls.

The external cooling is performed by air and also by natural convection. All the control and safety parts are sunk in the packaging body, at its upper part and protected against impact and fire by a shock-absorbent hood.

- A thermal transfer by conduction and an air cooling by natural convection allow the guarantee of the package cooling whatever the circumstances and the orientation of the package may be, after an accident.

- A fireproof shielding allows the appreciable limitation of the temperatures inside the package in case of real fire outbreak and thus the avoidance of the neutron and gamma shielding destruction and, especially, a slackening of the primary heat-carrier fluid, even when filtrated to the atmosphere.

- A solid neutron shielding guarantees its existence whithout restriction under normal conditions of use as well as under accidental conditions.

- Inside the package, there is a part for centering the containers, constituted by an aluminium alloy block (ALPAX), comprising five pits, each capable of taking three containers vertically, i.e. a total of 15 containers per cask.

- Several devices and fittings ensure the safety on the highway and allow the performance of each necessary control when loading and unloading the packaging :

  . safety valves provided to avoid dangerous overpressures in case of an accident worse than in legal tests;

  . self-closing connections coupled with taps used for possible draining of the internal fluid;

- self-closing connections also coupled with taps fitted for sampling and pressure measurements;
- temperature registration for thermal equilibrium control;
- openings for cap-tightness checking.

Technical characteristics

Total weight (loaded packaging) : approwimately 95 T

Total length (with shock-absorbing cover) : approximately : 6 m

Diameter : 2.5 m

Cavity length : 4.59 m

3.3. Reception and Intermediate Storage

3.3.1. Cask Receiving Hall

Coming from the reprocessing plant, the cask, on its road trailer, is brought into this hall which is equipped with :

- a door isolating the access corridor,

- a device for washing by jet to rid the cask of the dirt resulting from its transport by road.

  The washing wastes are recovered in a tank installed in a trench below the low level of the hall,

- a 3 T travelling crane for raising and handling the shock-absorbers fitted to the ends of the cask.

  The receiving hall communicates through an aperture in the ceiling with the air-lock which permits the connection without communication of ambiance with the monitoring and unloading room.

  The air-lock is equipped with a 120 T crane which manoeuvers the cask by means of a handling-frame from the receiving room to the monitoring room.

  Two motorized trap-doors permit the closing of the transfer apertures.

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3.3.2. Monitoring and Unloading Room

This room is equipped with :

- a self-propelling fork-lift truck which transports the cask from the transfer aperture with the air-lock to the door of the unloading cell, where, by means of its lifting movement, it connects the cask of the cell,
- a crane with nacelle which allows the operators to unbolt the cask lid, to place a handling-frame on it for in-cell handling and to connect the piping of the activity monitoring circuit,
- a 3 T travelling crane for moving the lid handling-frame,
- an activity monitoring device connected to the cask by flexible piping, comprising an air circulation device with filter, an installation for measuring the activity of the air.

3.3.3. Unloading Cell

This is made up of concrete walls to ensure the biological shielding of the operators.

4 working stations, each equipped with a shielded viewing window and a pair of "Master-Slave" telemanipulators which permit operations to be carried out inside the cell.

These stations are served by a working area situated in level - 48.

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Inside the cell, handling is performed by a travelling crane with a capacity of 8 tons. When it is not being used or in case of maintenance, the crane rests in an intervention cell which communicates with the unloading cell by an opening closed by a shielded door.

The introduction of the containers into the cell is made through an aperture in the bottom of the cell, which communicates between this and the unloading room.

The cask, placed on its transport cart, is connected to this aperture, which is closed by a shielded trap-door when not in use.

After the connection of the cask, its lid is removed by the cell crane and placed in an obturable box to avoid the propagation of the possible contamination of the lid.

The containers are removed from the cask and placed in an air cooled storage area by the cell crane which is equipped with a special grapple for this purpose.

After unloading the cask and closing the transfer aperture, each container, as it is evacuated, is placed in a receptacle situated to the right of the evacuation aperture in the cell roof. This aperture is closed by a shielded trap.

If the internal activity monitoring of the transport cask indicates that one or more containers have become contaminated following deterioration, all the containers contained in the cask are introduced, through the unloading cell into a recanning cell.

3.3.4. Recanning cell

This has the function of putting contaminating containers, or those which have become accidentally contaminated, into a second container, in order to avoid the contamination of the temporary storage.

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It comprises two working stations, at level - 55, each equipped with a shielded window and with a pair of "Master-Slave" telemanipulators.

2 apertures which can be closed by a shielded door make the connection with the unloading cell. One of these apertures is used for the introduction of the containers, the other for their evacuation.

A shielded transfer device permits the introduction of the empty containers and their lids into the cell from the intervention zone.

These containers are placed on a merry-go-round which carries them under the introduction aperture where they receive a container. At the next position of the merry-go-round, a lid is placed on the full container and automatically welded by a plasma torch device. After this operation, the container is brought under the evacuation position to be introduced into the unloading cell by means of the crane of the latter.

A trap-door situated in the ceiling of the conditioning cell permits the transfer of the cell equipment to the intervention cell for maintenance operations.

3.3.5. Container Transfer Cask

This is used to transport a container from the unloading cell to the temporary storage and from there to the encapsulation cell. Of a type similar to the AVM cask of CEA Marcoule, it is constituted by a lead wall lined internally with stainless steel, and can be closed at the bottom by a shielded door. An electric hoist with a cyclical grapple at the end of its cable carries out the gripping of the container from the top of the unloading or of the temporary stage.

An autonomous ventilation decice constituted by a fan and filters at the air inlet and outlet permits the internal cooling of the cask when a container is inside it.

The cask is connected to the transfer apertures of the unloading cell temporary stage by means of a movable shielded drawer.

3.3.6. Temporary Storage

This is constituted by two parallel concrete trench, the walls of which are covered with a carbon steel lining. On a metal frame on each of these are set out 150 steel pits which can each hold ten containers vertically, i.e. a total for the two trenches of 3,000 containers. Spaces are provided batween the tubes to ensure the cooling ventilation of the pits.

Each trench is closed horizontally by a concrete slab in which, at right angles to each pit, there is an aperture closed by a plug. This plug has a rod in its centre, which is terminated on the interior side of the storage by a disc which closes the pit concerned when it is empty so as to prevent the cooling air from passing through it. This disc can be opened from outside the storage so as to permit the ventilation of a pit containing one or more canisters.

A 45-ton crane carries out handling operations above the trenches.

When a canister is placed in a pit, a shielded drawer is drawn across the pit selected, as also is a cask for putting the pit plug into. After the plug has been removed, the shielded drawer is closed again and the cask with the plug is taken away and replaced by the cask with the container. After the container has been put down into the pit, the reverse procedure is carried out.

At the end of the storage is situated the storage ventilation installation area. Two ducts, one for the blowing and the other for air extraction, link the ventilation room to the storage.

3.4. Encapsulation

3.4.1. Encapsulation cell

The function of this is encapsulation of the containers coming from the temporary storage prior to final storage.

It consists of a concrete cell comprising 5 working-points, each one provided with a shielded window fitting and a pair of "Master-Slave" telemanipulators.

Handling within the cell is carried out by an 8-ton travelling crane, which is kept, when not in use, in the intervention cell communicating with the conditioning cell by means of a passage closed off by a shielded door.

The containers, coming from the temporary storage under shielded cask, are put in from an aperture, which can be closed off by a shielded trap, situated on the upper part of the cell at level - 40.

The container is placed in the cell on a cart which serves :

- The device for placing the canister on the container , constituted by a titanium jacket shielded with lead. These canisters are introduced into the cell through an aperture in the ceiling of the latter.

- The lead-pouring station at which the container in its canister is turned in order to allow an intervening pouring with molten lead. This lead is introduced into the container through a duct supplied from a lead-melter situated on the upper part of the cell.

- The lead-machining station, where, after cooling, the lead in the canister is surface-levelled by a machining-head in order to facilitate the putting on of the lid.

- The canister-lid welding station. After the lid has been placed on the canister with a remote-control handler, an automatic welding head, type CEA-AVM, makes a tight weld by plasma torch around the lid-canister junction.

- After welding, the canister is returned and taken, by the cell crane, to the welding radiography point. At this point, the canister is set in rotation in order to pass the line of the weld in front of an X-ray emitter, which acts upon a film placed in a device which allows it to be inserted and removed from outside the cell.

  After monitoring of the welding, the canister is taken up again by the crane and placed in a tight lid casing, in which the tightness monitoring is carried out in helium and in a vacuum.

  After tightness monitoring, the canister is placed in the evacuation point from where it is transferred into a lead cask, which connects with a transfer shielded drawer placed in the ceiling of the cell. This cask, put on a motorized cart, is used to transfer the titanium canister to the final storage.

3.4.2. Titanium Canister Drawing N° D 0014

The canister into which the container is put for its final storage is constituted by a shell 6 mm thick, made of titanium in order to provide it with excellent resistance to corrosion by brackish water.

The interior of the drum is lined with a lead wall with a thickness of 50 mm, in the centre of which the canister rests.

The space between the lead lining and the container is then filled with molten lead, which ensures, after cooling, a total lead shielding thickness of 100 mm and contact between the walls so as to :

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- ensure good thermal dissipation,

- reduce the activity on contact and the radiolysis which can damage the titanium drum,

- increase the protection against corrosion and the mechanical strength under a water pressure of 50 bars.

After pouring the lead a titanium lid is welded on to the canister in a tight manner.

For handling, the canister comprises a gripping head identical to that of the container so as to provide the same type of grip.

Characteristics of the Canister

Total height	1800 mm
External diameter	612 mm
Internal cavity diameter (before filling the space)	500 mm
Internal cavity height	1600 mm
Approximate empty weight	3400 kg
Approximate weight with container	3900 kg

Completion of the Canister

In order to obtain the proper adhesion to the titanium wall, the lead will be poured in portions into the canister in a horizontal position. After the cooling of one portion, the container will be rotated in accordance with an angular value, so that another portion can be poured. After pouring all the portions, the internal cavity will be put on the final side for machining.

To increase resistance to corrosion, the lead used will be pure.

Another method can be used. It consists to cast the lead against the titanium enveloppe by extrusion process and to close the canister with a prefabricated lid.

3.4.3. Intervention Cell

Situated between the unloading and the encapsulation cells at the same level, it comprises a concrete-walled enclosure, consisting of two working-points provided with shielding windows fittings and master-slave manipulators.

Its function is :

- To facilitate interventions on the cell crane.
- The possible decontamination of equipment coming from the three cells with which it communicates.
- To facilitate the transfer of this equipment to the outside.
- To perform maintenance or small repair operations on the cell equipment.

The intervention cell has on top of it an enclosure made of sheet steel in which there is a 8 ton crane. This enclosure communicates with the intervention cell by means of a shielded trap-door and its function is to maintain isolation with the handling hall when the intervention cell is open. It facilitates manual treating, for example under vinyl, of the equipment coming from the cell.

It also receives the mechanisms for opening the shielded doors of the passages between the unloading and intervention cells and of the latter with the treatment cell.

It also receives the drums of the supply cables for the cell cranes.

3.5. AUXILIARY SYSTEM

3.5.1. Temporary Storage Ventilation

3.5.1.1. General Description and Main Characteristics

The cooling of the temporary storage is performed by a ventilation installation.

3.5.1.2. Introduction of Air

. This will be achieved by suction.

. Taking into consideration an air temperature of + 20° C at the inlet and + 80°C at the outlet, the necessary flow-rate will be

150,000 m3/h per storage.

. The collection of air is performed on the surface in a suction chamber fitted with external air intakes with a surface of approximately 21 m2.

. Before introduction into the storage this air is firstly filtered over a bank of filters with 90 % efficiency for particles of 5 .

. The filtration system can be by-passed by a system of ducts and dampers.

. The connecting headers will have a minimum interior surface of 4.5. m2.

3.5.1.3. Air Exhaust

At the storage outlet the air will be filtered over an absolute filtration device with 99.99 % DOP efficiency.

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The circulation of air and therfore of the exhaust will be performed by two half-flowrate fans, N° 1 and N° 2,

i.e. 75,000 m3/h.

These fans will have a total manometric height of approwimately 35 mb corresponding to the following estimated needs :

5 mb for the suction

15 mb for the storage

7 mb for the filtration

8 mb for the exhaust

35 mb

Power absorbed approximately 150 Kw per fan.

These two fans will be doubled by a stand-by fan with identical characteristics, N° 3.

The set of 3 fans and the filters will be laid out on level - - 30 m.

A by-pass circuit with an automatic damper will, in the event of a defect of the filters or of the fans, permit the by-passing of the filter and fan system.

At ground level and in the vicinity of the release stack, a second stand-by fan, N° 4 connected to the exhaust circuit by a duct and damper device will permit the exhaust of 65 % of the normal flowrate.

3.5.2. Ventilation of Rooms

3.5.2.1. Purpose of the Installation

For safety reasons :

- A positive and negative pressure cascade is maintained according to the activity and contamination present or likely to be present in the various rooms, in order to prevent any non-controlled exchange of gas between them. These rooms are classified into four areas, according to the degree of activity, likely to be present in them.

- The exhaust air passes through absolute filters before being released to the outside.

For Reasons of Comfort :

- Pleasant atmospheric conditions are maintained whatever the season in rooms where personnel are present (heating, humidification, chilling of in-blown air).

3.5.2.2. Conditions Maintained

Temperatures and moistures in the rooms

In accordance with the usual local conditions.

Pressure and negative pressure in the rooms

White area	:	over pressurized		
Green area	:	- 3 mm WG	P	- 5 mm WG
Amber area	:	- 6 mm WG	P	- 8 mm WG
Red area	:	-48 mm WG	P	-57 mm WG

Glove boxes and enclosures damp and dry channel : -25 mm WG

Average air renewals

White area : 4 rn/h

Green area : 6 rn/h

Amber area : 6 rn/h

Red area : 10 rn/h

3.5.3. Operating Principle

The air admitted into the building will be previously filtered and treated so as to obtain the requisite thermal conditions in the rooms. Maximum use will be made of the possibilities of transfers going from one area to another more active area.

In the red cells, the air will be compulsorily introduced by transfer,no blowing being authorized in order to avoid all risk of accidental overpressure.

These transfers will be performed from the intervention areas.

According to the particular conditions in the cell, the introductions of air will be equipped (if applicable) with transfer screws, filters, dampers and non-return valves.

The air exhaust will be performed by centrifugal fans, doubled on stand-by.

The air will be filtered prior to release to atmosphere.

Absolute filtration : 99.99 % DOP

2 filter stages for the red areas

1 filter stage for the other areas.

3.6. OPERATIONS OF FACILITY

3.6.1. Cask Receiving Hall

- Arrival of transport cask on its trailer.
- External washing of cask.
- Dismounting of shock-absorbers.
- Transfer of cask by 120 T crane into the monitoring and unloading room.

3.6.2. Monitoring and Unloading Room

- Lowering of cask on to the transfer cart.
- Connection of flexible piping, circulation of air for monitoring the internal activity of the cask.
- After monitoring, disconnection of the piping.
- Undoing of the cask lid fastening screw (bolt).
- Positioning of lid-handling frame.
- Moving of cask under the transfer aperture of the unloading cell.

3.6.3. Unloading Cell

- After connection of cask on transfer aperture in cell bottom, opening of cask and placing of its lid in its tight receptacle.
- Unloading of containers and placing them in the ventilated storage of the cell.

- Closing of cask and returning it to the receiving hall.
- Positioning in the cell of a container at the evacuation post.
- Positioning on the cell of the container transfer cask.
- Opening of the shielded drawer of the cell.
- Lowering of the cask grapple and gripping of the container, which is then taken up into the cask.
- Transfer of the cask to the temporary storage.

3.6.4. Recanning Cell

In the case where the cask contains contaminated containers, these are taken from the cask by means of the unloading cell crane and transferred directly through the unloading cell into the conditioning cell after opening of the container introduction aperture.

- Placing of each container in the empty container brought by the merry-go-round right under the transfer aperture.
- Closing of the unloading cell and conditioning cell transfer apertures and return of the cask to the receiving hall.
- Lowering and welding of the lid of each full container.
- Opening of transfer aperture to the unloading cell and, with the crane in this cell, taking up of each container on the merry-go-round.
- When arriving in the unloading cell, each container is subjected to an external contamination control.
- In the case where traces of contamination are ascertained, the container is placed in a tight box where it is subjected to external washing at high pressure.
- In the opposite case, the container is put in the ventilated storage of the cell, to await its transfer towards the temporary storage.

3.6.5. Temporary Storage

- Positioning by crane of shielded drawer above the selected storage pit.
- Positioning on the drawer of the cask for the pit plug.
- Opening of gates of drawer and cask and introduction of plug into cask.
- Closing of drawer and placing on it of container transfer cask.
- Opening of gates of drawer and cask and lowering of container into pit by the cask hoist.
- Return of transfer cask to unloading cell.
- Replacement of plug on pit from out of its cask.
- Adjustment of pit ventilation valve.

3.6.6. Encapsulation Cell

After decay in the temporary storage, the containers are taken out and brought into the final conditioning cell. To this effect, the following operations are carried out :

- The shielded drawer and the plug cask are placed on the temporary storage pit and the pit is opened.
- The cask for transfer to temporary storage is placed above the pit and the container is introduced into the cask.
- The activity of the air ventilating the cask is monitored.

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- If contamination is detected, the cask is directed towards the unloading cell where the containers will be treated in the re-canning cell like the contaminated canisters before temporary storage. The transfer cask will then be decontaminated before being put back into service.

- The container transfer cask is then set down on the final conditioning cell and the container is lowered on to the in-cell cart.

- The titanium container is lowered by the in-cell crane.

- The container is tipped over.

- The cart is brought to the lead-pouring station and the final filling is carried out.

- After cooling, the cart is brought to the lead surface-grinding station.

- The cart is brought to the container-lid welding station and the lid is welded after being positioned by telemanipulator. After welding, the container is tipped over.

- The container is picked up by the cell crane and is set down at the welding inspection station.

- When this inspection has been completed, the container is taken by crane to the helium-tightness inspection station, station for checking the tightness by helium.

- After this operation, the cask is introduced into the cask for transfer to final storage.

3.9. Construction time schedule and costs

3.9.1. Evaluation of construction cost

The following evaluation are included :

- Special equipments in the cell.
- Cell walls.
- Fuel shielding casks.
- Over head cranes.
- Ventilation.
- Electricity.
- Radioprotection equipment.
- Engineering and site monitoring.

Are excluded :

- The excavation cost.
- The civil work other than cell and storage wall.
- Lift, mobile truck.
- Consumable material, titanium canister, lead, etc..

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3.9.1.1. Reception

Cell equipment	15.000.000 FF
Cell (concrete and lining)	18.000.000 FF
Cask	300.000 FF
Ventilation	7.500.000 FF
Electricity	1.700.000 FF
Radioprotection	3.000.000 FF
Miscellaneous	2.000.000 FF
	47.500.000 FF
Engineering and erection	16.000.000 FF
	63.500.000 FF

3.9.1.2. Intermediate storage (Cost of one module with 300 pits Capacity : 3000 containers)

Concrete and lining	21.000.000 FF
Equipment	9.000.000 FF
Cask	700.000 FF
Crane	600.000 FF
Ventilation	6.000.000 FF
Electricity	600.000 FF
Radioprotection	600.000 FF
Miscellaneous	1.000.000 FF
	39.500.000 FF
Engineering and erection	12.000.000 FF
	51.500.000 FF

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3.9.1.3. Encapsulation - Canister transport in gallery

Encapsulation cell equipment	6.000.000 FF
Cell wall	6.500.000 FF
Cask	1.800.000 FF
Ventilation	700.000 FF
Electricity	500.000 FF
Radioprotection	500.000 FF
Miscellaneous	1.000.000 FF
	17.000.000 FF
Engineering and erection	8.000.000 FF
	25.000.000 FF

3.9.2. Time schedule

1. Reception and intermediate storage

Design - 12 months

Fabrication (
Building } 24 months

Erection - 12 months

Tests - 12 months

.... total 4 to 5 years

2. Encapsulation

Design - 12 months

Fabrication - 18 months

Erection - 10 months

Tests - 6 months

.... total 3 to 4 years

3.9.3. Operating personnel

Working in one shift/day.

- 1st phase : Reception of transport casks and transfer of containers to intermediate storage :

  1 Manager
  2 Clerks
  2 Crane-drivers
  4 Operators
  1 Electrician
  1 Mecanician
  3 Health physicists

  Total 14 persons

- 2nd phase : Retrieval of containers from intermediate storage, encapsulation and final disposal :

  1 Manager
  2 Clerks
  1 Crane-driver
  2 Truck-drivers
  5 Operators
  1 Electrician
  1 Mecanician
  3 Health physicists

  Total 16 persons

IV. FINAL STORAGE

4.1. General Description of Facilities

After conditioning in a titanium container, each glass container is directed towards the final storage situated 500 m below the rock surface.

The final storage is constituted by 41 parallel tunnels, 1 km long, each separated from the next by a distance of 25 m, i.e. an area of 1 km2.

This area is traversed by transport tunnels which separate it into four storage divisions which will be constructed in six stages. Each tunnel comprises storage pits, at intervals of four metres, into which the canisters will be put.

These pits, which number 9000 in total, are five metres deep and 1 m in diameter.

A shaft elevator performs the liaison between the temporary storage and encapsulation installation and the final storage.

4.2. K.B.S.

4.3. Transport to Place of Final Storage

The transport of the canister is performed by a shielded transfer cask mounted on a motorized cart which runs on rails.

The canister transfer cask is equipped with a hoist for introducing and setting down the canister, and with a lifting complementary shielding on the lower part which ensure a complementary shielding around the storage pit in the event of intervention on the cask while a canister is being set down. This skirt is raised up against the cask by an electrical jack device while the cask is being moved.

The cart's power supply comes from batteries. It runs on rails and in the final storage it is directed from the transport tunnel towards the storage tunnel by a turntable. Movable stops ensure that that it is positioned above the selected storage pit.

When all the pits in one tunnel are filled with canisters, the running rails are dismantled and reassembled in the next tunnel, as is the turntable. The rails in the transport tunnel are extended.

4.4. Final disposal

4.4.1. Placing of Canisters

The canister transfer cask is brought on its cart above the selected pit and positioned by the centering stops.

The lifting complementary shielding is placed on the pit, the cask trap is opened and the canister is lowered into the pit. At about 50 cm from the setting-down level, the hoist is stopped for a few minutes to stabilize the canister and then the descent continues until it is set down.

The cyclical grapple is then raised, as is the complementary shielding.

4.4.2. Sealing of Final Storage

When the canister has been set down, the pit is filled with a mixture of sand and bentonite.

The filling is performed from a shielded hood mounted on a cart which runs on the same rails as the transfer cart.

This hood is constituted by a lead jacket comprising the bentonite tank and the injection pump on the outside and, on the inside, an annular pouring device equipped with 3 vibrating needles.

This device can be lowered into the pit around the canister and gradually raised again as the filling progresses, at the same time being endowed with an alternating angular motion of 120° to increase the efficiency of the vibrating needles.

When it is positioned above the pit, the filling cart is connected to the transfer cask before the latter is moved from its unloading position.

After connecting the two carts, the whole assembly is moved so as to bring the filling cart over the pit. This operation is intended to prevent the breaking of the shielding before the pit completely filled.

When the filling cart is over the pit, the transfer cask can be brought back to the encapsulation cell.

After the filling with bentonite, the filling cart is moved towards the next pit and a granitecover is placed on the pit which has just been filled.

V. SAFETY

5.1. HANDLING

5.1.1. Cask Handling Cranes

- To ensure handling safety, the travelling cranes for the casks are classified in a mechanical group of the European Federation of Handling which is one higher in relation to the class of actual use and requirements.

- They are designed to have very slow loaded speeds so as to avoid serious dynamic reactions.

- The speed reducing gear of the winches is of the irreversible type and the braking devices are doubled.

- The lifting cables are subjected to frequent examinations and are changed periodically.

- The handling frames are constructed of steel selected from grades of 80 to 90 kg/mm2 and calculated for a workrate of 6 kg/mm2.

- The links between frames and casks are fixed positevely after being put in place.

The strength of the casks and the equipment in the handling zones is calculated to take into account the possible dropping of a cask in relation to the maximum height necessary for handling it.

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5.1.2. In-Cell Cranes

These cranes, which operate in a hostile medium, are designed in such a way as to be able to terminate the operation in progress in the event of an incident and to return under their own power into an intervention zone where they can be repaired.

For this purpose, all the movements of raising - lowering, travelling and direction are performed at two speeds, one slow and the other fast, obtained from an independant source.

The electricity supply comes from two cables, one for the HV motors and one for the LV motors. In this way an operation performed at a chosen speed can be terminated, in the event of a power-supply incident or a motor breakdown, at the other speed, the crane then being immediately brought back into the intervention cell to be repaired.

5.2. IN-CELL OPERATIONS

All the in-cell equipment is designed in order to :

- Complete the operating sequence by manual means in case of failure of the motorized controls.
- To remove from or introduce into the cells the in-cell equipment without the necessity of the operators having to enter.
- Permit its maintenance and small repairs by remote control.
- Alarm or stopping devices are provided in the machines operating cycle or for operating sequences to give warning of any operating defect and to prevent the deterioration of the equipment.

5.3. VENTILATION OF THE TEMPORARY STORAGE

5.3.1. Description

Each storage cell, capable of 3000 containers, includes an independent ventilation facility.

According to the calculation (annex 9), the nominal air flowrate is 150 000 Nm3/h and the total normal differential pressure is 35 mbars.

The total flowrate is given by two identical fans, 75 000 Nm3/h each and a third stand-by fan in parallel set-up in an underground room.

For the most conservative case, i.e. 3000 canisters regularly loaded in 10 years, the total thermal power is 3000 Kw. With such conditions, the temperature difference of air between entrance and exit is 60°C. So the exit is at 80°C when the atmosphere is at 20°C.

A supplementary emergency fan is set-up at the ground level. The characteristics of it are the same as for the others.

Automatic check-gates are put in the ducts for by-passing the filters and by-passing the supplementary fan.

5.3.2. Normal operating

Two fans are operating in parallel in the underground chamber. The total flowrate is 150 000 Nm3/h,

the exit air temperature : 80°C

the upper canister surface temperature : 86,4°C

5.3.3. First emergency

A fan is stopped, the stand-by third fan is started, the operating conditions are the same.

5.3.4. Second emergency

Two fans are stopped, the third one only is operating. The flowrate falls to 65 % = 100 000 Nm3/h.

The temperature of exit air gradually rises within 40 hours up to 112°C when normal loading is completed or 66°C for half total thermal power.

The upper canister surface temperature to 123°C when the normal loading is completed or 72°C for half total thermal power.

5.3.5. Third emergency

The three fans of the underground chamber are stopped.

It is possible to start the emergency ground level fan and have access to the others.

The underground filters are by-passed.

The flowrate is approximately 100 000 Nm3/h and the conditions are the same as preceding.

5.3.6. Total break-down

In that case, all by-pass gates are open. The filters and blowers are out off the circuit and the air is circulating in natural convection.

The exit air temperature gradually rises within 40 hours up to 336°C when normal loading is completed.

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The upper canister surface temperature is 370°C.

The center temperature in glass is 434°C.

In such a case, the ambiance temperature could be high in the underground chamber. It will be necessary to start the upper fan before having access to the chamber of the others.

This very exceptional event could cause some damages to the concrete of the storage cell. So this cell is to be provided with steel coating and frame in order to be sufficiently strong to withstand the above temperature during the necessary time to repair the ventilation system.

5.4. NUCLEAR SAFETY OF THE ACTIVE FACILITY

5.4.1. Nature of the risk

In this facility are received HLW incorporated in glass enclosed in sealed canisters. These canisters are normally transferred to the intermediate storage and, after at least 30 years cooling, conditioned in special containers and lowered to the final storage.

The nuclear safety will take into account the risk of irradiation through γ and neutron radiations by proper shieldings.

The risk of contamination is not normally present as the canisters are tight, and have been decontaminated in the vitrification facility before stripping.

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Remark

The transportation of containers comply with the safety regulations of radioactive materials (IAEA regulations). After exceptional events, it could happen that a container is ruptured. In this event some glass dust could exceptionally be found in the transport cask. This activity is likely to be fixed and not contaminating, but if some dust may be entrained by air sweeping during monitoring of the cask, this activity would be detected on filters. In that case washing of the cask and recanning of the containers could be performed, giving way to liquid effluents with some risk of contamination in the cells specially foreseen for this operations. This risk has to be taken into consideration for the cells where damaged containers can be transferred.

5.4.2. Hot cells facility

In these cells the operations are remotely controlled from behind biological shielding.

The main risk is coming from irradiation due to the rather high activity of the glass handled.

The construction of the buildings, rooms and cells that form the facility will comply with the principles for shielding and prevention against the action of ionizing radiation defined in "Norm ISO R 1710" of 1970 for radioactive facilities.

- Irradiation

  The biological shielding will be designed for the activity calculated as per Annex2.

The equivalent dose rate will not exceed :

- 0.25 mrem/h in zone 1
- 2.5 mrem/h in zone 2 (operating zone)

(Where operators are frequently present, the dose rate is limited to about 0.25 mrem/h).

The transfer of the glass canisters or final containers in shielded casks is a routine operation. It must be checked that the equivalent dose rate at the surface of the cask remains lower than 2.5 mrem/h.

- Contamination

The containment of activity will be ensured by the cascade of negative pressures of the ventilation system explained in ch. 3.5.2.

In normal operation, there will be no contamination inside the cells. In case of accidental contamination of canisters by glass dust, monitoring of the air extracted from the cell (zone 4) will be provided by means of α or β sniffers with monitoring instruments installed in the operating zone (zone 2). Linings and equipment inside the cell shall be easy to decontaminate.

Telemanipulation means will make mechanical decontaminations possible and will be used to remove contaminated equipment in the intervention cell where it will be packaged for take-off.

Outside the cells, the surface contamination of rooms and equipment will have to be less than the following values :

- Non-fixed contamination : Maximum admissible limit is :

  2×10^{-6} μ Ci/cm2 for α contamination

  3×10^{-4} μ Ci/cm2 for β contamination

- Fixed contamination : Maximum admissible limit is :

  2×10^{-5} μ Ci/cm2 for α contamination

  10^{-3} μ Ci/cm2 for β contamination

These latter limits are taken into account, only when they are more restraining than those for irradiation.

5.4.3. Liquid wastes

Liquid wastes arise from the rinsing of the transport cask in case of detection of non-fixed contamination or from the washing of contaminated canisters.

They are received in a tank installed in a separate cell located on the lower level of the active facility and equipped with a drip-tray. These wastes will be of medium-level activity (in the range of 1 Ci β/m3). They have to be transferred periodically by means of a syphoning device in a shielded flask for evacuation to the ground surface. Monitoring of their activity will be made before transfer.

Production of these wastes will be very occasional and their volume can be estimated to some cubic meters per year during reception of glass canisters.

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5.4.4. Intermediate Storage of Glass Canisters

This storage receives sealed glass canisters or canisters formerly recanned in hot cells in case of external contamination. There is normally no risk of contamination of the cooling air during the 30 years of storage. The experience of the PIVER glass canisters storage in Marcoule (about 5 million curies) has shown no detectable contamination of this air even from non sealed canisters. Nevertheless absolute filters are provided on the outlet of the air before release to the stack for additional safety.

Multiple redundancy has been foreseen on the ventilation system as described in ch. 5.3 . In the most improbable case of power failure of the four fans cooling will be achieved by natural convection of air, and it has been shown in the calculations of Annex 2 that the temperature of air will increase in a time of about 50 hours to 330°C in the worst case i.e. at the end of the filling of the storage.

In this event the maximum temperature of the hottest glass will remain below the crystallization temperature of 600°C, and far below the melting point. Then no risk of contamination of the cooling air will appear. But if these conditions are maintained for too long, some damages (cracks) will result in the concrete structure of the storage, not-withstanding the thermal shield.

The atmosphere of the intervention zone, even in the hereabove conditions, will remain at a higher pressure than the cooling air, due to the natural draft of the stack.

5.4.5. Organization of the Safety

Safety monitoring will be the duty of a Health Physics team. Health Physics will be permanently attached to the facility for checking of the instruments. They will attend all the intervention operations to survey the conditions of work.

5.5. CONTAINMENT OF THE RADIOACTIVITY

This containment is ensured by the successive barriers :

1/ The glass itself

2/ The stainless-steel container

3/ The lead shielding

4/ The titanium canister

5/ The sand + bentonite filling of the pit

6/ The granite and the underground water

After completion of loading of the underground storage and backfilling of the tunnels with bentonite + quartz sand, the final storage will be exposed to ground water.

5.5.1. The titanium enveloppe will constitute the main barrier to corrosion during the first period of decay of the HLW. This enveloppe will have a thickness of 6 mm. The welding of the cover will be carefully executed and controlled in a hot cell. The excellent resistance of titanium in ground water can be appreciated on the following basis (1) :

(1). DE GELAS
Résistance à la corrosion du titane et de ses alliages
(Informations Chimie - N° 92 - Janvier 1971)

. DE GELAS
Principes d'emploi du titane en génie chimique
(Informations chimie - N° 136 - Octobre 1974)

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- Titanium metal is protected by the formation in air of a protecting film of titanium oxide, which is remarkably stable, except for very low pH values.

- The rupture voltage of this film in chlorine solution is relatively high, of the order of 10 Volts.

- Welding properties of titanium are good under inert gas (argon). Corrosion around weld is excluded by using an alloy of Titanium.

- Pitting corrosion does not occur even in saline water below 140°C. The temperature of the titanium surface in saline water will not exceed 80°C.

- Stress corrosion does not occur in saline water.

- General corrosion is very low in saline water and difficult to measure.

  A sample immersed during 18 years in sea water did not show appreciable corrosion, except a slight decoloration.

  According to tests performed in U.S.A. with samples immersed in sea water, the corrosion thickness calculated over 1000 years would be less than 25 μ.

- The chemical composition, the pH and the oxyde-reduction potential of the saline water can be modified by the effect of radiolysis due to the γ and neutron flux coming out of the glass. These flux

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are minimized by the lead shielding of 10 cm thickness and will be of the order of 0.1 rad/S at the time of disposal, after 40 years cooling. According to calculations made by Atomenergi, the radiolysis process on the saline water will very rapidly (after 10 hours) come to an equilibrium state corresponding to a concentration of some ppb (parties per billion) of radiolyzed elements in the saline water. This would have a negligible effect on the corrosion.

From the foregoing, it can be concluded that the corrosion resistance of the titanium enveloppe will last more than 1000 years, at which time the concentration of radioactive fission products will be very low and their potential health hazard become negligible. Then will remain only the radioactivity due to the actinides.

5.5.2. The lead shielding will have 3 main functions :

- The first function, already mentioned in 5.5.1. is to minimize the radiolysis effect. The thickness of 10 cm has been chosen, so as to reduce the γ flux outside the container to the order to magnitude of the neutron flux (see Annex n° 5).

- The lead will give the container the mechanical resistance necessary to withstand the hydraulic pressure of the underground water, i.e. 50 bars.

  We have calculated that the crushing pressure of the lead will be 70 bars (reckoned with an empty canister). As an indicative figure, the buckling pressure is about 700 bars.

- Lastly, the lead shielding will provide an additional resistance to corrosion. The resistance of lead to ground water is good, but not comparable to that of titanium, and is more sensitive to the presence of oxygen in the solution. In the absence of oxygen, the corrosion at 50°C has been estimated to be less than 2 mm in 1000 years, but with unfavourable conditions the corrosion could be 10 to 100 times higher, hence a lifetime of 500 to 5000 years.

Therefore, we can consider the lead shielding as a corrosion barrier additional to the titanium enveloppe or at least as safety barrier in case of failure of the titanium enveloppe.

5.5.3. The stainless-steel container is a barrier to possible contamination in the intermediate storage. On the other hand, its resistance to corrosion by saline water is very weak, and it cannot be considered as a reliable barrier in the final storage.

5.5.4. The glass will ultimately come into contact with the underground water after destruction of the titanium and the lead, i.e. after a time delay of the order of 1000 years. At that time, the heat power of the glass canister will be reduced to 33 watts, so its temperature will have decreased in the range of 20°C - 30°C. The release of radio-isotopes of actinides in the underground water will be limited by the leachability of the glass.

The leaching rate of the radioisotopes from the glass by sea water or natural water are not significantly different. They are not affected by the internal irradiation (α, β or γ) during the decay of the HLW.

The measured rates at 25°C are the following for the actinides :

$$10^{-7} \text{ to } 10^{-9} \text{ g/cm2 x day}$$

The value for the plutonium is in the lower range, the value for americium in the higher range.

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The surface of the glass considered as a solid block in the container is about 2×10^4 cm2. Actually, the surface of the glass block can be increased by a factor of 5 during the transportation due to possible cracks. The leachable surface will then be taken as :

$$S = 10^5 \text{ cm}$$

The leaching rate of an element M is defined by the formule :

$$L = \frac{a}{A} \cdot \frac{P}{S} \text{ g cm}^{-2} \text{ day}^{-1}$$

where a is the weight of M leached out per day, A is the total weight of M in the canister, P is the weight of the glass in the canister and S the effective surface as defined above. P is equal to 420 kg (420 000 g). Taking the value $L = 2 \times 10^{-7}$ g cm^{-2} day for the actinides, which is probable for Pu and probably conservative for the other actinides, the quantity of M leached out per day should be :

$$a = \frac{A.2 \times 10^{-7} \times 10^{-5}}{420\ 000} = 4.76 \times 10^{-8} \text{ A g}$$

According to appendix 1, the weights of the actinides 100 years after removal from the reactor are :

Pu	:	99.2 g
Am	:	458 g
Cm	:	2.83 g
Np	:	541 g

Using these values in the formula above gives the following release of radioisotope from the canister :

Pu	:	4.7 μ g/day
Am	:	22 μ g/day
Cm	:	0.13 μ g/day
Np	:	26 μ g/day

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The further movement of these actinides in the underground system and their eventual release to the surface will depend on several parameters, among others the water flow. Calculations of those movements are beyond the scope of this study.

5.5.5. The bentonite has a very high ion exchange capacity.

Tests are presently performed in France by the CEA and the B.R.G.M. (Bureau de Recherches Géologiques et Minières) under contract of the EEC. First results have shown that bentonite is one of the best materials for absorption of actinides by ion-exchange. The absorption takes place very rapidly by exchange of the sodium included in the molecule of bentonite with the radioisotope, and the absorption is not reversible. The distribution coefficient between bentonite and the solution is higher than 10^4 for plutonium, neptunium, americium, and also cerium.

The absorption capacity of the bentonite is of the order of :

$$60\ Ca^{++}\ meg/100\ g$$

On this basis, it has been calculated (see Annex 7) that a quantity of 826 kg of bentonite would be sufficient to absorb all the leached radioisotopes released.

This has to be compared with the volume of filling of the pit which is approximately 5 m3. The weight of this filling will be about 10 tonnes, of which 10 % i.e. 1000 kg will be constituted by bentonite.

ANNEX 1

COMPOSITION OF HLW CONTAINER

The weight of elements included in one 150 liters container corresponding to 1 equivalent metric ton of heavy metal charged in the reactor, are calculated by the Origen program.

The assumed nuclear fuel charged in the reactor is:

- PWR enriched 3.3%

- Regular irradiation in 1100 days at 30 MW/MT

- Total burn-up 33000 MWD/MT

RESULTS

1.1 - Actinides - Storage period

1.2 - Actinides - After reprocessing at 10 years

1.3 - Fission products - Storage period

1.4 - Fission products - After reprocessing at 10 years.

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- FUEL DECAY TIMES

POWER= 30.00MW, BURNUP= 33000.MWD, FLUX= 2.93E+13N/CM**2-SEC

ELEMENT CONCENTRATIONS, GRAMS
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	CHARGE	DISCHARGE	30. D	60. D	120. D	182. D	274. D	365. D	730. D	1096. D	REPRO 3652. D	7305. D
HE	0.0	2.32E-01	2.56E-01	2.78E-01	3.15E-01	3.47E-01	3.84E-01	4.13E-01	4.91E-01	5.47E-01	9.04E-01	1.42E+00
TL	0.0	1.86E-12	1.99E-12	2.17E-12	2.58E-12	2.97E-12	3.58E-12	4.21E-12	6.80E-12	9.35E-12	1.98E-11	2.12E-11
PB	0.0	4.61E-07	5.14E-07	5.71E-07	6.98E-07	8.50E-07	1.12E-06	1.43E-06	3.22E-06	5.86E-06	4.16E-05	1.11E-04
BI	0.0	1.66E-10	1.79E-10	1.92E-10	2.17E-10	2.41E-10	2.78E-10	3.17E-10	4.76E-10	6.35E-10	1.39E-09	1.94E-09
PO	0.0	8.97E-14	9.73E-14	1.05E-13	1.22E-13	1.41E-13	1.72E-13	2.07E-13	3.87E-13	6.46E-13	6.92E-12	3.56E-11
AT	0.0	1.19E-19	6.90E-20	3.56E-20	2.21E-20	2.16E-20	2.22E-20	2.29E-20	2.59E-20	2.88E-20	5.14E-20	9.09E-20
RN	0.0	1.75E-12	1.87E-12	2.03E-12	2.40E-12	2.76E-12	3.31E-12	3.88E-12	6.24E-12	8.60E-12	1.90E-11	2.37E-11
FR	0.0	1.45E-15	1.01E-15	7.26E-16	6.47E-16	6.89E-16	7.63E-16	8.37E-16	1.13E-15	1.43E-15	3.37E-15	5.95E-15
RA	0.0	2.59E-08	2.72E-08	2.87E-08	3.22E-08	3.57E-08	4.12E-08	4.69E-08	7.20E-08	1.00E-07	3.41E-07	8.85E-07
AC	0.0	1.33E-08	1.42E-08	1.50E-08	1.67E-08	1.84E-08	2.10E-08	2.36E-08	3.37E-08	4.36E-08	1.09E-07	1.92E-07
TH	0.0	1.16E-03	1.20E-03	1.24E-03	1.31E-03	1.39E-03	1.51E-03	1.63E-03	2.10E-03	2.58E-03	5.99E-03	1.11E-02
PA	0.0	5.29E-04	5.31E-04	5.32E-04	5.33E-04	5.35E-04	5.37E-04	5.38E-04	5.46E-04	5.54E-04	6.07E-04	6.83E-04
U	9.99E+05	9.55E+05	9.55E+05	9.55E+05	9.55E+05	9.55E+05	9.55E+05	9.55E+05	9.55E+05	9.55E+05	9.55E+05	9.55E+05
NP	0.0	5.53E+02	4.82E+02	4.82E+02	4.82E+02	4.82E+02	4.82E+02	4.82E+02	4.82E+02	4.83E+02	4.86E+02	4.94E+02
PU	0.0	8.90E+03	8.98E+03	8.98E+03	8.97E+03	8.97E+03	8.96E+03	8.94E+03	8.90E+03	8.86E+03	8.60E+03	8.34E+03
AM	0.0	1.21E+02	1.25E+02	1.29E+02	1.37E+02	1.45E+02	1.57E+02	1.69E+02	2.15E+02	2.58E+02	5.08E+02	7.43E+02
CM	0.0	4.28E+01	4.16E+01	4.04E+01	3.84E+01	3.68E+01	3.50E+01	3.37E+01	3.09E+01	2.95E+01	2.30E+01	1.64E+01
BK	0.0	2.19E-06	2.05E-06	1.92E-06	1.68E-06	1.47E-06	1.20E-06	9.78E-07	4.37E-07	1.95E-07	6.93E-10	2.18E-13
CF	0.0	9.03E-07	1.04E-06	1.17E-06	1.40E-06	1.61E-06	1.87E-06	2.07E-06	2.58E-06	2.79E-06	2.82E-06	2.68E-06
ES	0.0	1.22E-10	1.02E-10	5.55E-11	1.12E-11	1.77E-12	9.76E-14	5.12E-15	2.88E-20	1.42E-25	0.0	0.0
TOTALS	9.99E+05	9.65E+05	9.65E+05	9.65E+05	9.65E+05	9.65E+05	9.65E+05	9.65E+05	9.65E+05	9.65E+05	9.65E+05	9.65E+05

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- WASTE DECAY TIMES

POWER= 30.00MW, BURNUP= 33000.MWD, FLUX= 2.93E+13N/CM**2-SEC

ELEMENT CONCENTRATIONS, GRAMS
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	CHARGE	REPRO ~~DISCHARGE~~	5. Y	10. Y	30. Y	90. Y	190. Y	490. Y	990. Y	1990. Y	4990. Y	9990. Y
HE	0.0	9.04E-01	1.02E+00	1.13E+00	1.47E+00	2.20E+00	3.14E+00	5.19E+00	7.06E+00	8.42F+00	9.30E+00	1.01E+01
TL	0.0	1.98E-11	3.47E-12	8.04E-13	2.86E-13	2.43E-13	1.88E-13	1.59E-13	1.68E-13	2.00E-13	3.61E-13	7.96E-13
PB	0.0	4.16E-05	5.68E-05	5.96E-05	6.15E-05	6.48E-05	6.83E-05	7.49E-05	8.93E-05	1.47E-04	6.52E-04	2.87E-03
BI	0.0	1.39E-09	6.61E-10	6.91E-10	1.60E-09	1.05E-08	7.52E-08	1.27E-06	1.12E-05	9.90E-05	1.66E-03	1.27E-02
PO	0.0	6.92E-12	1.71E-11	3.21E-11	1.27E-10	5.66E-10	1.45E-09	5.13E-09	1.31E-08	3.63E-08	1.37E-07	3.31E-07
AT	0.0	5.14E-20	5.26E-20	5.60E-20	9.14E-20	4.14E-19	1.72E-18	1.21E-17	5.36E-17	2.35E-16	1.52E-15	5.53E-15
RN	0.0	1.90E-11	5.78E-12	4.62E-12	9.00E-12	2.40E-11	5.08E-11	1.50E-10	3.83E-10	1.06E-09	4.00E-09	9.69E-09
FR	0.0	3.37E-15	4.48E-15	5.44E-15	8.31E-15	1.37E-14	2.62E-14	1.21E-13	5.02E-13	2.17E-12	1.40E-11	5.07F-11
RA	0.0	3.41E-07	4.47E-07	6.22E-07	1.38E-06	3.72E-06	7.90E-06	2.34E-05	5.97E-05	1.65E-04	6.23E-04	1.51E-03
AC	0.0	1.09E-07	1.50E-07	1.85E-07	2.80E-07	3.73E-07	3.92E-07	4.07E-07	4.29E-07	4.75E-07	6.38E-07	9.71E-07
TH	0.0	5.99E-03	5.99E-03	6.01E-03	6.12E-03	6.52E-03	7.35E-03	1.05E-02	1.63E-02	2.90F-02	7.25E-02	1.59E-01
PA	0.0	6.07E-04	6.08E-04	6.08E-04	6.10E-04	6.15E-04	6.23E-04	6.46E-04	6.81E-04	7.48E-04	9.42E-04	1.28E-03
U	9.99E+05	9.55E+03	9.55E+03	9.55E+03	9.55E+03	9.55E+03	9.55E+03	9.56E+03	9.56E+03	9.56E+03	9.58E+03	9.60E+03
NP	0.0	4.86E+02	4.89E+02	4.92E+02	5.05E+02	5.41E+02	5.94E+02	7.10E+02	8.13E+02	8.81E+02	8.97E+02	8.96E+02
PU	0.0	8.60E+01	8.82E+01	9.00E+01	9.49E+01	9.92E+01	9.96E+01	1.00E+02	1.01E+02	1.03E+02	1.06E+02	1.06E+02
AM	0.0	5.08E+02	5.06E+02	5.04E+02	4.93E+02	4.58E+02	4.03E+02	2.82E+02	1.73E+02	9.67E+01	6.06E+01	3.84E+01
CM	0.0	2.30E+01	1.94E+01	1.64E+01	8.79E+00	2.83E+00	2.16E+00	2.09E+00	1.99E+00	1.82E+00	1.40E+00	8.99E-01
BK	0.0	6.93E-10	1.23E-11	2.18E-13	4.58E-20	2.42E-20	2.41E-20	2.38E-20	2.33E-20	2.24E-20	1.99E-20	1.63E-20
CF	0.0	2.82E-06	2.74E-06	2.68E-06	2.50E-06	2.20E-06	1.82E-06	1.04E-06	4.27E-07	8.61E-08	3.89E-09	7.99E-11
TOTALS	9.99E+05	1.07E+04	1.07E+04	1.07E+04	1.07E+04	1.07E+04	1.07E+04	1.07E+04	1.07E+04	1.07E+04	1.07E+04	1.07E+04

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- FUEL DECAY TIMES

POWER= 30.00MW, BURNUP= 33000.MWD, FLUX= 2.93E+13N/CM**2-SEC

ELEMENT CONCENTRATIONS, GRAMS
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	CHARGE	DISCHARGE	30. D	60. D	120. D	182. D	274. D	365. D	730. D	1096. D	REPRO 3652. D	7305. D
H	0.0	7.32E-02	7.28E-02	7.25E-02	7.18E-02	7.11E-02	7.01E-02	6.91E-02	6.54E-02	6.18E-02	4.16E-02	2.37E-02
ZN	0.0	2.17E-05	4.73E-10	1.03E-14	4.91E-24	1.14E-33	5.81E-48	4.22E-62	0.0	0.0	0.0	0.0
GA	0.0	1.20E-05	2.06E-10	4.49E-15	2.14E-24	4.98E-34	2.53E-48	1.84E-62	0.0	0.0	0.0	0.0
GE	0.0	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01
AS	0.0	8.70E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02
SE	0.0	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01
BR	0.0	1.53E+01	1.53E+01	1.53E+01	1.53E+01	1.53E+01	1.53E+01	1.53E+01	1.53E+01	1.53E+01	1.53E+01	1.53E+01
KR	0.0	3.75E+02	3.75E+02	3.74E+02	3.74E+02	3.74E+02	3.73E+02	3.73E+02	3.71E+02	3.70E+02	3.61E+02	3.54E+02
RB	0.0	3.33E+02	3.33E+02	3.33E+02	3.34E+02	3.34E+02	3.35E+02	3.35E+02	3.37E+02	3.38E+02	3.47E+02	3.54E+02
SR	0.0	9.24E+02	9.14E+02	9.07E+02	8.99E+02	8.94E+02	8.89E+02	8.85E+02	8.72E+02	8.59E+02	7.78E+02	6.84E+02
Y	0.0	4.80E+02	4.77E+02	4.74E+02	4.71E+02	4.69E+02	4.67E+02	4.67E+02	4.67E+02	4.67E+02	4.67E+02	4.67E+02
ZR	0.0	3.68E+03	3.68E+03	3.67E+03	3.67E+03	3.67E+03	3.67E+03	3.67E+03	3.68E+03	3.69E+03	3.78E+03	3.87E+03
NB	0.0	3.53E+01	3.27E+01	2.76E+01	1.73E+01	9.78E+00	3.90E+00	1.52E+00	3.35E-02	2.21E-03	3.94E-03	7.34E-03
MO	0.0	3.37E+03	3.39E+03	3.40E+03	3.43E+03	3.45E+03	3.46E+03	3.46E+03	3.47E+03	3.47E+03	3.47E+03	3.47E+03
TC	0.0	8.38E+02	8.41E+02	8.41E+02	8.41E+02	8.41E+02	8.41E+02	8.41E+02	8.41E+02	8.41E+02	8.41E+02	8.41E+02
RU	0.0	2.35E+03	2.32E+03	2.31E+03	2.28E+03	2.26E+03	2.24E+03	2.23E+03	2.19E+03	2.17E+03	2.15E+03	2.15E+03
RH	0.0	3.51E+02	3.65E+02	3.74E+02	3.83E+02	3.86E+02	3.88E+02	3.88E+02	3.88E+02	3.88E+02	3.88E+02	3.88E+02
PD	0.0	1.25E+03	1.26E+03	1.27E+03	1.28E+03	1.30E+03	1.32E+03	1.33E+03	1.37E+03	1.39E+03	1.41E+03	1.41E+03
AG	0.0	6.08E+01	6.06E+01	6.05E+01	6.04E+01	6.03E+01	6.02E+01	6.01E+01	5.99E+01	5.99E+01	5.98E+01	5.98E+01
CD	0.0	8.31E+01	8.34E+01	8.35E+01	8.36E+01	8.37E+01	8.38E+01	8.39E+01	8.41E+01	8.41E+01	8.42E+01	8.41E+01
IN	0.0	1.20E+00	1.22E+00	1.22E+00	1.23E+00	1.23E+00	1.23E+00	1.23E+00	1.24E+00	1.24E+00	1.25E+00	1.26E+00
SN	0.0	5.23E+01	5.20E+01	5.18E+01	5.16E+01	5.15E+01	5.13E+01	5.12E+01	5.11E+01	5.11E+01	5.11E+01	5.11E+01
SB	0.0	1.76E+01	1.74E+01	1.73E+01	1.72E+01	1.70E+01	1.67E+01	1.64E+01	1.51E+01	1.39E+01	1.07E+01	1.01E+01
TE	0.0	5.71E+02	5.65E+02	5.65E+02	5.64E+02	5.64E+02	5.65E+02	5.65E+02	5.66E+02	5.67E+02	5.71E+02	5.71E+02
I	0.0	2.75E+02	2.68E+02	2.68E+02	2.69E+02	2.69E+02	2.69E+02	2.70E+02	2.70E+02	2.70E+02	2.70E+02	2.70E+02
XE	0.0	5.43E+03	5.43E+03	5.43E+03	5.43E+03	5.43E+03	5.43E+03	5.43E+03	5.43E+03	5.43E+03	5.43E+03	5.43E+03
CS	0.0	2.75E+03	2.76E+03	2.75E+03	2.73E+03	2.72E+03	2.70E+03	2.68E+03	2.61E+03	2.56E+03	2.32E+03	2.12E+03
BA	0.0	1.37E+03	1.36E+03	1.37E+03	1.38E+03	1.40E+03	1.42E+03	1.44E+03	1.50E+03	1.56E+03	1.79E+03	2.00E+03
LA	0.0	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03
CE	0.0	2.86E+03	2.82E+03	2.79E+03	2.74E+03	2.70E+03	2.66E+03	2.62E+03	2.54E+03	2.50E+03	2.48E+03	2.48E+03
PR	0.0	1.17E+03	1.18E+03	1.19E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03
ND	0.0	3.76E+03	3.79E+03	3.82E+03	3.86E+03	3.89E+03	3.94E+03	3.97E+03	4.06E+03	4.09E+03	4.12E+03	4.12E+03
PM	0.0	1.15E+02	1.15E+02	1.13E+02	1.08E+02	1.03E+02	9.63E+01	9.02E+01	6.92E+01	5.31E+01	8.34E+00	5.91E-01
SM	0.0	7.91E+02	7.96E+02	7.99E+02	8.04E+02	8.09E+02	8.16E+02	8.22E+02	8.42E+02	8.58E+02	9.00E+02	9.05E+02
EU	0.0	1.88E+02	1.86E+02	1.85E+02	1.84E+02	1.83E+02	1.82E+02	1.81E+02	1.79E+02	1.76E+02	1.66E+02	1.58E+02
GD	0.0	9.66E+01	1.00E+02	1.01E+02	1.02E+02	1.03E+02	1.04E+02	1.05E+02	1.08E+02	1.11E+02	1.23E+02	1.35E+02
TB	0.0	1.90E+00	1.87E+00	1.84E+00	1.82E+00	1.80E+00	1.79E+00	1.78E+00	1.78E+00	1.78E+00	1.78E+00	1.78E+00
DY	0.0	9.86E-01	1.02E+00	1.04E+00	1.07E+00	1.09E+00	1.10E+00	1.10E+00	1.10E+00	1.11E+00	1.11E+00	1.11E+00
HO	0.0	1.02E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01
ER	0.0	3.06E-02	3.08E-02	3.08E-02	3.08E-02	3.08E-02	3.08E-02	3.08E-02	3.08E-02	3.08E-02	3.08E-02	3.08E-02
TOTALS	0.0	3.49E+04	3.49E+04	3.49E+04	3.49E+04	3.49E+04	3.49E+04	3.49E+04	3.49E+04	3.49E+04	3.49E+04	3.49E+04

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- WASTE DECAY TIMES

POWER= 30.00MW, BURNUP= 33000.MWD, FLUX= 2.93E+13N/CM**2-SEC

ELEMENT CONCENTRATIONS, GRAMS
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	CHARGE	REPRO ~~DISCHARGE~~	5. Y	10. Y	30. Y	90. Y	190. Y	490. Y	990. Y	1990. Y	4990. Y	9990. Y
H	0.0	4.16E-02	3.14E-02	2.37E-02	7.68E-03	2.61E-04	9.33E-07	4.24E-14	2.45E-26	0.0	0.0	0.0
GE	0.0	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01
AS	0.0	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02	8.46E-02
SE	0.0	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.20E+01	5.19E+01	5.17E+01	5.15E+01
BR	0.0	1.53E+01	1.53E+01	1.53E+01	1.53E+01	1.53E+01	1.53E+01	1.54E+01	1.54E+01	1.55E+01	1.56E+01	1.59E+01
RB	0.0	3.47E+02	3.47E+02	3.47E+02	3.47E+02	3.47E+02	3.47E+02	3.47E+02	3.47E+02	3.47E+02	3.47E+02	3.47E+02
SR	0.0	7.78E+02	7.28E+02	6.84E+02	5.54E+02	3.96E+02	3.53E+02	3.50E+02	3.50E+02	3.50E+02	3.50E+02	3.50E+02
Y	0.0	4.67E+02	4.67E+02	4.67E+02	4.67E+02	4.66E+02	4.66E+02	4.66E+02	4.66E+02	4.66E+02	4.66E+02	4.66E+02
ZR	0.0	3.78E+03	3.82E+03	3.87E+03	4.00E+03	4.16E+03	4.20E+03	4.20E+03	4.20E+03	4.20E+03	4.20E+03	4.20E+03
NB	0.0	3.94E-03	5.64E-03	7.34E-03	1.41E-02	3.45E-02	6.85E-02	1.70E-01	3.40E-01	6.80E-01	1.70E+00	3.39E+00
MO	0.0	3.47E+03	3.47E+03	3.47E+03	3.47E+03	3.47E+03	3.47E+03	3.47E+03	3.47E+03	3.47E+03	3.47E+03	3.47E+03
TC	0.0	8.41E+02	8.41E+02	8.41E+02	8.41E+02	8.41E+02	8.41E+02	8.40E+02	8.39E+02	8.36E+02	8.28E+02	8.14E+02
RU	0.0	2.15E+03	2.15E+03	2.15E+03	2.15E+03	2.15E+03	2.15E+03	2.15E+03	2.15E+03	2.15E+03	2.16E+03	2.17E+03
RH	0.0	3.88E+02	3.88E+02	3.88E+02	3.88E+02	3.88E+02	3.88E+02	3.88E+02	3.88E+02	3.88E+02	3.88E+02	3.88E+02
PD	0.0	1.41E+03	1.41E+03	1.41E+03	1.41E+03	1.41E+03	1.41E+03	1.41E+03	1.41E+03	1.41E+03	1.41E+03	1.41E+03
AG	0.0	5.98E+01	5.98E+01	5.98E+01	5.98E+01	5.98E+01	5.98E+01	5.99E+01	5.99E+01	5.99E+01	6.00E+01	6.01E+01
CD	0.0	8.42E+01	8.41E+01	8.41E+01	8.41E+01	8.41E+01	8.41E+01	8.41E+01	8.41E+01	8.41E+01	8.41E+01	8.41E+01
IN	0.0	1.25E+00	1.26E+00	1.26E+00	1.27E+00	1.28E+00	1.28E+00	1.28E+00	1.28E+00	1.28E+00	1.28E+00	1.28E+00
SN	0.0	5.11E+01	5.11E+01	5.11E+01	5.11E+01	5.11E+01	5.11E+01	5.10E+01	5.10E+01	5.08E+01	5.04E+01	4.98E+01
SB	0.0	1.07E+01	1.03E+01	1.01E+01	1.01E+01	1.01E+01	1.01E+01	1.01E+01	1.01E+01	1.01E+01	1.01E+01	1.01E+01
TE	0.0	5.71E+02	5.71E+02	5.71E+02	5.71E+02	5.71E+02	5.71E+02	5.71E+02	5.71E+02	5.71E+02	5.72E+02	5.72E+02
I	0.0	2.70E+02	2.70E+02	2.70E+02	2.70E+02	2.70E+02	2.70E+02	2.70E+02	2.70E+02	2.70E+02	2.70E+02	2.70E+02
XE	0.0	0.0	4.68E-05	9.36E-05	2.81E-04	8.43E-04	1.78E-03	4.59E-03	9.27E-03	1.86E-02	4.67E-02	9.35E-02
CS	0.0	2.32E+03	2.21E+03	2.12E+03	1.83E+03	1.46E+03	1.35E+03	1.33E+03	1.33E+03	1.33E+03	1.33E+03	1.33E+03
BA	0.0	1.79E+03	1.90E+03	2.00E+03	2.29E+03	2.66E+03	2.77E+03	2.78E+03	2.78E+03	2.78E+03	2.78E+03	2.78E+03
LA	0.0	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03
CE	0.0	2.48E+03	2.48E+03	2.48E+03	2.48E+03	2.48E+03	2.48E+03	2.48E+03	2.48E+03	2.48E+03	2.48E+03	2.48E+03
PR	0.0	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03	1.20E+03
ND	0.0	4.12E+03	4.12E+03	4.12E+03	4.12E+03	4.12E+03	4.12E+03	4.12E+03	4.12E+03	4.12E+03	4.12E+03	4.12E+03
PM	0.0	8.34E+00	2.22E+00	5.92E-01	2.97E-03	3.79E-10	1.22E-21	0.0	0.0	0.0	0.0	0.0
SM	0.0	9.00E+02	9.05E+02	9.05E+02	9.00E+02	8.87E+02	8.76E+02	8.67E+02	8.66E+02	8.66E+02	8.66E+02	8.66E+02
EU	0.0	1.66E+02	1.61E+02	1.58E+02	1.52E+02	1.57E+02	1.67E+02	1.76E+02	1.77E+02	1.77E+02	1.77E+02	1.77E+02
GD	0.0	1.23E+02	1.30E+02	1.35E+02	1.46E+02	1.54E+02	1.55E+02	1.55E+02	1.55E+02	1.55E+02	1.55E+02	1.55E+02
TB	0.0	1.78E+00	1.78E+00	1.78E+00	1.78E+00	1.78E+00	1.78E+00	1.78E+00	1.78E+00	1.78E+00	1.78E+00	1.78E+00
DY	0.0	1.11E+00	1.11E+00	1.11E+00	1.11E+00	1.11E+00	1.11E+00	1.11E+00	1.11E+00	1.11E+00	1.11E+00	1.11E+00
HO	0.0	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01	1.01E-01
ER	0.0	3.08E-02	3.08E-02	3.08E-02	3.08E-02	3.08E-02	3.08E-02	3.09E-02	3.10E-02	3.11E-02	3.12E-02	3.12E-02
TOTALS	0.0	2.91E+04	2.91E+04	2.91E+04	2.91E+04	2.91E+04	2.91E+04	2.91E+04	2.91E+04	2.91E+04	2.91E+04	2.91E+04

A N N E X 2

ACTIVITY SPECTRA OF H L W CONTAINER

The activity spectra are calculated by the Origen program in following assumptions:

- The HLW quantity included in one container corresponds to one metric ton of heavy metal charged in reactor.
- The total volume of one container is 150 liters.
- The nuclear fuel charged in the reactor is a PWR type enriched 3.3%.
- The irradiation has been at constant rate in 1100 days at a power 30 MW/metric ton, the total burn-up at discharge is 33000 MWD per ton.
- The irradiated elements are stored 10 years before reprocessing.
- When reprocessing is performed, we suppose 1% of fissile materials U and Pu stays in the wastes, but 0% of volatile materials Kr and Xe remain.
- The spectra are given:
  - in 18 energy groups for actinides
  - in 12 energy groups for fission products
- The calculation is made separately for actinides with heavy materials and for fission products. Those spectra are reproduced in annexed tables.

RESULTS

2.1 - For actinides
fuel elements storage period

2.2 - For actinides
wastes after reprocessing

2.3 - For fission products - Storage period

2.4 - For fission products - After reprocessing at 10 years

2.5 - α, N neutron source - Storage period

2.6 - α, N neutron source - After reprocessing

2.7 - Spontaneous fission neutron - Storage period

2.8 - Spontaneous fission neutron - After reprocessing

ANNEX 2 (cont.)

Ex : For 10, 40 and 1000 years after discharge, the total activity is :

	10 years	40 years	1000 years
Actinides phot/s Ci γ	2.31 E 13 624.3	2.23 E 13 602.7	6.21 E 12 167.8
Fission products phot/s Ci γ	4.33 E 15 1.170 E 05	1.71 E 15 4.62 E 04	8.32 E 10 2.25

PHOTON SPECTRUM AS A FUNCTION OF TIME FOR HEAVY METALS AND THEIR DAUGHTERS

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- FUEL DECAY TIMES
POWER= 30.00 MW, BURNUP= 33000.MWD, FLUX= 2.93E+13 N**2-SEC

ACTINIDE PHOTON RELEASE RATES, PHOTONS/SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

EMEAN (MEV)	INITIAL	TIME AFTER DISCHARGE 30. D	60. D	120. D	182. D	274. D	365. D	730. D	1096. D	REPRO 3652. D	7305. D
3.00E-02	5.24E+16	5.69E+14	2.63E+13	2.44E+11	2.19E+11	2.62E+11	3.05E+11	4.71E+11	6.29E+11	1.54E+12	2.40E+12
4.00E-02	2.01E+17	5.79E+13	7.56E+12	6.04E+12	5.96E+12	5.88E+12	5.83E+12	5.73E+12	5.71E+12	5.69E+12	5.67E+12
6.00E-02	2.56E+17	5.85E+14	2.74E+13	2.64E+12	2.95E+12	3.50E+12	4.03E+12	6.10E+12	8.07E+12	1.94E+13	3.01E+13
1.00E-01	3.91E+17	1.22E+12	1.18E+11	6.26E+10	5.59E+10	4.90E+10	4.46E+10	3.85E+10	3.88E+10	5.03E+10	6.13E+10
1.50E-01	1.80E+17	5.85E+13	1.83E+12	3.41E+11	3.35E+11	3.31E+11	3.28E+11	3.23E+11	3.22E+11	3.18E+11	3.16E+11
2.00E-01	1.42E+17	3.72E+14	1.64E+13	2.14E+11	1.79E+11	1.78E+11	1.78E+11	1.77E+11	1.75E+11	1.67E+11	1.58E+11
3.00E-01	9.57E+16	4.98E+13	1.78E+12	1.24E+11	1.20E+11	1.20E+11	1.20E+11	1.19E+11	1.19E+11	1.16E+11	1.13E+11
6.30E-01	1.60E+16	2.54E+12	7.19E+11	6.79E+11	6.48E+11	6.15E+11	5.92E+11	5.55E+11	5.47E+11	5.45E+11	5.44E+11
1.10E+00	8.61E+15	5.23E+11	1.39E+11	1.39E+11	1.39E+11	1.39E+11	1.39E+11	1.39E+11	1.39E+11	1.39E+11	1.39E+11
1.55E+00	2.77E+08	2.46E+08	2.35E+08	2.17E+08	2.03E+08	1.87E+08	1.76E+08	1.55E+08	1.47E+08	1.18E+08	8.45E+07
1.99E+00	1.37E+08	1.29E+08	1.24E+08	1.14E+08	1.06E+08	9.81E+07	9.23E+07	8.11E+07	7.69E+07	6.12E+07	4.37E+07
2.38E+00	6.74E+07	6.43E+07	6.15E+07	5.67E+07	5.28E+07	4.86E+07	4.56E+07	3.99E+07	3.75E+07	2.87E+07	1.98E+07
2.75E+00	5.04E+07	5.04E+07	5.09E+07	5.28E+07	5.51E+07	5.94E+07	6.44E+07	8.82E+07	1.13E+08	2.16E+08	2.26E+08
3.25E+00	1.95E+07	1.86E+07	1.78E+07	1.64E+07	1.53E+07	1.41E+07	1.32E+07	1.15E+07	1.08E+07	8.28E+06	5.71E+06
3.70E+00	1.25E+07	1.19E+07	1.14E+07	1.05E+07	9.81E+06	9.02E+06	8.47E+06	7.40E+06	6.96E+06	5.32E+06	3.66E+06
4.22E+00	7.89E+06	7.54E+06	7.20E+06	6.64E+06	6.19E+06	5.69E+06	5.35E+06	4.67E+06	4.39E+06	3.35E+06	2.31E+06
4.70E+00	3.74E+06	3.57E+06	3.41E+06	3.14E+06	2.93E+06	2.69E+06	2.53E+06	2.21E+06	2.08E+06	1.59E+06	1.09E+06
5.25E+00	2.35E+06	2.24E+06	2.14E+06	1.98E+06	1.84E+06	1.69E+06	1.59E+06	1.39E+06	1.31E+06	9.99E+05	6.88E+05
TOTAL	1.34E+18	1.70E+15	8.22E+13	1.05E+13	1.06E+13	1.11E+13	1.16E+13	1.37E+13	1.58E+13	2.80E+13	3.95E+13
MEV/SEC	1.68E+17	1.55E+14	7.44E+12	1.13E+12	1.11E+12	1.12E+12	1.14E+12	1.24E+12	1.35E+12	2.06E+12	2.72E+12

ACTINIDE ENERGY RELEASE RATES, MEV/WATT-SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

EMEAN (MEV)	INITIAL	TIME AFTER DISCHARGE 30. D	60. D	120. D	182. D	274. D	365. D	730. D	1096. D	REPRO 3652. D	7305. D
3.00E-02	5.24E+07	5.69E+05	2.63E+04	2.44E+02	2.19E+02	2.62E+02	3.05E+02	4.71E+02	6.29E+02	1.54E+03	2.40E+03
4.00E-02	2.67E+08	7.72E+04	1.01E+04	8.06E+03	7.95E+03	7.84E+03	7.77E+03	7.64E+03	7.62E+03	7.59E+03	7.55E+03
6.00E-02	5.11E+08	1.17E+06	5.48E+04	5.27E+03	5.91E+03	7.00E+03	8.06E+03	1.22E+04	1.61E+04	3.89E+04	6.01E+04
1.00E-01	1.30E+09	4.08E+03	3.94E+02	2.09E+02	1.86E+02	1.63E+02	1.49E+02	1.28E+02	1.29E+02	1.68E+02	2.04E+02
1.50E-01	9.01E+08	2.92E+05	9.16E+03	1.71E+03	1.67E+03	1.65E+03	1.64E+03	1.61E+03	1.61E+03	1.59E+03	1.58E+03
2.00E-01	9.44E+08	2.48E+06	1.09E+05	1.42E+03	1.19E+03	1.19E+03	1.19E+03	1.18E+03	1.17E+03	1.11E+03	1.05E+03
3.00E-01	9.57E+08	4.98E+05	1.78E+04	1.24E+03	1.20E+03	1.20E+03	1.20E+03	1.19E+03	1.19E+03	1.16E+03	1.13E+03
6.30E-01	3.37E+08	5.33E+04	1.51E+04	1.43E+04	1.36E+04	1.29E+04	1.24E+04	1.17E+04	1.15E+04	1.14E+04	1.14E+04
1.10E+00	3.16E+08	1.92E+04	5.10E+03	5.10E+03	5.10E+03	5.10E+03	5.10E+03	5.09E+03	5.09E+03	5.09E+03	5.08E+03
1.55E+00	1.43E+01	1.27E+01	1.21E+01	1.12E+01	1.05E+01	9.66E+00	9.09E+00	8.01E+00	7.60E+00	6.08E+00	4.37E+00
1.99E+00	9.12E+00	8.57E+00	8.20E+00	7.57E+00	7.06E+00	6.51E+00	6.12E+00	5.38E+00	5.10E+00	4.06E+00	2.90E+00
2.38E+00	5.34E+00	5.10E+00	4.88E+00	4.50E+00	4.19E+00	3.86E+00	3.62E+00	3.16E+00	2.98E+00	2.27E+00	1.57E+00
2.75E+00	4.62E+00	4.62E+00	4.66E+00	4.84E+00	5.05E+00	5.44E+00	5.90E+00	8.09E+00	1.04E+01	1.98E+01	2.07E+01
3.25E+00	2.11E+00	2.01E+00	1.93E+00	1.78E+00	1.66E+00	1.52E+00	1.43E+00	1.25E+00	1.17E+00	8.97E-01	6.18E-01
3.70E+00	1.54E+00	1.47E+00	1.41E+00	1.30E+00	1.21E+00	1.11E+00	1.05E+00	9.12E-01	8.58E-01	6.56E-01	4.52E-01
4.22E+00	1.11E+00	1.06E+00	1.01E+00	9.34E-01	8.71E-01	8.01E-01	7.52E-01	6.56E-01	6.18E-01	4.72E-01	3.25E-01
4.70E+00	5.85E-01	5.59E-01	5.34E-01	4.93E-01	4.59E-01	4.22E-01	3.96E-01	3.46E-01	3.26E-01	2.49E-01	1.71E-01
5.25E+00	4.11E-01	3.93E-01	3.75E-01	3.46E-01	3.23E-01	2.97E-01	2.78E-01	2.43E-01	2.29E-01	1.75E-01	1.20E-01
TOTAL	5.59E+09	5.17E+06	2.48E+05	3.76E+04	3.71E+04	3.73E+04	3.79E+04	4.12E+04	4.51E+04	6.86E+04	9.06E+04
GAMMA WATTS	2.69E+04	2.48E+01	1.19E+00	1.81E-01	1.78E-01	1.80E-01	1.82E-01	1.98E-01	2.17E-01	3.30E-01	4.36E-01

PHOTON SPECTRUM AS A FUNCTION OF TIME FOR HEAVY METALS AND THEIR DAUGHTERS

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- WASTE DECAY TIMES
POWER= 30.00 MW, BURNUP= 33000.MWD, FLUX= 2.93E+13 N**2-SEC

ACTINIDE PHOTON RELEASE RATES, PHOTONS/SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

EMEAN	REPRO	TIME AFTER DISCHARGE									
(MEV)	~~INITIAL~~	5. Y	10. Y	30. Y	90. Y	190. Y	490. Y	990. Y	1990. Y	4990. Y	9990. Y
3.00E-02	1.52E+12	1.51E+12	1.50E+12	1.47E+12	1.34E+12	1.14E+12	7.07E+11	3.20E+11	6.80E+10	4.80E+09	4.18E+09
4.00E-02	8.56E+11	8.48E+11	8.39E+11	7.99E+11	6.75E+11	5.21E+11	3.16E+11	2.44E+11	2.16E+11	1.62E+11	1.01E+11
6.00E-02	1.94E+13	1.93E+13	1.92E+13	1.87E+13	1.71E+13	1.47E+13	9.32E+12	4.51E+12	1.35E+12	4.34E+11	2.73E+11
1.00E-01	2.55E+10	2.46E+10	2.43E+10	2.34E+10	2.13E+10	1.87E+10	1.31E+10	8.00E+09	4.64E+09	3.62E+09	3.41E+09
1.50E-01	3.11E+11	3.11E+11	3.10E+11	3.10E+11	3.08E+11	3.05E+11	2.97E+11	2.84E+11	2.59E+11	1.98E+11	1.26E+11
2.00E-01	1.53E+11	1.50E+11	1.48E+11	1.42E+11	1.34E+11	1.30E+11	1.26E+11	1.21E+11	1.10E+11	8.40E+10	5.35E+10
3.00E-01	1.15E+11	1.13E+11	1.11E+11	1.07E+11	1.02E+11	9.96E+10	9.83E+10	9.56E+10	8.90E+10	7.07E+10	4.91E+10
6.30E-01	5.45E+11	5.44E+11	5.43E+11	5.42E+11	5.39E+11	5.34E+11	5.20E+11	4.96E+11	4.53E+11	3.46E+11	2.20E+11
1.10E+00	1.39E+11	1.39E+11	1.39E+11	1.38E+11	1.37E+11	1.36E+11	1.33E+11	1.27E+11	1.16E+11	8.81E+10	5.60E+10
1.55E+00	1.16E+08	8.97E+07	7.34E+07	3.45E+07	4.36E+06	1.08E+06	1.17E+06	1.66E+06	3.24E+06	1.10E+07	2.82E+07
1.99E+00	6.03E+07	4.73E+07	3.87E+07	1.82E+07	2.27E+06	5.17E+05	4.73E+05	4.99E+05	6.12E+05	1.22E+06	2.51E+06
2.38E+00	2.82E+07	2.33E+07	1.93E+07	9.09E+06	1.13E+06	2.70E+05	2.82E+05	3.67E+05	6.33E+05	1.84E+06	4.25E+06
2.75E+00	2.16E+08	4.59E+07	1.65E+07	6.06E+06	1.55E+06	5.07E+05	1.24E+05	9.74E+04	9.10E+04	9.02E+04	1.17E+05
3.25E+00	8.15E+06	6.74E+06	5.58E+06	2.63E+06	3.25E+05	7.18E+04	6.31E+04	5.91E+04	5.27E+04	4.13E+04	3.69E+04
3.70E+00	5.24E+06	4.33E+06	3.58E+06	1.69E+06	2.09E+05	4.60E+04	4.03E+04	3.74E+04	3.24E+04	2.10E+04	1.03E+04
4.22E+00	3.30E+06	2.73E+06	2.26E+06	1.07E+06	1.32E+05	2.90E+04	2.54E+04	2.36E+04	2.04E+04	1.33E+04	6.51E+03
4.70E+00	1.56E+06	1.29E+06	1.07E+06	5.04E+05	6.23E+04	1.37E+04	1.20E+04	1.12E+04	9.66E+03	6.27E+03	3.08E+03
5.25E+00	9.83E+05	8.13E+05	6.73E+05	3.17E+05	3.92E+04	8.65E+03	7.57E+03	7.02E+03	6.08E+03	3.95E+03	1.94E+03
TOTAL	2.31E+13	2.29E+13	2.28E+13	2.23E+13	2.04E+13	1.76E+13	1.15E+13	6.21E+12	2.66E+12	1.39E+12	8.87E+11
MEV/SEC	1.85E+12	1.85E+12	1.84E+12	1.80E+12	1.69E+12	1.53E+12	1.17E+12	8.38E+11	5.92E+11	4.15E+11	2.65E+11

ACTINIDE ENERGY RELEASE RATES, MEV/WATT-SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

EMEAN	REPRO	TIME AFTER DISCHARGE									
(MEV)	~~INITIAL~~	5. Y	10. Y	30. Y	90. Y	190. Y	490. Y	990. Y	1990. Y	4990. Y	9990. Y
3.00E-02	1.52E+03	1.51E+03	1.50E+03	1.47E+03	1.34E+03	1.14E+03	7.07E+02	3.20E+02	6.80E+01	4.80E+00	4.18E+00
4.00E-02	1.14E+03	1.13E+03	1.12E+03	1.07E+03	9.00E+02	6.94E+02	4.21E+02	3.25E+02	2.88E+02	2.17E+02	1.35E+02
6.00E-02	3.88E+04	3.86E+04	3.84E+04	3.75E+04	3.43E+04	2.94E+04	1.86E+04	9.02E+03	2.69E+03	8.69E+02	5.46E+02
1.00E-01	8.51E+01	8.19E+01	8.09E+01	7.79E+01	7.12E+01	6.24E+01	4.35E+01	2.67E+01	1.55E+01	1.21E+01	1.14E+01
1.50E-01	1.55E+03	1.55E+03	1.55E+03	1.55E+03	1.54E+03	1.52E+03	1.48E+03	1.42E+03	1.30E+03	9.88E+02	6.29E+02
2.00E-01	1.02E+03	1.00E+03	9.88E+02	9.49E+02	8.93E+02	8.68E+02	8.42E+02	8.04E+02	7.34E+02	5.60E+02	3.57E+02
3.00E-01	1.15E+03	1.13E+03	1.11E+03	1.07E+03	1.02E+03	9.96E+02	9.83E+02	9.56E+02	8.90E+02	7.07E+02	4.91E+02
6.30E-01	1.14E+04	1.14E+04	1.14E+04	1.14E+04	1.13E+04	1.12E+04	1.09E+04	1.04E+04	9.52E+03	7.26E+03	4.62E+03
1.10E+00	5.09E+03	5.08E+03	5.08E+03	5.07E+03	5.04E+03	4.99E+03	4.86E+03	4.64E+03	4.24E+03	3.23E+03	2.05E+03
1.55E+00	5.97E+00	4.63E+00	3.79E+00	1.78E+00	2.25E-01	5.56E-02	6.04E-02	8.57E-02	1.67E-01	5.67E-01	1.46E+00
1.99E+00	4.00E+00	3.14E+00	2.57E+00	1.21E+00	1.51E-01	3.43E-02	3.14E-02	3.31E-02	4.06E-02	8.07E-02	1.66E-01
2.38E+00	2.23E+00	1.85E+00	1.53E+00	7.21E-01	8.99E-02	2.14E-02	2.24E-02	2.91E-02	5.03E-02	1.46E-01	3.37E-01
2.75E+00	1.98E+01	4.21E+00	1.51E+00	5.55E-01	1.42E-01	4.65E-02	1.14E-02	8.93E-03	8.34E-03	8.27E-03	1.07E-02
3.25E+00	8.83E-01	7.31E-01	6.04E-01	2.85E-01	3.52E-02	7.78E-03	6.84E-03	6.40E-03	5.71E-03	4.48E-03	4.00E-03
3.70E+00	6.46E-01	5.34E-01	4.42E-01	2.08E-01	2.57E-02	5.68E-03	4.97E-03	4.61E-03	3.99E-03	2.59E-03	1.27E-03
4.22E+00	4.65E-01	3.84E-01	3.18E-01	1.50E-01	1.85E-02	4.09E-03	3.58E-03	3.32E-03	2.87E-03	1.86E-03	9.15E-04
4.70E+00	2.45E-01	2.03E-01	1.68E-01	7.90E-02	9.76E-03	2.15E-03	1.89E-03	1.75E-03	1.51E-03	9.83E-04	4.83E-04
5.25E+00	1.72E-01	1.42E-01	1.18E-01	5.55E-02	6.86E-03	1.51E-03	1.32E-03	1.23E-03	1.06E-03	6.90E-04	3.39E-04
TOTAL	6.18E+04	6.15E+04	6.13E+04	6.01E+04	5.64E+04	5.09E+04	3.89E+04	2.79E+04	1.97E+04	1.38E+04	8.85E+03
GAMMA WATTS	2.97E-01	2.96E-01	2.95E-01	2.89E-01	2.71E-01	2.45E-01	1.87E-01	1.34E-01	9.50E-02	6.66E-02	4.26E-02

PHOTON SPECTRUM AS A FUNCTION OF TIME FOR FISSION PRODUCTS

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- FUEL DECAY TIMES
POWER= 30.00 MW, BURNUP= 33000.MWD, FLUX= 2.93E+13 N**2-SEC

TWELVE GROUP PHOTON RELEASE RATES, PHOTONS/SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

EMEAN		TIME AFTER DISCHARGE								REPRO	
(MEV)	INITIAL	30. D	60. D	120. D	182. D	274. D	365. D	730. D	1096. D	3652. D	7305. D
3.00E-01	9.13E+17	2.19E+16	1.31E+16	9.21E+15	7.49E+15	5.91E+15	4.81E+15	2.24E+15	1.12E+15	1.76E+14	1.28E+14
6.30E-01	1.72E+18	1.74E+17	1.30E+17	8.27E+16	5.63E+16	3.68E+16	2.81E+16	1.74E+16	1.29E+16	4.01E+15	2.58E+15
1.10E+00	6.40E+17	4.97E+15	2.60E+15	1.71E+15	1.47E+15	1.24E+15	1.08E+15	6.50E+14	4.30E+14	1.36E+14	8.23E+13
1.55E+00	3.90E+17	1.27E+16	2.99E+15	6.39E+14	4.93E+14	4.20E+14	3.64E+14	2.15E+14	1.34E+14	1.05E+13	1.13E+12
1.99E+00	6.54E+16	7.95E+14	4.44E+14	2.99E+14	2.52E+14	2.03E+14	1.63E+14	6.92E+13	2.94E+13	1.23E+11	2.39E+10
2.38E+00	7.13E+16	4.24E+14	1.09E+14	3.15E+13	2.55E+13	2.13E+13	1.79E+13	8.92E+12	4.44E+12	3.49E+10	3.50E+07
2.75E+00	2.98E+16	2.57E+12	2.43E+12	2.17E+12	1.93E+12	1.62E+12	1.36E+12	6.84E+11	3.42E+11	2.74E+09	2.76E+06
3.25E+00	5.20E+16	8.10E+10	7.66E+10	6.84E+10	6.08E+10	5.11E+10	4.30E+10	2.16E+10	1.08E+10	8.67E+07	8.74E+04
3.70E+00	3.07E+15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.22E+00	9.39E+15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.70E+00	4.32E+15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25E+00	1.08E+15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	3.90E+18	2.15E+17	1.49E+17	9.46E+16	6.60E+16	4.46E+16	3.45E+16	2.05E+16	1.46E+16	4.33E+15	2.80E+15
MEV/SEC	3.29E+18	1.44E+17	9.42E+16	5.84E+16	4.07E+16	2.74E+16	2.12E+16	1.28E+16	9.20E+15	2.74E+15	1.76E+15

TWELVE GROUP ENERGY RELEASE RATES, MEV/WATT-SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

EMEAN		TIME AFTER DISCHARGE								REPRO	
(MEV)	INITIAL	30. D	60. D	120. D	182. D	274. D	365. D	730. D	1096. D	3652. D	7305. D
3.00E-01	9.13E+09	2.19E+08	1.31E+08	9.21E+07	7.49E+07	5.91E+07	4.81E+07	2.24E+07	1.12E+07	1.76E+06	1.28E+06
6.30E-01	3.61E+10	3.66E+09	2.72E+09	1.74E+09	1.18E+09	7.72E+08	5.89E+08	3.64E+08	2.70E+08	8.42E+07	5.43E+07
1.10E+00	2.35E+10	1.82E+08	9.54E+07	6.29E+07	5.39E+07	4.56E+07	3.95E+07	2.38E+07	1.58E+07	4.99E+06	3.02E+06
1.55E+00	2.01E+10	6.59E+08	1.55E+08	3.30E+07	2.54E+07	2.17E+07	1.88E+07	1.11E+07	6.92E+06	5.45E+05	5.85E+04
1.99E+00	4.34E+09	5.27E+07	2.95E+07	1.98E+07	1.67E+07	1.34E+07	1.08E+07	4.59E+06	1.95E+06	8.19E+03	1.58E+03
2.38E+00	5.66E+09	3.36E+07	8.64E+06	2.50E+06	2.02E+06	1.69E+06	1.42E+06	7.07E+05	3.52E+05	2.77E+03	2.78E+00
2.75E+00	2.73E+09	2.36E+05	2.23E+05	1.99E+05	1.77E+05	1.49E+05	1.25E+05	6.27E+04	3.14E+04	2.51E+02	2.53E-01
3.25E+00	5.63E+09	8.78E+03	8.30E+03	7.41E+03	6.59E+03	5.54E+03	4.66E+03	2.34E+03	1.17E+03	9.39E+00	9.47E-03
3.70E+00	3.78E+08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.22E+00	1.32E+09	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.70E+00	6.76E+08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25E+00	1.90E+08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	1.10E+11	4.81E+09	3.14E+09	1.95E+09	1.36E+09	9.14E+08	7.08E+08	4.27E+08	3.07E+08	9.15E+07	5.86E+07
GAMMA WATTS	5.28E+05	2.31E+04	1.51E+04	9.36E+03	6.52E+03	4.39E+03	3.41E+03	2.05E+03	1.47E+03	4.40E+02	2.82E+02

PHOTON SPECTRUM AS A FUNCTION OF TIME FOR FISSION PRODUCTS

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- WASTE DECAY TIMES
POWER= 30.00 MW, BURNUP= 33000.MWD, FLUX= 2.93E+13 N**2-SEC

TWELVE GROUP PHOTON RELEASE RATES, PHOTONS/SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

EMEAN (MEV)	REPRO ~~INITIAL~~	TIME AFTER DISCHARGE 5. Y	10. Y	30. Y	90. Y	190. Y	490. Y	990. Y	1990. Y	4990. Y	9990. Y
3.00E-01	1.74E+14	1.46E+14	1.27E+14	7.66E+13	1.74E+13	1.53E+12	8.48E+09	6.37E+09	6.30E+09	6.17E+09	5.97E+09
6.30E-01	4.01E+15	3.02E+15	2.58E+15	1.60E+15	3.95E+14	3.90E+13	1.13E+11	7.52E+10	7.47E+10	7.31E+10	7.06E+10
1.10E+00	1.36E+14	1.03E+14	8.23E+13	3.53E+13	3.03E+12	8.31E+10	3.26E+07	9.54E+05	5.35E+05	9.46E+04	5.26E+03
1.55E+00	1.05E+13	2.65E+12	1.13E+12	4.90E+11	1.11E+11	1.09E+10	1.66E+09	1.65E+09	1.64E+09	1.61E+09	1.55E+09
1.99E+00	1.23E+11	2.90E+10	2.39E+10	1.45E+10	3.31E+09	2.81E+08	1.72E+05	7.54E-01	1.46E-11	0.0	0.0
2.38E+00	3.49E+10	1.10E+09	3.50E+07	3.56E+01	3.75E-17	0.0	0.0	0.0	0.0	0.0	0.0
2.75E+00	2.74E+09	8.68E+07	2.76E+06	2.81E+00	2.96E-18	0.0	0.0	0.0	0.0	0.0	0.0
3.25E+00	8.67E+07	2.75E+06	8.75E+04	8.90E-02	9.38E-20	0.0	0.0	0.0	0.0	0.0	0.0
3.70E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.22E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.70E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	4.33E+15	3.27E+15	2.79E+15	1.71E+15	4.15E+14	4.07E+13	1.24E+11	8.32E+10	8.26E+10	8.09E+10	7.82E+10
MEV/SEC	2.74E+15	2.06E+15	1.76E+15	1.07E+15	2.58E+14	2.52E+13	7.66E+10	5.19E+10	5.15E+10	5.04E+10	4.87E+10

TWELVE GROUP ENERGY RELEASE RATES, MEV/WATT-SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

EMEAN (MEV)	REPRO ~~INITIAL~~	TIME AFTER DISCHARGE 5. Y	10. Y	30. Y	90. Y	190. Y	490. Y	990. Y	1990. Y	4990. Y	9990. Y
3.00E-01	1.74E+06	1.46E+06	1.27E+06	7.66E+05	1.74E+05	1.53E+04	8.48E+01	6.37E+01	6.30E+01	6.17E+01	5.97E+01
6.30E-01	8.41E+07	6.34E+07	5.43E+07	3.36E+07	8.29E+06	8.20E+05	2.38E+03	1.58E+03	1.57E+03	1.54E+03	1.48E+03
1.10E+00	4.99E+06	3.78E+06	3.02E+06	1.29E+06	1.11E+05	3.05E+03	1.20E+00	3.50E-02	1.96E-02	3.47E-03	1.93E-04
1.55E+00	5.45E+05	1.37E+05	5.85E+04	2.53E+04	5.74E+03	5.64E+02	8.59E+01	8.53E+01	8.47E+01	8.30E+01	8.02E+01
1.99E+00	8.19E+03	1.92E+03	1.58E+03	9.65E+02	2.20E+02	1.86E+01	1.14E-02	5.00E-08	9.67E-19	0.0	0.0
2.38E+00	2.77E+03	8.76E+01	2.78E+00	2.82E-06	2.98E-24	0.0	0.0	0.0	0.0	0.0	0.0
2.75E+00	2.51E+02	7.96E+00	2.53E-01	2.57E-07	2.71E-25	0.0	0.0	0.0	0.0	0.0	0.0
3.25E+00	9.39E+00	2.98E-01	9.47E-03	9.64E-09	1.02E-26	0.0	0.0	0.0	0.0	0.0	0.0
3.70E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.22E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.70E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.25E+00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	9.14E+07	6.88E+07	5.86E+07	3.56E+07	8.58E+06	8.39E+05	2.55E+03	1.73E+03	1.72E+03	1.68E+03	1.62E+03
GAMMA WATTS	4.40E+02	3.31E+02	2.82E+02	1.71E+02	4.13E+01	4.03E+00	1.23E-02	8.31E-03	8.25E-03	8.08E-03	7.81E-03

NEUTRON SOURCE

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- FUEL DECAY TIMES
ALPHA-N NEUTRON SOURCE IN DISCHARGED FUEL, NEUTRONS/SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

REPRO

	INITIAL	30. D	60. D	120. D	182. D	274. D	365. D	730. D	1096. D	3652. D	7305. D
BI211	3.44E-03	3.67E-03	3.91E-03	4.39E-03	4.88E-03	5.62E-03	6.34E-03	9.54E-03	1.24E-02	3.09E-02	5.45E-02
BI212	3.76E-02	4.03E-02	4.39E-02	5.22E-02	6.02E-02	7.25E-02	8.52E-02	1.38E-01	1.89E-01	4.01E-01	4.29E-01
BI213	9.61E-12	5.56E-12	2.87E-12	1.78E-12	1.74E-12	1.79E-12	1.84E-12	2.09E-12	2.32E-12	4.15E-12	7.33E-12
PO210	6.74E-07	7.31E-07	7.91E-07	9.17E-07	1.06E-06	1.30E-06	1.56E-06	2.93E-06	4.93E-06	5.43E-05	2.81E-04
PO211	1.61E-05	1.72E-05	1.83E-05	2.05E-05	2.28E-05	2.62E-05	2.96E-05	4.46E-05	5.78E-05	1.44E-04	2.54E-04
PO212	1.06E+01	1.14E+01	1.24E+01	1.47E+01	1.70E+01	2.05E+01	2.40E+01	3.88E+01	5.35E+01	1.13E+02	1.21E+02
PO213	1.76E-03	1.02E-03	5.25E-04	3.26E-04	3.18E-04	3.28E-04	3.38E-04	3.83E-04	4.25E-04	7.59E-04	1.34E-03
PO214	1.10E-04	1.14E-04	1.18E-04	1.29E-04	1.39E-04	1.55E-04	1.72E-04	2.53E-04	3.53E-04	1.62E-03	5.22E-03
PO215	5.18E-03	5.53E-03	5.89E-03	6.61E-03	7.36E-03	8.46E-03	9.55E-03	1.44E-02	1.86E-02	4.66E-02	8.21E-02
PO216	6.43E+00	6.89E+00	7.50E+00	8.91E+00	1.03E+01	1.24E+01	1.46E+01	2.35E+01	3.24E+01	6.85E+01	7.33E+01
PO218	4.46E-05	4.60E-05	4.78E-05	5.19E-05	5.60E-05	6.25E-05	6.94E-05	1.02E-04	1.43E-04	6.52E-04	2.11E-03
AT217	9.64E-04	5.58E-04	2.88E-04	1.79E-04	1.75E-04	1.80E-04	1.85E-04	2.10E-04	2.33E-04	4.16E-04	7.36E-04
RN219	3.87E-03	4.13E-03	4.40E-03	4.93E-03	5.49E-03	6.31E-03	7.12E-03	1.07E-02	1.39E-02	3.47E-02	6.12E-02
RN220	4.88E+00	5.24E+00	5.70E+00	6.77E+00	7.81E+00	9.41E+00	1.11E+01	1.79E+01	2.46E+01	5.20E+01	5.57E+01
RN222	3.21E-05	3.32E-05	3.45E-05	3.74E-05	4.04E-05	4.51E-05	5.00E-05	7.36E-05	1.03E-04	4.70E-04	1.52E-03
FR221	6.48E-04	3.75E-04	1.93E-04	1.20E-04	1.17E-04	1.21E-04	1.24E-04	1.41E-04	1.57E-04	2.80E-04	4.95E-04
RA223	2.24E-03	2.39E-03	2.54E-03	2.85E-03	3.18E-03	3.65E-03	4.12E-03	6.21E-03	8.05E-03	2.01E-02	3.54E-02
RA224	3.37E+00	3.62E+00	3.93E+00	4.68E+00	5.39E+00	6.50E+00	7.64E+00	1.23E+01	1.70E+01	3.59E+01	3.85E+01
RA226	1.95E-05	2.02E-05	2.10E-05	2.26E-05	2.44E-05	2.73E-05	3.03E-05	4.45E-05	6.22E-05	2.85E-04	9.19E-04
AC225	4.75E-04	2.75E-04	1.42E-04	8.81E-05	8.60E-05	8.85E-05	9.12E-05	1.03E-04	1.15E-04	2.05E-04	3.62E-04
AC227	3.16E-12	3.36E-12	3.56E-12	3.96E-12	4.38E-12	4.99E-12	5.59E-12	7.99E-12	1.03E-11	2.59E-11	4.56E-11
TH227	2.53E-03	2.70E-03	2.87E-03	3.21E-03	3.56E-03	4.08E-03	4.59E-03	6.77E-03	8.78E-03	2.19E-02	3.86E-02
TH228	2.83E+00	3.09E+00	3.36E+00	3.92E+00	4.52E+00	5.45E+00	6.40E+00	1.04E+01	1.43E+01	3.02E+01	3.24E+01
TH229	4.93E-05	4.98E-05	5.03E-05	5.14E-05	5.25E-05	5.41E-05	5.58E-05	6.25E-05	6.95E-05	1.24E-04	2.19E-04
TH230	1.96E-02	2.02E-02	2.08E-02	2.20E-02	2.32E-02	2.50E-02	2.68E-02	3.41E-02	4.15E-02	9.52E-02	1.78E-01
TH232	1.60E-08	1.67E-08	1.74E-08	1.89E-08	2.04E-08	2.26E-08	2.48E-08	3.37E-08	4.26E-08	1.05E-07	1.93E-07
PA231	3.58E-02	3.59E-02	3.59E-02	3.60E-02	3.61E-02	3.63E-02	3.64E-02	3.69E-02	3.75E-02	4.12E-02	4.65E-02
U232	1.07E+01	1.12E+01	1.17E+01	1.26E+01	1.35E+01	1.47E+01	1.59E+01	1.99E+01	2.29E+01	3.07E+01	2.97E+01
U233	5.59E-02	5.61E-02	5.62E-02	5.65E-02	5.68E-02	5.73E-02	5.77E-02	5.97E-02	6.17E-02	7.43E-02	9.24E-02
U234	8.87E+02	8.88E+02	8.89E+02	8.90E+02	8.92E+02	8.94E+02	8.97E+02	9.06E+02	9.16E+02	9.80E+02	1.07E+03
U235	1.76E+01	1.76E+01	1.76E+01	1.76E+01	1.76E+01	1.76E+01	1.76E+01	1.76E+01	1.76E+01	1.76E+01	1.76E+01
U236	2.73E+02	2.73E+02	2.73E+02	2.73E+02	2.73E+02	2.73E+02	2.73E+02	2.73E+02	2.73E+02	2.73E+02	2.74E+02
U238	2.32E+02	2.32E+02	2.32E+02	2.32E+02	2.32E+02	2.32E+02	2.32E+02	2.32E+02	2.32E+02	2.32E+02	2.32E+02
NP237	4.24E+02	4.33E+02	4.33E+02	4.33E+02	4.33E+02	4.33E+02	4.33E+02	4.34E+02	4.34E+02	4.37E+02	4.44E+02
PU236	8.27E+02	8.14E+02	7.98E+02	7.67E+02	7.36E+02	6.97E+02	6.52E+02	5.11E+02	4.00E+02	7.30E+01	6.41E+00
PU238	5.41E+06	5.49E+06	5.52E+06	5.58E+06	5.62E+06	5.65E+06	5.68E+06	5.69E+06	5.66E+06	5.36E+06	4.96E+06
PU239	4.98E+05	5.05E+05	5.05E+05	5.05E+05	5.05E+05	5.05E+05	5.05E+05	5.05E+05	5.05E+05	5.05E+05	5.05E+05
PU240	7.54E+05	7.54E+05	7.54E+05	7.54E+05	7.54E+05	7.54E+05	7.54E+05	7.54E+05	7.55E+05	7.56E+05	7.58E+05
PU241	4.56E-14	4.55E-14	4.53E-14	4.49E-14	4.46E-14	4.40E-14	4.35E-14	4.15E-14	3.96E-14	2.84E-14	1.77E-14
PU242	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03
PU244	1.72E-12	2.24E-12	2.75E-12	3.78E-12	4.84E-12	6.42E-12	7.98E-12	1.42E-11	2.05E-11	6.43E-11	1.27E-10
AM241	1.76E+05	2.04E+05	2.32E+05	2.88E+05	3.45E+05	4.29E+05	5.11E+05	8.30E+05	1.13E+06	2.89E+06	4.53E+06
AM243	3.27E+04	3.27E+04	3.27E+04	3.27E+04	3.27E+04	3.27E+04	3.27E+04	3.27E+04	3.27E+04	3.27E+04	3.27E+04
CM242	9.77E+07	8.65E+07	7.62E+07	5.90E+07	4.53E+07	3.07E+07	2.08E+07	4.43E+06	9.51E+05	2.10E+04	2.00E+04
CM243	1.06E+04	1.05E+04	1.05E+04	1.05E+04	1.05E+04	1.04E+04	1.03E+04	1.01E+04	9.90E+03	8.51E+03	6.85E+03
CM244	5.94E+06	5.93E+06	5.91E+06	5.87E+06	5.83E+06	5.78E+06	5.72E+06	5.51E+06	5.30E+06	4.05E+06	2.76E+06
CM245	6.98E+02	6.98E+02	6.98E+02	6.98E+02	6.98E+02	6.98E+02	6.98E+02	6.98E+02	6.97E+02	6.97E+02	6.97E+02
CM246	1.27E+02	1.27E+02	1.27E+02	1.27E+02	1.27E+02	1.27E+02	1.27E+02	1.27E+02	1.27E+02	1.27E+02	1.27E+02
CM247	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04
CM248	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.95E-04
BK249	9.91E-22	9.28E-22	8.69E-22	7.61E-22	6.64E-22	5.42E-22	4.43E-22	1.98E-22	8.83E-23	3.14E-25	9.87E-29
CF249	3.48E-03	5.22E-03	6.86E-03	9.82E-03	1.25E-02	1.58E-02	1.85E-02	2.52E-02	2.82E-02	3.02E-02	2.96E-02
CF250	1.02E-01	1.02E-01	1.02E-01	1.01E-01	1.00E-01	9.87E-02	9.74E-02	9.24E-02	8.76E-02	6.05E-02	3.56E-02
CF251	6.91E-04	6.91E-04	6.91E-04	6.91E-04	6.91E-04	6.91E-04	6.91E-04	6.90E-04	6.90E-04	6.86E-04	6.81E-04
CF252	1.30E-01	1.27E-01	1.25E-01	1.19E-01	1.14E-01	1.07E-01	1.00E-01	7.71E-02	5.93E-02	9.48E-03	6.90E-04
CF253	1.27E-21	3.96E-22	1.23E-22	1.19E-23	1.07E-24	2.97E-26	8.61E-28	5.83E-34	3.80E-40	0.0	0.0
CF254	2.80E-25	1.98E-25	1.41E-25	7.07E-26	3.48E-26	1.21E-26	4.27E-27	6.52E-29	9.85E-31	1.88E-43	1.26E-61
ES253	1.19E-02	1.00E-02	5.42E-03	1.10E-03	1.73E-04	9.55E-06	5.00E-07	2.82E-12	1.39E-17	0.0	0.0
TOTAL	1.11E+08	9.95E+07	8.91E+07	7.21E+07	5.84E+07	4.38E+07	3.41E+07	1.78E+07	1.43E+07	1.36E+07	1.36E+07

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- WASTE DECAY TIMES
ALPHA-N NEUTRON SOURCE IN DISCHARGED FUEL, NEUTRONS/SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	INITIAL	5. Y	10. Y	30. Y	90. Y	190. Y	490. Y	990. Y	1990. Y	4990. Y	9990. Y
BI211	3.09E-02	4.25E-02	5.25E-02	7.95E-02	1.06E-01	1.11E-01	1.15E-01	1.21E-01	1.33E-01	1.69E-01	2.31E-01
BI212	4.01E-01	6.93E-02	1.49E-02	3.61E-03	2.02E-03	7.72E-04	4.30E-05	3.57E-07	1.19E-08	2.53E-08	5.16E-08
BI213	4.15E-12	4.25E-12	4.52E-12	7.38E-12	3.34E-11	1.39E-10	9.73E-10	4.32E-09	1.90E-08	1.23E-07	4.46E-07
PO210	5.43E-05	1.35E-04	2.53E-04	1.00E-03	4.47E-03	1.15E-02	4.05E-02	1.04E-01	2.86E-01	1.08E+00	2.62E+00
PO211	1.44E-04	1.99E-04	2.45E-04	3.71E-04	4.93E-04	5.18E-04	5.37E-04	5.65E-04	6.20E-04	7.88E-04	1.08E-03
PO212	1.13E+02	1.96E+01	4.20E+00	1.02E+00	5.71E-01	2.18E-01	1.21E-02	1.01E-04	3.35E-06	7.15E-06	1.46E-05
PO213	7.59E-04	7.77E-04	8.27E-04	1.35E-03	6.11E-03	2.53E-02	1.78E-01	7.91E-01	3.48E+00	2.24E+01	8.16E+01
PO214	1.62E-03	2.86E-03	4.15E-03	9.24E-03	2.49E-02	5.30E-02	1.57E-01	4.00E-01	1.11E+00	4.18E+00	1.01E+01
PO215	4.66E-02	6.41E-02	7.91E-02	1.20E-01	1.59E-01	1.67E-01	1.73E-01	1.82E-01	2.00E-01	2.54E-01	3.48E-01
PO216	6.85E+01	1.18E+01	2.54E+00	6.18E-01	3.46E-01	1.32E-01	7.35E-03	6.10E-05	2.03E-06	4.33E-06	8.82E-06
PO218	6.52E-04	1.16E-03	1.67E-03	3.73E-03	1.01E-02	2.14E-02	6.33E-02	1.62E-01	4.47E-01	1.69E+00	4.09E+00
AT217	4.16E-04	4.26E-04	4.53E-04	7.40E-04	3.35E-03	1.39E-02	9.75E-02	4.34E-01	1.91E+00	1.23E+01	4.47E+01
RN219	3.47E-02	4.78E-02	5.90E-02	8.94E-02	1.19E-01	1.25E-01	1.29E-01	1.36E-01	1.49E-01	1.90E-01	2.60E-01
RN220	5.20E+01	8.99E+00	1.93E+00	4.69E-01	2.63E-01	1.00E-01	5.58E-03	4.63E-05	1.54E-06	3.29E-06	6.70E-06
RN222	4.70E-04	8.38E-04	1.21E-03	2.69E-03	7.26E-03	1.54E-02	4.56E-02	1.17E-01	3.23E-01	1.22E+00	2.95E+00
FR221	2.80E-04	2.86E-04	3.05E-04	4.98E-04	2.25E-03	9.34E-03	6.56E-02	2.91E-01	1.28E+00	8.27E+00	3.01E+01
RA223	2.01E-02	2.77E-02	3.41E-02	5.17E-02	6.87E-02	7.21E-02	7.48E-02	7.86E-02	8.63E-02	1.10E-01	1.50E-01
RA224	3.59E+01	6.21E+00	1.33E+00	3.24E-01	1.81E-01	6.92E-02	3.86E-03	3.20E-05	1.06E-06	2.27E-06	4.63E-06
RA226	2.85E-04	5.07E-04	7.30E-04	1.63E-03	4.39E-03	9.34E-03	2.76E-02	7.06E-02	1.95E-01	7.36E-01	1.78E+00
AC225	2.05E-04	2.10E-04	2.23E-04	3.65E-04	1.65E-03	6.85E-03	4.81E-02	2.14E-01	9.39E-01	6.06E+00	2.20E+01
AC227	2.59E-11	3.56E-11	4.39E-11	6.66E-11	8.85E-11	9.29E-11	9.64E-11	1.01E-10	1.11E-10	1.41E-10	1.94E-10
TH227	2.19E-02	3.02E-02	3.72E-02	5.64E-02	7.49E-02	7.87E-02	8.16E-02	8.58E-02	9.42E-02	1.20E-01	1.64E-01
TH228	3.02E+01	5.20E+00	1.12E+00	2.73E-01	1.53E-01	5.83E-02	3.25E-03	2.69E-05	8.95E-07	1.91E-06	3.90E-06
TH229	1.24E-04	1.27E-04	1.35E-04	2.21E-04	9.98E-04	4.14E-03	2.91E-02	1.29E-01	5.68E-01	3.67E+00	1.33E+01
TH230	9.52E-02	9.57E-02	9.61E-02	9.79E-02	1.05E-01	1.20E-01	1.76E-01	2.80E-01	4.91E-01	1.11E+00	2.10E+00
TH232	1.05E-07	1.05E-07	1.05E-07	1.07E-07	1.13E-07	1.22E-07	1.49E-07	1.96E-07	2.96E-07	6.34E-07	1.29E-06
PA231	4.12E-02	4.12E-02	4.12E-02	4.13E-02	4.16E-02	4.20E-02	4.34E-02	4.56E-02	5.00E-02	6.36E-02	8.71E-02
U232	3.07E-01	3.07E-01	2.97E-01	2.47E-01	1.38E-01	5.29E-02	2.94E-03	2.39E-05	1.57E-09	4.49E-22	5.57E-43
U233	7.43E-04	9.79E-03	1.89E-02	5.59E-02	1.73E-01	3.83E-01	1.11E+00	2.54E+00	5.70E+00	1.55E+01	3.17E+01
U234	9.80E+00	1.02E+01	1.07E+01	1.23E+01	1.61E+01	2.03E+01	2.51E+01	2.64E+01	2.65E+01	2.63E+01	2.60E+01
U235	1.76E-01	1.76E-01	1.76E-01	1.76E-01	1.76E-01	1.77E-01	1.78E-01	1.79E-01	1.83E-01	1.97E-01	2.22E-01
U236	2.73E+00	2.73E+00	2.74E+00	2.74E+00	2.75E+00	2.78E+00	2.85E+00	2.97E+00	3.19E+00	3.73E+00	4.33E+00
U238	2.32E+00	2.32E+00	2.32E+00	2.32E+00	2.32E+00	2.32E+00	2.32E+00	2.32E+00	2.32E+00	2.32E+00	2.32E+00
NP237	4.37E+02	4.40E+02	4.42E+02	4.54E+02	4.86E+02	5.34E+02	6.38E+02	7.31E+02	7.91E+02	8.06E+02	8.05E+02
PU236	7.30E-01	2.16E-01	6.41E-02	4.95E-04	2.27E-10	6.21E-21	0.0	0.0	0.0	0.0	0.0
PU238	5.36E+04	5.21E+04	5.06E+04	4.52E+04	3.23E+04	1.88E+04	4.10E+03	3.85E+02	1.79E+00	4.51E-06	5.63E-16
PU239	5.05E+03	5.06E+03	5.06E+03	5.08E+03	5.12E+03	5.18E+03	5.38E+03	5.68E+03	6.22E+03	7.41E+03	8.36E+03
PU240	7.56E+03	8.80E+03	9.81E+03	1.24E+04	1.43E+04	1.44E+04	1.40E+04	1.33E+04	1.20E+04	8.80E+03	5.27E+03
PU241	2.84E-16	2.24E-16	1.77E-16	6.84E-17	4.10E-18	1.82E-19	1.44E-19	1.38E-19	1.27E-19	9.86E-20	6.48E-20
PU242	1.80E+01	1.80E+01	1.80E+01	1.81E+01	1.83E+01	1.85E+01	1.88E+01	1.89E+01	1.90E+01	1.92E+01	1.93E+01
PU244	6.43E-13	3.19E-11	6.32E-11	1.88E-10	5.64E-10	1.19E-09	3.07E-09	6.19E-09	1.24E-08	3.11E-08	6.19E-08
AM241	2.89E+06	2.87E+06	2.86E+06	2.79E+06	2.54E+06	2.17E+06	1.34E+06	6.02E+05	1.22E+05	1.48E+03	3.06E+02
AM243	3.27E+04	3.27E+04	3.27E+04	3.26E+04	3.24E+04	3.21E+04	3.13E+04	2.99E+04	2.73E+04	2.08E+04	1.32E+04
CM242	2.10E+04	2.05E+04	2.00E+04	1.83E+04	1.39E+04	8.81E+03	2.24E+03	2.29E+02	2.40E+00	2.75E-06	3.44E-16
CM243	8.51E+03	7.63E+03	6.85E+03	4.44E+03	1.21E+03	1.39E+02	2.10E-01	4.16E-06	1.63E-15	0.0	0.0
CM244	4.05E+06	3.35E+06	2.76E+06	1.28E+06	1.29E+05	2.80E+03	2.87E-02	1.58E-10	3.85E-11	9.62E-11	1.92E-10
CM245	6.97E+02	6.97E+02	6.97E+02	6.95E+02	6.92E+02	6.86E+02	6.69E+02	6.42E+02	5.90E+02	4.59E+02	3.02E+02
CM246	1.27E+02	1.27E+02	1.27E+02	1.26E+02	1.25E+02	1.23E+02	1.18E+02	1.10E+02	9.47E+01	6.09E+01	2.92E+01
CM247	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04	4.17E-04
CM248	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.95E-04	7.94E-04	7.92E-04	7.88E-04	7.80E-04
BK249	3.14E-25	5.57E-27	9.88E-29	9.79E-36	9.54E-57	0.0	0.0	0.0	0.0	0.0	0.0
CF249	3.02E-02	2.99E-02	2.96E-02	2.85E-02	2.53E-02	2.08E-02	1.15E-02	4.30E-03	6.00E-04	1.64E-06	8.65E-11
CF250	6.05E-02	4.64E-02	3.56E-02	1.23E-02	5.13E-04	2.56E-06	2.47E-10	2.42E-10	2.32E-10	2.06E-10	1.69E-10
CF251	6.86E-04	6.83E-04	6.81E-04	6.70E-04	6.40E-04	5.93E-04	4.70E-04	3.20E-04	1.48E-04	1.47E-05	3.12E-07
CF252	9.48E-03	2.56E-03	6.90E-04	3.66E-06	5.45E-13	2.28E-24	0.0	0.0	0.0	0.0	0.0
CF254	1.88E-43	1.54E-52	1.26E-61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	7.07E+06	6.35E+06	5.75E+06	4.19E+06	2.77E+06	2.25E+06	1.40E+06	6.53E+05	1.69E+05	4.00E+04	2.86E+04

NEUTRON SOURCE IN FUEL AS A FUNCTION OF TIME

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- FUEL DECAY TIMES
SPONTANEOUS FISSION NEUTRON SOURCE IN DISCHARGED FUEL, NEUTRONS/SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	INITIAL	30. D	60. D	120. D	182. D	274. D	365. D	730. D	1096. D	REPRO 3652. D	7305. D
PU238	3.74E+05	3.80E+05	3.82E+05	3.86E+05	3.89E+05	3.91E+05	3.93E+05	3.94E+05	3.91E+05	3.71E+05	3.43E+05
PU240	2.04E+06	2.04E+06	2.04E+06	2.04E+06	2.04E+06	2.04E+06	2.04E+06	2.04E+06	2.04E+06	2.05E+06	2.05E+06
PU242	7.10E+05	7.10E+05	7.10E+05	7.10E+05	7.10E+05	7.10E+05	7.10E+05	7.10E+05	7.10E+05	7.10E+05	7.10E+05
PU244	2.25E-07	2.93E-07	3.60E-07	4.94E-07	6.33E-07	8.39E-07	1.04E-06	1.86E-06	2.68E-06	8.41E-06	1.66E-05
CM242	1.99E+08	1.76E+08	1.55E+08	1.20E+08	9.23E+07	6.24E+07	4.24E+07	9.02E+06	1.94E+06	4.27E+04	4.07E+04
CM244	3.47E+08	3.46E+08	3.45E+08	3.43E+08	3.41E+08	3.37E+08	3.34E+08	3.22E+08	3.09E+08	2.37E+08	1.61E+08
CM246	2.07E+06	2.07E+06	2.07E+06	2.07E+06	2.07E+06	2.07E+06	2.07E+06	2.07E+06	2.07E+06	2.07E+06	2.07E+06
CM248	8.26E+03	8.26E+03	8.26E+03	8.26E+03	8.26E+03	8.26E+03	8.26E+03	8.26E+03	8.26E+03	8.26E+03	8.27E+03
CM250	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.25E-03
CF250	4.02E+03	4.02E+03	4.01E+03	3.97E+03	3.94E+03	3.88E+03	3.83E+03	3.64E+03	3.45E+03	2.38E+03	1.40E+03
CF252	2.26E+05	2.22E+05	2.17E+05	2.08E+05	1.99E+05	1.86E+05	1.74E+05	1.34E+05	1.03E+05	1.65E+04	1.20E+03
CF254	1.70E+02	1.21E+02	8.57E+01	4.31E+01	2.12E+01	7.38E+00	2.60E+00	3.97E-02	6.00E-04	1.15E-16	7.65E-35
TOTAL	5.51E+08	5.28E+08	5.05E+08	4.68E+08	4.38E+08	4.05E+08	3.82E+08	3.36E+08	3.17E+08	2.42E+08	1.67E+08
TOTAL	6.67E+08	6.27E+08	5.94E+08	5.40E+08	4.97E+08	4.49E+08	4.16E+08	3.54E+08	3.31E+08	2.56E+08	1.80E+08

NEUTRON SOURCE IN FUEL AS A FUNCTION OF TIME

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- WASTE DECAY TIMES
SPONTANEOUS FISSION NEUTRON SOURCE IN DISCHARGED FUEL, NEUTRONS/SEC
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	REPRO ~~INITIAL~~	5. Y	10. Y	30. Y	90. Y	190. Y	490. Y	990. Y	1990. Y	4990. Y	9990. Y
PU238	3.71E+03	3.60E+03	3.50E+03	3.13E+03	2.24E+03	1.30E+03	2.84E+02	2.66E+01	1.24E-01	3.12E-07	3.90E-17
PU240	2.05E+04	2.38E+04	2.65E+04	3.35E+04	3.87E+04	3.89E+04	3.78E+04	3.59E+04	3.24E+04	2.38E+04	1.43E+04
PU242	7.10E+03	7.11E+03	7.11E+03	7.14E+03	7.21E+03	7.30E+03	7.41E+03	7.47E+03	7.51E+03	7.58E+03	7.62E+03
PU244	8.41E-08	4.18E-06	8.27E-06	2.46E-05	7.37E-05	1.56E-04	4.01E-04	8.09E-04	1.63E-03	4.06E-03	8.09E-03
CM242	4.27E+04	4.17E+04	4.08E+04	3.72E+04	2.83E+04	1.79E+04	4.56E+03	4.67E+02	4.88E+00	5.60E-06	6.99E-16
CM244	2.37E+08	1.95E+08	1.61E+08	7.50E+07	7.54E+06	1.64E+05	1.67E+00	9.20E-09	2.25E-09	5.62E-09	1.12E-08
CM246	2.07E+06	2.07E+06	2.07E+06	2.06E+06	2.04E+06	2.01E+06	1.92E+06	1.79E+06	1.54E+06	9.92E+05	4.76E+05
CM248	8.26E+03	8.27E+03	8.27E+03	8.26E+03	8.26E+03	8.26E+03	8.26E+03	8.25E+03	8.23E+03	8.18E+03	8.10E+03
CM250	1.25E-03	1.25E-03	1.25E-03	1.25E-03	1.24E-03	1.24E-03	1.22E-03	1.20E-03	1.15E-03	1.02E-03	8.38E-04
CF250	2.38E+03	1.83E+03	1.40E+03	4.85E+02	2.02E+01	1.01E-01	9.72E-06	9.51E-06	9.14E-06	8.11E-06	6.65E-06
CF252	1.65E+04	4.45E+03	1.20E+03	6.36E+00	9.49E-07	3.97E-18	0.0	0.0	0.0	0.0	0.0
CF254	1.15E-16	9.38E-26	7.67E-35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	2.39E+08	1.98E+08	1.64E+08	7.72E+07	9.66E+06	2.25E+06	1.98E+06	1.84E+06	1.59E+06	1.03E+06	5.06E+05
TOTAL	2.46E+08	2.04E+08	1.69E+08	8.14E+07	1.24E+07	4.50E+06	3.38E+06	2.49E+06	1.76E+06	1.07E+06	5.34E+05

ANNEX 3

THERMAL POWER IN CONTAINERS

The thermal power of one 150 liters container has been calculated by the Origen program with some hypothesis as for spectra.

RESULTS:

They are given in annexed tables.

3.1 - Element thermal power and total thermal power for actinides - Storage period.

3.2 - d° for period after reprocessing.

3.3 - d° for fission products - Storage period.

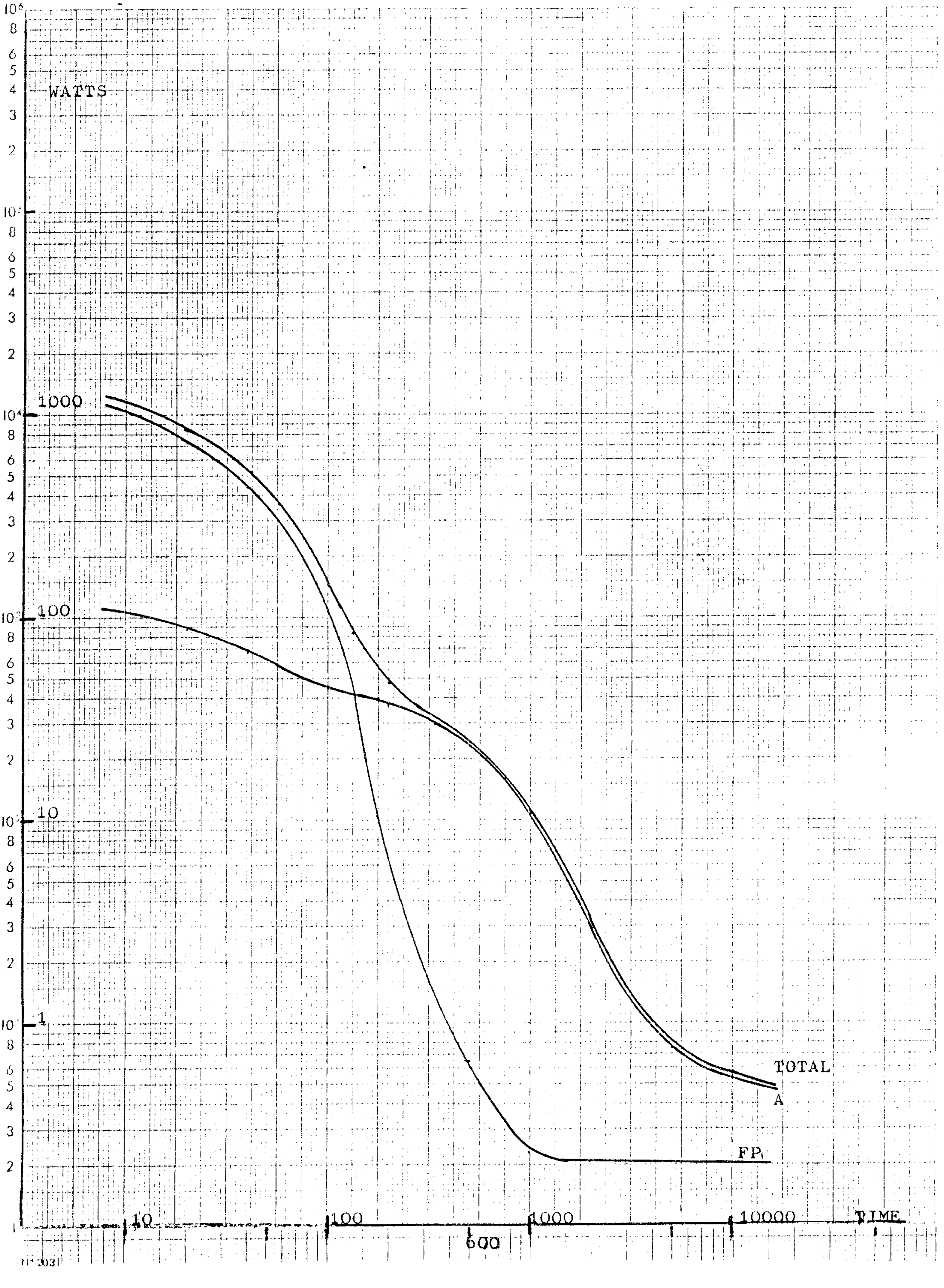
3.4 - d° for fission products - After reprocessing.

Ex : For 10, 40 and 1000 years after discharge, the total thermal power is in watts:

	10 years	40 years	1000 years
Actinides fission products	108.0 1030.0	66.2 447.0	10.8 22.6
Total	1138.0	513.2	33.4

150 l/MTU H L W GLASS CONTAINER

THERMAL ENERGY



REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- FUEL DECAY TIMES

POWER= 30.00MW, BURNUP= 33000.MWD, FLUX= 2.93E+13N/CM**2-SEC

ELEMENT THERMAL POWER, WATTS
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	CHARGE	DISCHARGE	30. D	60. D	120. D	182. D	274. D	365. D	730. D	1096. D	3652. D	7305. D
BI	0.0	1.99E-05	2.14E-05	2.33E-05	2.76E-05	3.19E-05	3.84E-05	4.51E-05	7.29E-05	1.00E-04	2.12E-04	2.28E-04
PO	0.0	1.13E-04	1.21E-04	1.31E-04	1.56E-04	1.80E-04	2.17E-04	2.55E-04	4.12E-04	5.67E-04	1.20E-03	1.28E-03
AT	0.0	8.26E-09	4.78E-09	2.47E-09	1.53E-09	1.50E-09	1.54E-09	1.59E-09	1.80E-09	2.00E-09	3.56E-09	6.31E-09
RN	0.0	5.71E-05	6.12E-05	6.66E-05	7.92E-05	9.13E-05	1.10E-04	1.29E-04	2.09E-04	2.87E-04	6.08E-04	6.51E-04
FR	0.0	7.41E-09	4.29E-09	2.21E-09	1.37E-09	1.34E-09	1.38E-09	1.42E-09	1.61E-09	1.79E-09	3.20E-09	5.66E-09
RA	0.0	5.16E-05	5.53E-05	6.02E-05	7.15E-05	8.25E-05	9.94E-05	1.17E-04	1.89E-04	2.60E-04	5.49E-04	5.88E-04
AC	0.0	7.21E-09	4.37E-09	2.49E-09	1.77E-09	1.79E-09	1.91E-09	2.03E-09	2.51E-09	2.98E-09	6.26E-09	1.11E-08
TH	0.0	4.95E-05	5.41E-05	5.88E-05	6.85E-05	7.90E-05	9.51E-05	1.12E-04	1.80E-04	2.48E-04	5.26E-04	5.66E-04
PA	0.0	7.45E-07	7.48E-07	7.49E-07	7.51E-07	7.53E-07	7.56E-07	7.59E-07	7.70E-07	7.81E-07	8.58E-07	9.69E-07
U	5.72E-02	3.80E-02	3.80E-02	3.81E-02	3.81E-02	3.82E-02	3.82E-02	3.83E-02	3.86E-02	3.89E-02	4.06E-02	4.27E-02
NP	0.0	9.77E-03	9.98E-03	9.99E-03	9.99E-03	9.99E-03	9.99E-03	9.99E-03	9.99E-03	1.00E-02	1.01E-02	1.02E-02
PU	0.0	1.15E+02	1.17E+02	1.18E+02	1.18E+02	1.19E+02	1.20E+02	1.20E+02	1.20E+02	1.20E+02	1.15E+02	1.08E+02
AM	0.0	3.46E+00	3.92E+00	4.38E+00	5.30E+00	6.23E+00	7.61E+00	8.95E+00	1.42E+01	1.92E+01	4.79E+01	7.48E+01
CM	0.0	1.32E+03	1.18E+03	1.05E+03	8.31E+02	6.58E+02	4.72E+02	3.47E+02	1.36E+02	8.91E+01	5.92E+01	4.05E+01
BK	0.0	2.60E-09	2.44E-09	2.28E-09	2.00E-09	1.74E-09	1.42E-09	1.16E-09	5.19E-10	2.32E-10	8.23E-13	2.59E-16
CF	0.0	3.28E-06	3.26E-06	3.24E-06	3.19E-06	3.13E-06	3.05E-06	2.97E-06	2.66E-06	2.38E-06	1.33E-06	8.63E-07
ES	0.0	1.21E-07	1.02E-07	5.52E-08	1.12E-08	1.76E-09	9.72E-11	5.09E-12	2.87E-17	1.42E-22	0.0	0.0
TOTALS	5.72E-02	1.44E+03	1.30E+03	1.17E+03	9.55E+02	7.83E+02	5.99E+02	4.76E+02	2.71E+02	2.28E+02	2.22E+02	2.23E+02

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- WASTE DECAY TIMES

POWER= 30.00MW, BURNUP= 33000.MWD, FLUX= 2.93E+13N/CM**2-SEC

ELEMENT THERMAL POWER, WATTS
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	CHARGE	REPRO ~~DISCHARGE~~	5. Y	10. Y	30. Y	90. Y	190. Y	490. Y	990. Y	1990. Y	4990. Y	9990. Y
BI	0.0	2.12E-04	3.71E-05	8.41E-06	2.73E-06	2.16E-06	1.55E-06	1.22E-06	1.31E-06	1.66E-06	3.66E-06	9.39E-06
PO	0.0	1.20E-03	2.08E-04	4.52E-05	1.19E-05	7.69E-06	4.58E-06	5.08E-06	1.25E-05	3.92E-05	1.95E-04	6.19E-04
AT	0.0	3.56E-09	3.65E-09	3.89E-09	6.34E-09	2.87E-08	1.19E-07	8.36E-07	3.72E-06	1.63E-05	1.05E-04	3.84E-04
RN	0.0	6.08E-04	1.06E-04	2.31E-05	6.37E-06	4.31E-06	2.61E-06	2.05E-06	3.24E-06	6.82E-06	2.22E-05	5.19E-05
FR	0.0	3.20E-09	3.27E-09	3.49E-09	5.69E-09	2.58E-08	1.07E-07	7.50E-07	3.33E-06	1.46E-05	9.46E-05	3.44E-04
RA	0.0	5.49E-04	9.53E-05	2.09E-05	5.72E-06	3.84E-06	2.30E-06	1.78E-06	2.81E-06	5.93E-06	1.93E-05	4.52E-05
AC	0.0	6.26E-09	7.59E-09	8.85E-09	1.38E-08	3.50E-08	1.10E-07	7.01E-07	3.07E-06	1.35E-05	8.69E-05	3.16E-04
TH	0.0	5.26E-04	9.30E-05	2.23E-05	7.97E-06	6.32E-06	5.18E-06	6.22E-06	1.09E-05	2.55E-05	1.06E-04	3.31E-04
PA	0.0	8.58E-07	8.59E-07	8.59E-07	8.61E-07	8.67E-07	8.76E-07	9.04E-07	9.50E-07	1.04E-06	1.33E-06	1.82E-06
U	5.72E-02	4.06E-04	4.17E-04	4.28E-04	4.67E-04	5.62E-04	6.68E-04	8.03E-04	8.71E-04	9.54E-04	1.20E-03	1.59E-03
NP	0.0	1.01E-02	1.01E-02	1.02E-02	1.05E-02	1.12E-02	1.23E-02	1.47E-02	1.68E-02	1.82E-02	1.86E-02	1.86E-02
PU	0.0	1.15E+00	1.15E+00	1.14E+00	1.10E+00	9.26E-01	7.03E-01	4.51E-01	3.81E-01	3.60E-01	3.21E-01	2.70E-01
AM	0.0	4.79E+01	4.76E+01	4.74E+01	4.62E+01	4.22E+01	3.60E+01	2.25E+01	1.04E+01	2.49E+00	3.99E-01	2.43E-01
CM	0.0	5.92E+01	4.89E+01	4.05E+01	1.89E+01	2.08E+00	1.67E-01	4.15E-02	1.54E-02	1.14E-02	8.64E-03	5.49E-03
BK	0.0	8.23E-13	1.46E-14	2.59E-16	2.57E-23	2.50E-44	0.0	0.0	0.0	0.0	0.0	0.0
CF	0.0	1.33E-06	1.04E-06	8.63E-07	5.25E-07	3.25E-07	2.63E-07	1.47E-07	5.71E-08	9.45E-09	2.30E-10	4.46E-12
TOTALS	5.72E-02	1.08E+02	9.77E+01	8.90E+01	6.62E+01	4.52E+01	3.69E+01	2.30E+01	1.08E+01	2.88E+00	7.49E-01	5.41E-01

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- FUEL DECAY TIMES

POWER= 30.00MW, BURNUP= 33000.MWD, FLUX= 2.93E+13N/CM**2-SEC

ELEMENT THERMAL POWER, WATTS
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

REPRO

	CHARGE	DISCHARGE	30. D	60. D	120. D	182. D	274. D	365. D	730. D	1096. D	3652. D	7305. D
H	0.0	2.52E-02	2.51E-02	2.50E-02	2.48E-02	2.45E-02	2.42E-02	2.38E-02	2.25E-02	2.13E-02	1.44E-02	8.17E-03
ZN	0.0	2.70E-02	5.90E-07	1.29E-11	6.13E-21	1.43E-30	7.26E-45	5.27E-59	0.0	0.0	0.0	0.0
GA	0.0	1.91E+01	1.37E-05	2.99E-10	1.42E-19	3.32E-29	1.69E-43	1.23E-57	0.0	0.0	0.0	0.0
GE	0.0	3.81E+01	5.83E-19	3.85E-38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AS	0.0	4.47E+02	9.35E-06	2.35E-11	1.48E-22	3.93E-34	2.63E-51	0.0	0.0	0.0	0.0	0.0
SE	0.0	5.35E+03	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04
BR	0.0	4.43E+04	2.84E-05	2.06E-11	1.08E-23	2.21E-36	3.28E-55	0.0	0.0	0.0	0.0	0.0
KR	0.0	5.18E+04	1.83E+01	1.82E+01	1.80E+01	1.78E+01	1.75E+01	1.72E+01	1.62E+01	1.52E+01	9.67E+00	5.09E+00
RB	0.0	1.16E+05	7.67E-01	2.52E-01	2.73E-02	2.74E-03	9.06E-05	3.12E-06	1.28E-08	1.28E-08	1.28E-08	1.28E-08
SR	0.0	5.61E+04	1.83E+03	1.26E+03	6.22E+02	3.28E+02	1.67E+02	1.19E+02	9.69E+01	9.44E+01	7.94E+01	6.20E+01
Y	0.0	1.06E+05	2.98E+03	2.23E+03	1.33E+03	8.71E+02	5.90E+02	4.94E+02	4.35E+02	4.24E+02	3.57E+02	2.79E+02
ZR	0.0	2.47E+04	5.21E+03	3.79E+03	2.00E+03	1.03E+03	3.87E+02	1.46E+02	2.99E+00	6.05E-02	2.24E-04	2.24E-04
NB	0.0	1.08E+05	6.20E+03	5.24E+03	3.28E+03	1.85E+03	7.39E+02	2.87E+02	6.12E+00	1.24E-01	1.49E-04	2.24E-04
MO	0.0	5.95E+04	3.61E+00	2.10E-03	7.13E-10	1.47E-16	1.77E-26	2.72E-36	0.0	0.0	0.0	0.0
TC	0.0	7.64E+04	7.28E-01	1.01E-02	9.69E-03	9.69E-03	9.69E-03	9.69E-03	9.69E-03	9.69E-03	9.69E-03	9.69E-03
RU	0.0	1.67E+04	2.41E+03	1.44E+03	5.18E+02	1.89E+02	5.25E+01	2.30E+01	8.16E+00	4.08E+00	3.27E-02	3.22E-05
RH	0.0	2.81E+04	5.76E+03	5.32E+03	4.64E+03	4.09E+03	3.42E+03	2.88E+03	1.44E+03	7.24E+02	5.79E+00	5.84E-03
PD	0.0	1.30E+03	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06
AG	0.0	2.34E+03	6.70E+01	5.63E+01	4.75E+01	4.00E+01	3.11E+01	2.43E+01	8.92E+00	3.27E+00	2.98E-03	1.34E-07
CD	0.0	2.94E+02	1.26E+00	7.81E-01	3.05E-01	1.21E-01	3.78E-02	1.89E-02	1.26E-02	1.20E-02	8.50E-03	5.18E-03
IN	0.0	1.20E+03	7.28E-03	3.82E-03	1.66E-03	7.04E-04	1.97E-04	5.57E-05	3.53E-07	2.21E-09	9.03E-25	0.0
SN	0.0	4.17E+04	3.61E+01	2.36E+01	1.62E+01	1.15E+01	6.89E+00	4.16E+00	5.52E-01	7.36E-02	5.92E-04	5.91E-04
SB	0.0	1.04E+05	4.14E+01	3.72E+01	3.44E+01	3.23E+01	2.98E+01	2.79E+01	2.15E+01	1.66E+01	2.77E+00	2.22E-01
TE	0.0	9.04E+04	1.74E+02	1.02E+02	4.31E+01	2.23E+01	1.21E+01	8.37E+00	4.10E+00	2.95E+00	4.84E-01	3.71E-02
I	0.0	1.60E+05	2.69E+02	1.78E+01	1.01E-01	5.09E-04	2.48E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05
XE	0.0	7.26E+04	6.47E+01	2.23E+00	3.60E-02	9.53E-04	4.31E-06	2.06E-08	1.01E-17	4.63E-27	0.0	0.0
CS	0.0	1.11E+05	2.89E+03	2.68E+03	2.51E+03	2.38E+03	2.20E+03	2.04E+03	1.50E+03	1.11E+03	2.29E+02	1.14E+02
BA	0.0	5.91E+04	1.35E+03	5.83E+02	4.01E+02	3.92E+02	3.89E+02	3.87E+02	3.78E+02	3.70E+02	3.14E+02	2.50E+02
LA	0.0	9.26E+04	5.81E+03	1.14E+03	4.44E+01	1.55E+00	1.06E-02	7.69E-05	2.00E-13	4.94E-22	0.0	0.0
CE	0.0	3.20E+04	2.29E+03	1.55E+03	8.89E+02	6.39E+02	4.74E+02	3.74E+02	1.53E+02	6.26E+01	1.23E-01	1.65E-05
PR	0.0	4.04E+04	8.64E+03	7.58E+03	6.43E+03	5.52E+03	4.41E+03	3.53E+03	1.45E+03	5.93E+02	1.16E+00	1.56E-04
ND	0.0	5.35E+03	2.94E+02	4.51E+01	1.06E+00	2.22E-02	7.09E-05	2.41E-07	3.04E-17	3.61E-27	0.0	0.0
PM	0.0	6.75E+03	3.97E+02	2.43E+02	1.21E+02	7.44E+01	5.16E+01	4.44E+01	3.32E+01	2.54E+01	3.99E+00	2.83E-01
SM	0.0	1.36E+03	2.21E+00	2.18E+00	2.18E+00	2.17E+00	2.17E+00	2.17E+00	2.15E+00	2.13E+00	2.02E+00	1.86E+00
EU	0.0	2.53E+03	6.29E+02	2.05E+02	7.13E+01	6.22E+01	6.06E+01	5.96E+01	5.59E+01	5.27E+01	3.76E+01	2.43E+01
GD	0.0	1.54E+01	4.71E-02	4.32E-02	3.64E-02	3.05E-02	2.34E-02	1.80E-02	6.34E-03	2.22E-03	1.47E-06	4.20E-11
TB	0.0	1.73E+01	8.25E+00	6.15E+00	3.45E+00	1.90E+00	7.85E-01	3.27E-01	9.80E-03	2.90E-04	6.18E-15	3.46E-30
DY	0.0	1.44E+00	2.09E-05	4.66E-08	2.24E-13	7.13E-19	4.99E-27	4.27E-35	0.0	0.0	0.0	0.0
HO	0.0	5.49E-01	1.68E-04	7.85E-06	7.49E-06	7.49E-06	7.49E-06	7.49E-06	7.49E-06	7.48E-06	7.45E-06	7.41E-06
TOTALS	0.0	1.52E+06	4.74E+04	3.36E+04	2.30E+04	1.76E+04	1.30E+04	1.05E+04	5.62E+03	3.50E+03	1.04E+03	7.36E+02

REFERENCE PWR EQUILIBRIUM FUEL CYCLE -- WASTE DECAY TIMES

POWER= 30.00MW, BURNUP= 33000.MWD, FLUX= 2.93E+13N/CM**2-SEC

ELEMENT THERMAL POWER, WATTS
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	CHARGE	REPRO ~~DISCHARGE~~	5. Y	10. Y	30. Y	90. Y	190. Y	490. Y	990. Y	1990. Y	4990. Y	9990. Y
H	0.0	1.44E-02	1.08E-02	8.17E-03	2.65E-03	9.00E-05	3.22E-07	1.46E-14	8.44E-27	0.0	0.0	0.0
SE	0.0	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.51E-04	1.50E-04	1.50E-04	1.48E-04	1.43E-04	1.36E-04
RB	0.0	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08	1.28E-08
SR	0.0	7.94E+01	7.02E+01	6.20E+01	3.79E+01	8.62E+00	7.31E-01	4.47E-04	1.96E-09	3.80E-20	0.0	0.0
Y	0.0	3.57E+02	3.15E+02	2.79E+02	1.70E+02	3.87E+01	3.29E+00	2.01E-03	8.83E-09	1.71E-19	0.0	0.0
ZR	0.0	2.24E-04	2.24E-04	2.24E-04	2.24E-04	2.24E-04	2.24E-04	2.24E-04	2.23E-04	2.23E-04	2.23E-04	2.23E-04
NB	0.0	1.49E-04	1.91E-04	2.24E-04	2.95E-04	3.33E-04	3.35E-04	3.35E-04	3.35E-04	3.35E-04	3.35E-04	3.34E-04
TC	0.0	9.69E-03	9.69E-03	9.69E-03	9.69E-03	9.68E-03	9.68E-03	9.67E-03	9.66E-03	9.62E-03	9.53E-03	9.38E-03
RU	0.0	3.27E-02	1.04E-03	3.30E-05	3.36E-11	3.54E-29	0.0	0.0	0.0	0.0	0.0	0.0
RH	0.0	5.79E+00	1.84E-01	5.85E-03	5.95E-09	6.27E-27	0.0	0.0	0.0	0.0	0.0	0.0
PD	0.0	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.18E-06	9.17E-06	9.17E-06
AG	0.0	2.98E-03	2.00E-05	1.34E-07	2.73E-16	2.40E-33	0.0	0.0	0.0	0.0	0.0	0.0
CD	0.0	8.50E-03	6.63E-03	5.18E-03	1.92E-03	9.86E-05	6.98E-07	2.47E-13	4.37E-24	1.37E-45	0.0	0.0
IN	0.0	9.03E-25	9.11E-36	9.19E-47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SN	0.0	5.92E-04	5.91E-04	5.91E-04	5.91E-04	5.90E-04	5.90E-04	5.88E-04	5.86E-04	5.82E-04	5.70E-04	5.51E-04
SB	0.0	2.77E+00	7.74E-01	2.22E-01	1.20E-02	1.07E-02	1.07E-02	1.07E-02	1.07E-02	1.06E-02	1.04E-02	1.00E-02
TE	0.0	4.84E-01	1.34E-01	3.71E-02	2.19E-04	4.47E-11	3.16E-22	0.0	0.0	0.0	0.0	0.0
I	0.0	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05	2.46E-05
CS	0.0	2.29E+02	1.41E+02	1.14E+02	7.00E+01	1.75E+01	1.74E+00	1.83E-03	1.39E-04	1.39E-04	1.39E-04	1.39E-04
BA	0.0	3.14E+02	2.80E+02	2.50E+02	1.57E+02	3.93E+01	3.90E+00	3.80E-03	3.65E-08	3.37E-18	0.0	0.0
CE	0.0	1.23E-01	1.42E-03	1.65E-05	2.97E-13	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PR	0.0	1.16E+00	1.35E-02	1.56E-04	2.81E-12	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PM	0.0	3.99E+00	1.06E+00	2.83E-01	1.42E-03	1.81E-10	5.86E-22	0.0	0.0	0.0	0.0	0.0
SM	0.0	2.02E+00	1.94E+00	1.86E+00	1.59E+00	9.84E-01	4.44E-01	4.06E-02	7.56E-04	2.62E-07	1.09E-17	5.43E-35
EU	0.0	3.76E+01	3.01E+01	2.43E+01	1.02E+01	7.56E-01	9.92E-03	2.25E-08	8.78E-18	1.34E-36	0.0	0.0
GD	0.0	1.47E-06	7.85E-09	4.20E-11	3.43E-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TB	0.0	6.18E-15	1.46E-22	3.47E-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HO	0.0	7.45E-06	7.43E-06	7.41E-06	7.32E-06	7.07E-06	6.68E-06	5.61E-06	4.21E-06	2.36E-06	4.17E-07	2.32E-08
TOTALS	0.0	1.03E+03	8.41E+02	7.31E+02	4.47E+02	1.06E+02	1.01E+01	7.04E-02	2.26E-02	2.17E-02	2.14E-02	2.08E-02

ANNEX 4

SHIELDING γ AND N OF THE NTL 12 TRANSPORTATION CASK AT 10 YEARS

1 - GAMMA SHIELDING

- According to annex 2, the total amount of γ rays at 10 years is for one container :

$$\frac{4.33\ E\ 15}{3.7\ \ E\ 10} = 1.17\ E\ 05\ Ci\ \gamma$$

and for 15 containers (maximum in one cask) :

$$1.17\ E\ 05 \times 15 = 1.75\ E\ 06\ Ci\ \gamma$$

- Others assumptions:

  - The fifteen containers are dispatched in five longitudinal axis, regularly spaced around the main axis of the cask.

  - The thickness of the shielding is 300 mm around the internal diameter 1220 mm but, with the thermal evacuator and surrounding neutron shielding compound, the external effective diameter is 2500 mm.

  - So, the dose is calculated at a distance 1250 mm from the main axis, in contact with the external diameter.

    The theoretical geometry of the source is decomposed into 125 pieces and the calculation includes the absorption effect of each piece for the others.

    The build-up factor is calculated by Taylor formula for the lead shield.

- The calculation is performed by the program SN 018 PROTEC, with a eight energy groups distribution, according to annex 2-4.

Mev.	0.3	0.63	1.10	1.55	1.99	2.38	2.75	3.25
Ci/TU	4.70 E 03	1.08 E 05	3.67 E 03	2.84 E 02	3.32 E-01	9.43 E-01	7.40 E-02	2.34 E-03

RESULTS

Total dose: 146 mR/h

./...

ANNEX 4 (cont.)

2 - CALCULATION OF NEUTRON FLUX OF ONE CONTAINER

Are taken into account (see annexed tables 2.6 and 2.8)

α -N neutron sources coming from 1% of following nuclides:

Pu 238
Pu 239
Pu 240
Pu 242

The N/α production ratio is assumed as 2.10^{-6} that corresponds to 2 N for 10^6 α in glass.

α -N neutron sources coming from 100% of following nuclides:

Am 241
Cm 242
Cm 244

Spontaneous fission neutron sources coming from following nuclides:

Cm 242	Cf 250	Pu 238 (1%)
Cm 244	Cf 252	Pu 240 (1%)
Cm 246	Cf 254	Pu 242 (1%)
Cm 248		Pu 244 (1%)
Cm 250		

Supposing the neutrons are fast, the conversion dose factor in the material is assumed:

0.14 mRem/h for 1 N/cm2/s

The total surface of the cylinder is assumed to be approximately 2 m2 or 2.10^4 cm2.

The results of this calculation is given in the following table for times after discharge (in years):

10, 15, 20, 40, 100, 200, 500, 1000, 2000, 5000, 10 000

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A N N E X 4 (Cont.)

Years	Ci α	α/s	N(α.N) / s	Spont. N / s	Total N / s	Contact dose-rate mRem/h
10	3.78 E 03	1.40 E 14	2.80 E 08	2.39 E 08	5.19 E 08	3.63 E 03
15	3.36 E 03	1.24 E 14	2.48 E 08	1.98 E 08	4.46 E 08	3.12 E 03
20	3.00 E 03	1.11 E 14	2.22 E 08	1.64 E 08	3.86 E 08	2.70 E 03
40	1.56 E 03	5.77 E 13	1.15 E 08	7.72 E 07	1.92 E 08	1.39 E 03
100	1.34 E 03	4.96 E 13	9.92 E 07	9.66 E 06	1.09 E 08	7.63 E 02
200	1.09 E 03	4.03 E 13	8.06 E 07	2.25 E 06	8.28 E 07	5.80 E 02
500	6.71 E 02	2.48 E 13	4.96 E 07	1.98 E 06	5.16 E 07	3.61 E 02
1000	3.08 E 02	1.14 E 13	2.28 E 07	1.84 E 06	2.46 E 07	1.72 E 02
2000	7.15 E 01	2.65 E 12	5.30 E 06	1.59 E 06	6.89 E 06	4.82 E 01
5000	1.13 E 01	4.18 E 11	8.36 E 05	1.03 E 06	1.86 E 06	1.30 E 01
10000	8.98 E 00	3.22 E 11	6.44 E 05	5.06 E 05	1.15 E 06	8.05 E 00

3 - NEUTRON SHIELDING

- We suppose there is no absorption before the iron shield.
- Supplementary neutron shielding = 100 mm anti-neutron compound
- The neutron and gamma fission + capture dose-rates are calculated by Sabine program.

RESULTS

- neutron dose-rate : 3.8 mRem/h
- gamma dose-rate : 1.6 mRem/h

4 - TOTAL BIOLOGICAL DOSE-RATE

146 + 3.8 + 1.6 = 151.4 mRem/h

ANNEX 5

FLUX AND DOSE RATES γ AND N AROUND LEAD TITANIUM SHIELDED CANISTER (AT 40 YEARS)

1 - GAMMA DOSE RATE

The calculation has been made by SGN program SN 018 PROTEC, taking into account :

- homogeneous source = D = 400 mm ; L = 1400 mm
  glass density : 2.8 kg/dm3
  containing quantity of fission products equivalent to 1 metric ton of heavy material.
- main shielding: lead thickness = 100 mm
- build-up factor calculated by Taylor formula for lead
- the source is decomposed into 125 pieces and the calculation includes the absorption effect of each piece for the others.
- detector located at 300 mm from the axis-cylinder on contact of the titanium.
- the spectrum gamma is in total curies: (see annex 2)

Mev.	0.3	0.63	1.10	1.55	1.99	2.38	2.75	3.25
Ci/TU	2.07 E 03	4.32 E 04	9.54 E 02	1.32 E 01	3.92 E-01	9.62 E-10	7.59 E-11	2.40 E-12

RESULTS

- Total dose rate at the detector : 2 450 mRem/h

ANNEX 5 (cont.)

2 - N DOSE-RATE

- According to table of annex 4, the total neutron flux for one canister is at 40 years:

  1.92 E 08 N/s

- The approximate internal surface of the cylinder is:

  2 m2 = 20 000 cm2

- The flux per cm2 is:

  - on the glass (400 mm diameter) 9.6 E 03 N/cm2/s
  - on the titanium (600 mm diameter) 6.4 E 03 N/cm2/s

- Dose-rate calculated by Sabine program on the titanium external surface:

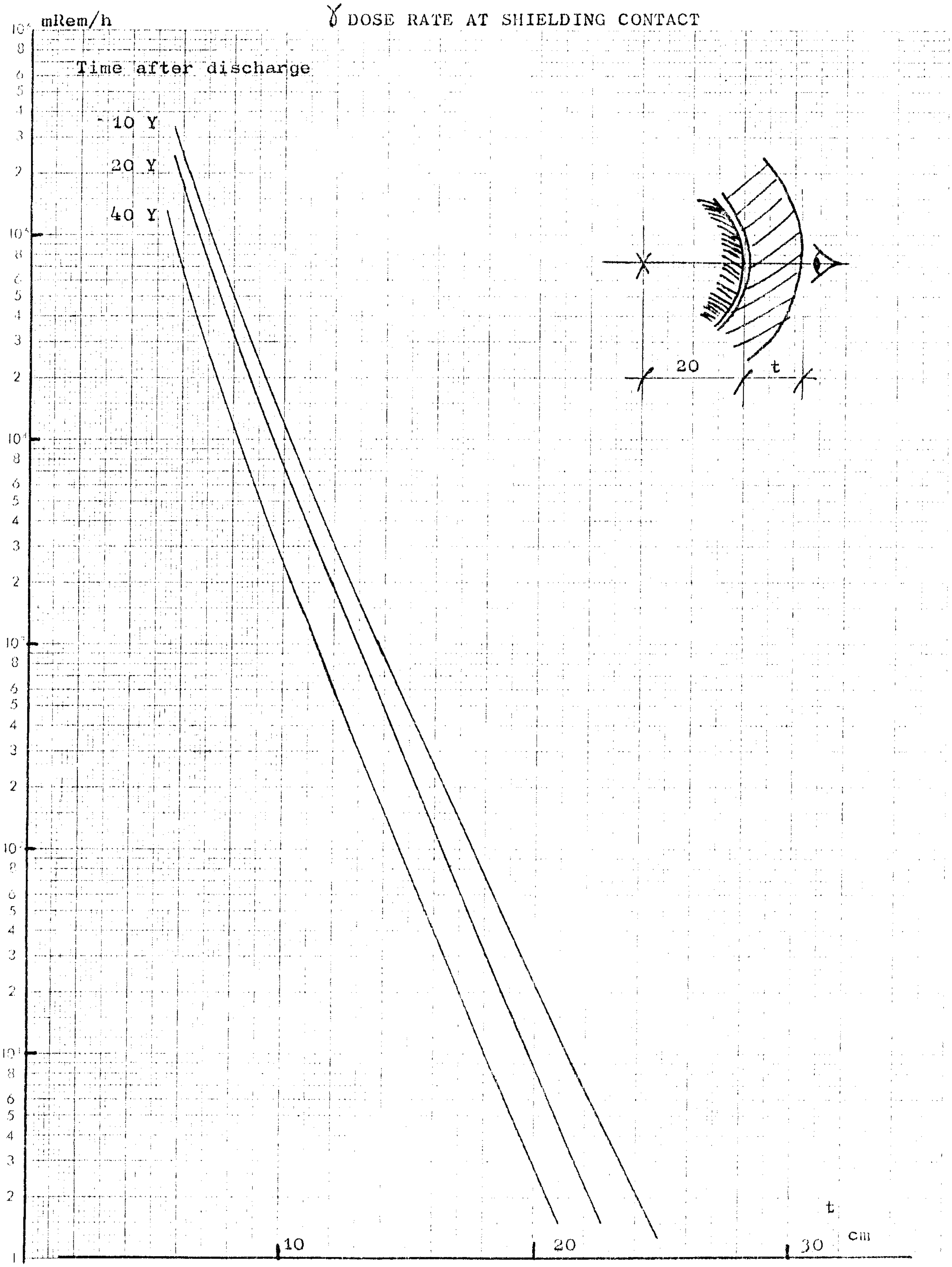
  - neutron dose-rate = 558 mRem/h
  - gamma (fission + capture) dose-rate = 4 mRem/h

3 - TOTAL BIOLOGICAL DOSE-RATE

2450 + 558 + 4 = 3012 mRem/h

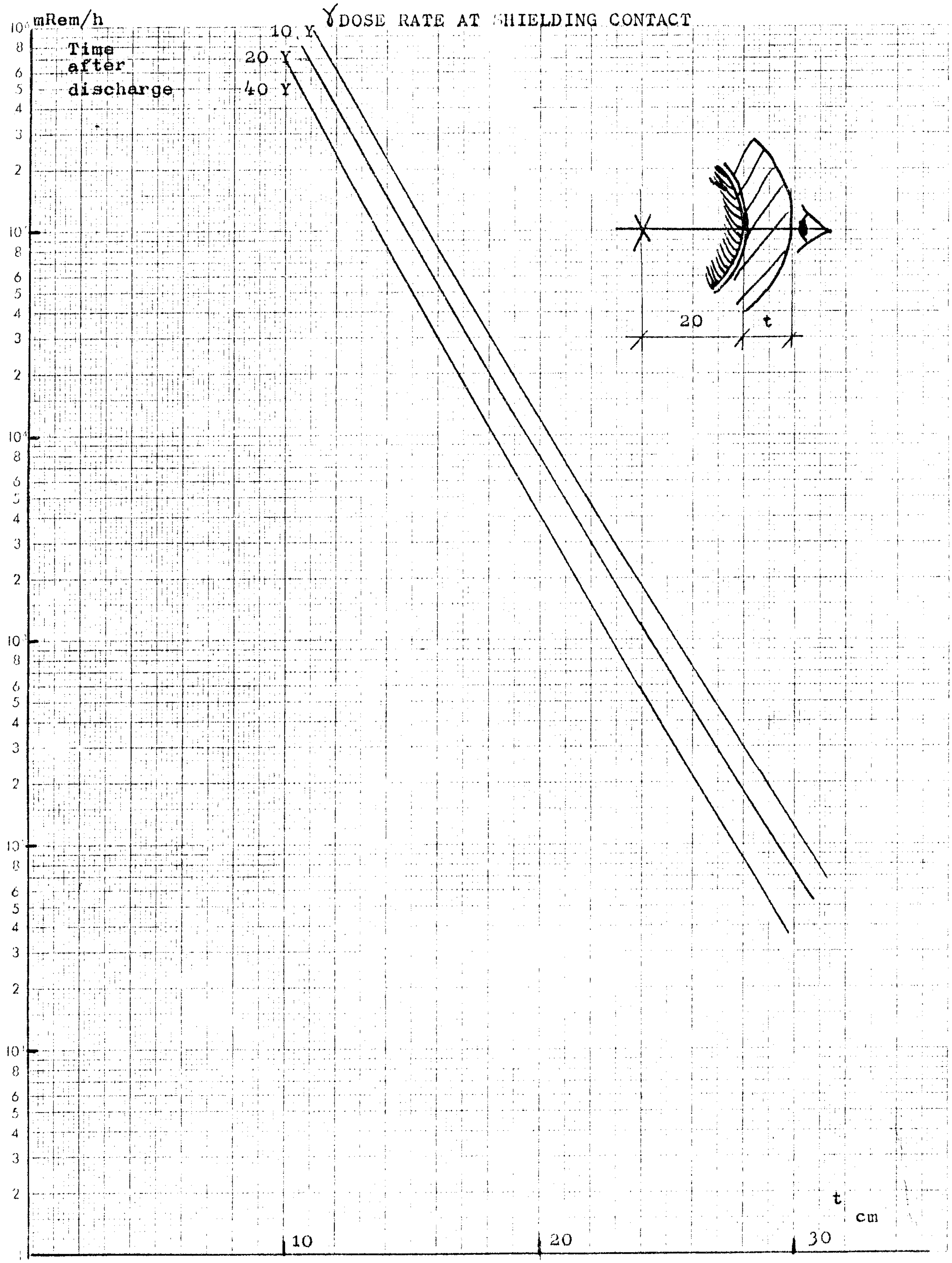
HLW CANISTER LEAD

γ DOSE RATE AT SHIELDING CONTACT



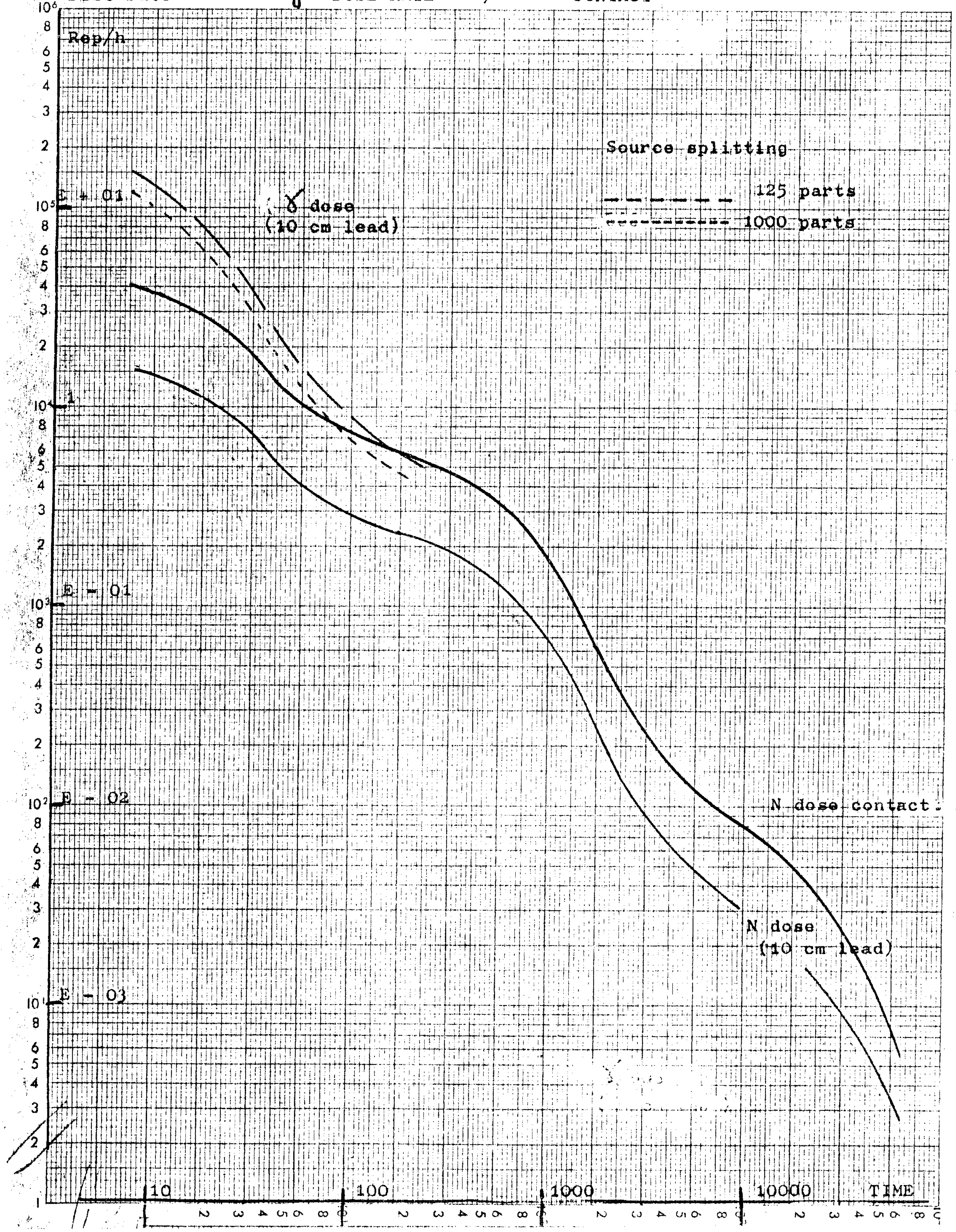
N° 2031

HLW CANISTER IRON



N° 2031

150 l/MTU H L W GLASS CANISTER
NEUTRON DOSE-RATE } 10 cm LEAD SHIELDING
γ DOSE-RATE } CONTACT



ANNEX 6

GAMMA AND N SHIELDING OF THE TRANSFER CASKS

1 - UNDERGROUND CANISTER TRANSFER CASK (CANISTER 40 Years)

1.1 - Gamma Shielding

The titanium-lead canister is supposed located inside a 10 cm lead supplementary shielding representing by the transportation cask, the outside diameter of that supplementary shield is 900 mm.

The source is the same as in the Annex 5 and the calculation procedure too.

The gap between the canister and the internal wall of the cask is 50 mm.

RESULTS

Total dose-rate at the detector calculated by program SN 018 :

1.25 mRem/h at 650 mm from center.

1.2 - N Shielding

According to Annex 5:

- Supplementary neutron shielding: 200 mm anti-neutron compound
- We assume the external diameter of the cask is: 1300 mm

$$\Sigma = 0.13 \text{ cm}^{-1}$$

- The neutron and gamma dose-rates are calculated by Sabine program.

  neutron dose-rate: 0.34 mRem/h

  gamma dose-rate : 0.07 mRem/h

1.3 - Total Biological Dose-Rate

1.25 + 0.34 + 0.07 = 1.66 mRem/h

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ANNEX 6 (cont.)

2 - CONTAINER TRANSFER CASK (10 years)

The shielding will be made by :

250 mm lead

\+ 220 mm anti-neutron compound

The gap between the container and the internal wall of the cask is supposed 50 mm.

So, the external diameter is : 1440 mm

2.1 - Gamma Dose-Rate

Calculated by program SN 018 : 0.60 mRem/h

2.2 - Neutron and Fission + Capture Gamma Dose-Rate

Calculated by program Sabine:

- neutron dose-rate : 1.20
- gamma dose-rate : 0.65

2.3 - Total Biological Dose-Rate

0.60 + 1.20 + 0.65 = 2.45 mRem/h

A N N E X 7

WATER RADIOLYSIS AND ABSORPTION CAPACITY IN THE WET PACKING OF THE PIT

1 - The quantity of water which would be radiolysed by irradiation in the pit can be estimated in following conditions:

- the total irradiation rate coming from the canister may be known:

  . in Mev/s/cm2 at the titanium limit for the γ rays (Origen and Protec programs)

  . in Mev/s at the titanium limit for the N rays (last column of the table Annex 4). Those figures must be divided by a factor 2.72 taking into account the decreasing of energy accross the lead container and multiplied by the mean energy = 8 Mev.

- the approximate external surface of the lead container is:

$$3.0 \text{ E } 04 \text{ cm2} = 3.0 \text{ m2}$$

- according to the Reactor Handbook AECD 3646 p. 673, the ratio of water radiolysis is the following:

  . for γ rays : 0.3 - 0.7 molecule per 100 EV

  . for fast neutrons : 1.5 molecule per 100 EV

So, we admit a general mean factor equal to 0.8 and we suppose 20 % of the total irradiation energy is delivered into the intersticial water in the packing material, which is probably a pessimistic hypothesis.

The recombination of H_2 and O_2 is not considered.

Results in the next table.

The quantity of radiolysed water per year is very low, in the range of the mg/y.

ANNEX 7 (Cont.)

WATER RADIOLYSIS FOR ONE CYLINDER

Years	Total N / s	Mev N / year	Mev γ / cm2/s	Mev / year	Mev Total / year	g H2O / year
40	1.92 E 08	1.78 E 16	5.19 E 04	1.92 E 15	1.97 E 16	9.26 E-04
100	1.09 E 08	1.01 E 16	1.12 E 04	4.14 E 14	1.05 E 16	4.94 E-04
200	8.88 E 07	8.24 E 15	8.23 E 02	3.04 E 13	8.27 E 15	3.88 E-04
500	5.16 E 07	4.79 E 15	2.73 E 02	1.01 E 13	4.80 E 15	2.26 E-04
1000	2.46 E 07	2.28 E 15	2.70 E 02	9.96 E 12	2.29 E 15	1.08 E-04
2000	6.89 E 06	6.39 E 14	2.68 E 02	9.92 E 12	6.49 E 14	3.05 E-05
5000	1.86 E 06	1.72 E 14	2.62 E 02	9.69 E 12	1.82 E 14	8.55 E-06
10000	1.15 E 06	1.07 E 14	2.50 E 02	9.25 E 12	1.16 E 14	5.45 E-06

N.B.:

- Coefficient transforming N/s in Mev N/y (mean energy : 8 Mev)

  86400 x 365.2 x 8/2.72 = **9.28 E 06**

- Coefficient transforming Mev/cm2/s in Mev γ/y

  86400 x 365.2 x 3.0 E 04 = **9.46 E 11**

- Conversion coefficient for Mev/y into g H_2O

  20 % of 0.8 molecule H_2O for 100 EV

  i.e.: in g H_2O for 1 Mev:

$$\frac{0.8 \times 18 \times 1\text{ E }04 \times 0.2}{6.02\text{ E }23} = \boxed{4.78\text{ E }-20}$$

ANNEX 7 (Cont.)

2 - ABSORPTION CAPACITY

According to Origen program results, the total weight of fission products in one canister corresponding to 1 MT of heavy metal is:

29.1 kg

The absorption capacity of ion exchanging is defined as follows:

- zeolite 24.06 milliequivalent for 100 g
- bentonite 64.26 milliequivalent for 100 g

or

- zeolite 0.24 equivalent for 1 kg
- bentonite 0.64 equivalent for 1 kg

We assume the mean atomic mass of the fission products is 110 and the mean valency is 2.

The absorption possibility will be :

- zeolite 0.24 x 110/2 = 13.2 g/kg
- bentonite 0.64 x 110/2 = 35.2 g/kg

The theoritical total quantity of absorbing material for one canister will be:

$$\frac{29.1 \times 1000}{13.2} = 2205 \text{ kg of zeolite}$$

or

$$\frac{29.1 \times 1000}{35.2} = 826 \text{ kg of bentonite}$$

Those quantities are to be compared to the useful volume of the pit (1 m diameter x 3 m).

$$V = \frac{\pi \times 1^2 \times 3}{4} - \frac{\pi \times 0.6^2 \times 1.6}{4} = 2 \text{ m3}$$

ANNEX 8

HEAT TRANSFER FROM THE CANISTER IN THE PIT

1 - THERMAL TRANSFER IN THE MASS OF A CYLINDER

The thermal power per unit volume is:

$$p = dP/dV$$

The transfer coefficient is λ

Write the equilibrium of thermal effects for:

- an area dR along the radius R
- an unit of length

The total thermal power to be transmitted is:

$$P = \pi R^2 p$$

The surface of crossing is:

$$S = 2 \pi R$$

The temperature gap across the area is:

$$\frac{d\theta}{dR} = \frac{\pi R^2 \times p}{2 \pi R \lambda} = \frac{R \times p}{2 \lambda}$$

The total temperature difference between the axis and a surface of radius Ro is:

$$\Delta\theta = \frac{p}{2\lambda} \int_{o}^{Ro} RdR = \left[\frac{p}{4}\frac{R^2}{\lambda}\right]_{o}^{Ro}$$

$$\boxed{\Delta\theta_{Ro} = \frac{p\ Ro^2}{4\ \lambda}}$$

For a cylindrical layer of material between two radius R1 and R2 and with a constant power P per unit of length, the calculation is:

$$\frac{d\theta}{dR} = \frac{P}{2 \pi R \lambda}$$

$$\boxed{\Delta\theta_{R1}^{R2} = \frac{P}{2 \pi \lambda} \text{Ln}\ (R2/R1)}$$

./...

A N N E X 8 (Cont.)

For such calculations, we make the assumption that the whole behaviour of the system is completely axisymetric.

2 - APPLICATION TO THE DISPOSAL AT 40 YEARS

The total power of a canister is ≈ 520 Watts (Annex 3)

The transfer coefficient are :

- in the glass : 1.2 W/m°C
- in the lead : 30 W/m°C
- in the packing:0.5 or 1 or 1.5 W/m°C

So the diagram of temperature differences from the center of the canister to the granite will be approximately:

- in the glass: p = 520/150 = 3.47 W/1 = 3470 W/m3

  Ro = 0.2 M

  $\Delta\theta$ .... 29°C (at 10 years = 64°C)

- in the stainless steel contact surfaces

  $\Delta\theta$ (estimated) .... 2°C

- in the lead : P = 520/1.6 = 325 W/M

  R1 = 0.2 M

  R2 = 0.3 M

  $\Delta\theta$ .... 1°C

- in the titanium contact surfaces

  $\Delta\theta$ (estimated) .... 2°C

- in the packing material

  P = 520/20 = 260 W/M

  R1 = 0.3 M

  R2 = 0.5 M

  $\Delta\theta$ .... for λ = 0.5 42°C

  for λ = 1.0 21°C

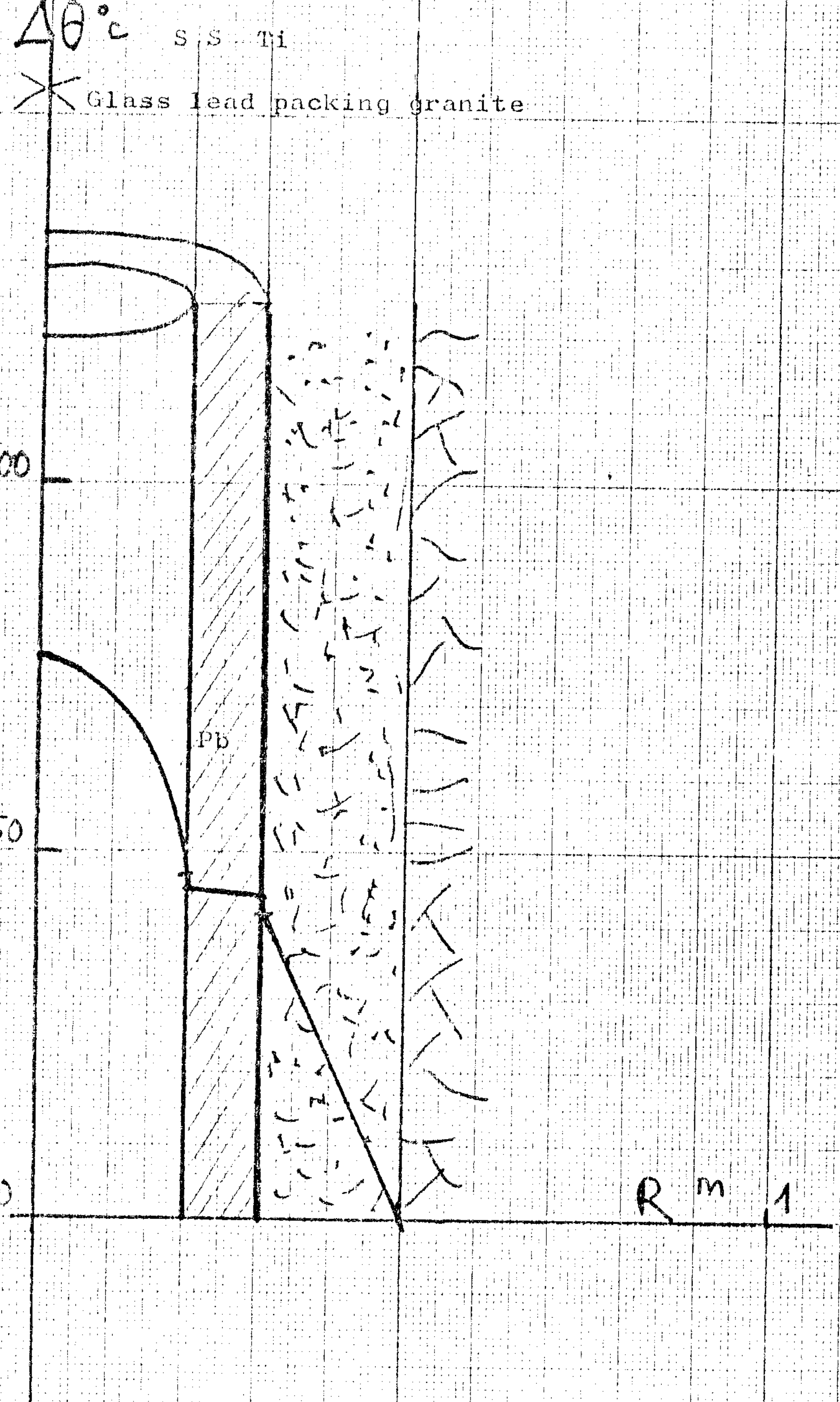
  for λ = 1.5 14°C

The total difference of temperature is:

- with λ packing = 0.5 .... 76°C
- with λ packing = 1.0 .... 55°C
- with λ packing = 1.5 .... 48°C

CANISTER AT 40 YEARS IN FINAL STORAGE

TEMPERATURES DIFFERENCES



A N N E X 9

THERMAL BEHAVIOUR OF CONTAINERS IN VARIOUS CONDITIONS

1 - TEMPERATURE OF A GLASS CONTAINER AT 10 YEARS IN FREE AIR

For a vertical cylinder in free air, the approximate transfer coefficient is given by:

$$k = 4.5 \sqrt[4]{\frac{\Delta\theta}{T \times H}}$$

with

$$P = k \times S \times \Delta\theta$$

- k = coef. in watts/m2°C
- $\Delta\theta$ = mean temperature difference between wall and air at infinite
- T = absolute temperature of air
- H = total height of cylinder in m
- S = surface in contact m2

So, the complete formula is:

$$P = 4.5 \times S \times \Delta\theta \times \sqrt[4]{\frac{\Delta\theta}{T \times H}}$$

and we can obtain $\Delta\theta$:

$$\Delta\theta = \left(\frac{P \times T^{1/4} \times H^{1/4}}{4.5 \times S}\right)^{4/5}$$

- P = 1138 W at 10 Y
- T = 273 + 20 = 293°k
- H = 1.50 m
- S = 2 m2

$\Delta\theta$ = **160°C**

The temperature difference between the center of the glass and the air will be:

$\Sigma\theta$ = 160 + 64 + 4 = **228°C**

N.B.: Temperature diff. in glass : see annex 8

ANNEX 9 (Cont.)

2 - TEMPERATURE OF A GLASS CONTAINER AT 40 YEARS IN FREE AIR

By the same way with P = 520 Watts

$$\Delta\theta = \boxed{72.5°C}$$

The temperature difference between the center of the glass and the air will be:

$$\theta = 72.5 + 29 + 2 = \boxed{103.5°C}$$

3 - TEMPERATURE OF GLASS CONTAINERS AT 10 YEARS IN THE NTL 12 CASK

- The cask will include 15 containers at 10 years.
- We suppose an air gap between the containers and the aluminium solid packing, and a quasi direct contact between the packing and the internal surface of the iron cask itself.
- On outside, the surface of the cask is made of radial blades which widely increases the useful contact of thermal evacuation surface.

heat transfer coefficient : in aluminium : λ = 146 Watts/m °C
in steel : λ = 43 Watts/m °C

3.1 - Temperature difference in aluminium

The total thermal power for the whole arrangement of 15 containers is:

P = 1138 x 15 = 17 070 Watts

For a 1 m long section:

P = 17 070/4.5 = 3800 Watts

Approximately half of this quantity has to go through the space between cylinders, in the aluminium packing.

This useful section is:

$$5 \times \left[(2 \times 0.39 \times \sin 36°) - 0.418\right] = 0.20 \text{ m2}$$

The distance to go to the internal surface of the cask is approximately: 0.30 m

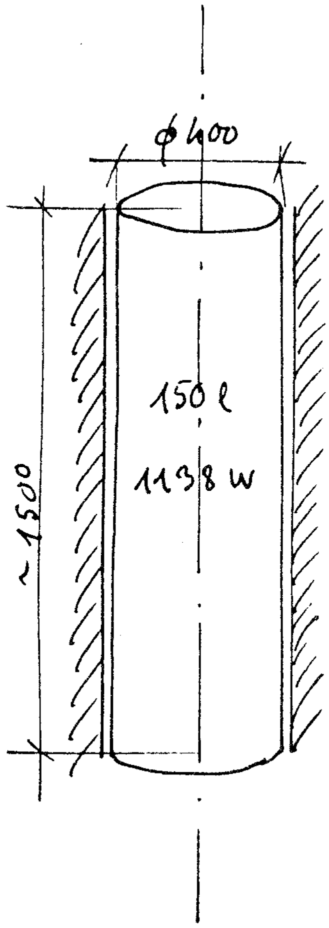
The temperature difference in the aluminium will be:

$$\Delta\theta_{Al} = \frac{3800 \times 0.30}{2 \times 0.20 \times 146} = \underline{20°C}$$

./...

A N N E X 9 (Cont.)

3.2 - Temperature difference in air gap



We suppose a 2 cm air gap between the external surface of the glass cylinder and the packing.

The thermal transfer is due to:

- conduction
- natural convection
- radiation

Considering the size of the gap and the range of temperature the most important effect is the radiation.

A - Conduction - Convection

The transfer coefficient for steady air is (at ∼ 200°C)

λ = 0.035 kcal/h m °C

λ = 0.040 W/m °C

For a 2 cm gap, the combined coefficient is (Cf.Tideström)

$\alpha cc = \lambda ac/d = 0.040 \cdot 1.5/0.02$

αcc = 3 W/m2°C (∼ 6 for each surface)

B - Radiation

Surfaces are supposed made of rough metal, not polished.

Their emission coefficient is approximately $\varepsilon = \sim 0.5$

The total power to be transferred is given by:

$$P = \varepsilon . Cn . (T_1^{\ 4} - T_2^{\ 4}) \ S$$

with Cn (black surface emission) = $5.66 \cdot 10^{-8}$ W/m2 °K^4

The total lateral emitting surface of the cylinder is: 1.88 m2

The complete equilibrium will be given by the formula:

$$3 \times (T_1 - T_2) + 2.83 \text{ E } 08 \times (T_1^{\ 4} - T_2^{\ 4}) = 1138/1.88$$

We make an assumption about the possible temperature of the cylinder surface: cc = 130°C

$$T1 \approx 130 + 273 = 403°k$$

By iterating computation, we find: $T2 \approx 333$°k

So, the temperature difference in the air gap is: 70°C

ANNEX 9 (Cont.)

3.3 - Temperature difference in aluminium-iron contact

We assume a good contact between aluminium packing and cast iron.

So, the temperature difference will be approximately : 5°C

3.4 - Temperature difference in the stainless steel contact surfaces (assumed) .... 4°C

3.5 - Temperature difference in the cast iron wall of the cask

We apply the second formula of Annex 8:

$$\Delta\theta_{R_1}^{R_2} = \frac{P}{2\pi\lambda} \quad Ln\ (R_2/R_1)$$

with P (per unit of length) = 3800 W

λ = 43 W/m°C

R_1 = 1.220/2 m

R_2 = 1.820/2 m

$\Delta\theta$ = 5.62°C .... ≈ 6°C

3.6 - Temperature difference outside the cask

The cylindrical surface is increased by a lot of blades in an approximate ratio 8.

The equivalent surface heat exchange coefficient will be approximately:

k = 3 x 8 = 24 W/m2 °C

The temperature difference:

$$\Delta\theta = \frac{3800}{1.82 \times \pi \times 24} = 28°C$$

3.7 - Total difference between center of containers and atmosphere

$$\Sigma\Delta\theta = 64 + 20 + 70 + 4 + 5 + 6 + 28 = 197°C$$

This result is in accordance with the preceding assumption made in § 3 .2 above.

./...

ANNEX 9 (Cont.)

4 - TEMPERATURE OF A CONTAINER AT 10 YEARS IN THE INTERMEDIATE TRANSFER CASK

The diagram of temperature difference from the center of the canister to the atmosphere will be approximately:

- in the glass (see Annex 8)

$\Delta\theta$ = ... 64°C

- in the stainless steel contact surface

$\Delta\theta$ = ... 4°C

- in the air gap (see § 2.2)

$\Delta\theta$ = ... 70°C

- in the lead shield (20 cm)

$$\Delta\theta_{R_1}^{R_2} = \frac{P}{2\pi\lambda} \text{Ln} (R_2/R_1)$$

with P = 1138/1.5 = 760 W

λ = 30 W/m °C

R_1 = 0.6 m

R_2 = 1.0 m

$\Delta\theta$ = ... 7°C

- in the polyethylene N shield

$$\Delta\theta_{R_1}^{R_2} = \frac{P}{2\pi\lambda} \text{Ln} (R_2/R_1)$$

with P = 760 W

λ = 0.4 W/m °C

R_1 = 1.0 m

R_2 = 1.4 m

$\Delta\theta$ = ... 101°C

This last figure is high but could be decreased by thermal evacuating blades as for the big transportation cask:

In that case, we assume $\Delta\theta$ = ... 30°C

- in the outside contact surface with atmosphere

$$\Delta\theta = \frac{760}{3 \times \pi \times 1.4}$$ = ... 56°C

The total difference will be:

$\Sigma\Delta\theta$ = 64 + 4 + 70 + 7 + 30 + 56 = ... 231°C

ANNEX 9 (Cont.)

5 - TEMPERATURE OF A LEAD-TITANIUM GLASS CANISTER AT 40 YEARS IN THE UNDERGROUND TRANSFER CASK

The diagram of temperature differences from the center of the canister to the atmosphere will be approximately:

- in the glass (see annex 8)

  $\Delta\theta$ = ... 29°C

- in the stainless steel contact surfaces

  $\Delta\theta$ = ... 2°C

- in the lead

  $\Delta\theta$ = ... 1°C

- in the titanium contact surfaces

  $\Delta\theta$ = ... 2°C

- in the air gap between titanium and internal surface of cask (see § 2.2 above)

  $3 \times (T1-T2) + 2.83\ E{-}08 \times (T1^4 - T2^4) = 520/1.50$

  assuming T1 $\sim$ 100°C
  we find T2 = 52°C

  and the difference:

  $\Delta\theta$ = ... 48°C

- in the complementary lead shield of cask

  $\Delta\theta$ = ... 1°C

- in the polyethylene N shielding of cask

$$\Delta\theta_{R1}^{R2} = \frac{P}{2\pi\lambda} \operatorname{Ln}(R2/R1)$$

with: P (per unit of length) = 346 W
λ = $\sim$ 0.4
R1 = 0.80 m
R2 = 1.20 m

  $\Delta\theta$ = ... 55°C

N.B.: This last figure is high, it will be useful to provide thermal evacuating blades on the cask in the same way as for the main transportation are

In that case, we assume $\Delta\theta$ = ... 15°C

./...

ANNEX 9 (Cont.)

- in the outside contact surface with atmosphere

$$\Delta\theta = \frac{346}{3 \text{ x } \quad \text{x } 1.2} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \underline{30°C}$$

The total difference will be:

$$\Sigma\Delta\theta = 29 + 2 + 1 + 2 + 48 + 1 + 15 + 30 = \ldots\ldots \quad \underline{128°C}$$

6 - NORMAL COOLING BY FORCED AIR FLOW IN THE TEMPORARY STORAGE

Each main storage cell is provided as follows:

- 3000 containers of 150 l each (1 MT equivalent U)
- The containers are put into vertical pits by set of 10 - There are 300 pits.
- The charging of pits is performed at 10 years for all containers, but all along a 10 years period.
- So the final composition of the storage includes containers from 10 years to 20 years.
- At 10 years the thermal power is 1138 W
  At 20 years the thermal power is 850 W
- So the approximate logarithmic mean power is, per container, 1000 W
  and the total thermal power when the cell is full, is ..... 3000 kW
- The forced ventilation is calculated for an entering air at 20°C
  an exit air at ... 80°C

  and the total flow-rate will be:

$$Qo = \frac{3000 \text{ x } 860}{60 \text{ x } 0.29} = \underline{150.000 \text{ Nm3/h}}$$

- The total pressure drop in the circuit will be, approximately 35 mbars including:

  filters .... 10 mbars

  chimney .... 10 mbars

  entrance and pits .... 15 mbars

- Mean surface container temperature .... 48°C
- Upper surface container temperature .... 72°C

./...

ANNEX 9 (Cont.)

7 - VENTILATION BY ONE FAN (HALF BREAK-DOWN)

With one fan operating instead of two, we may assume the air flow-rate is approximately 65% of the total flow-rate because of falling down pressure drop.

In such conditions, the exit temperature is increased up to 112°C (instead of 80°C).

In the case of the most powerful filling with 1000 W mean container thermal power, the other figures are:

- mean surface container temperature: .... 77°C
- upper surface container temperature: .... 123°C

and in the case of an half thermal power:

- temperature of exit air .... 66°C
- mean surface container temperature....................... 48°C
- upper surface container temperature....................... 72°C

8 - TRANSIENT EFFECT OF VENTILATION BREAK-DOWN

We assume the forced ventilation is completely stopped at a time to = 0 and we look at the transient effect on the temperature of the air and the temperature of the container.

We assume the filling of pits homogeneous.

The air flow gets an equilibrium for each mean temperature of the containers but the air cannot evacuate the whole thermal power. So the exceeding quantity of heat remains in the containers and the temperature of which increases.

Later on, the system gets a new constant flow in an asymptotic way.

The dynamic calculation has been programmed and performed in following conditions:

- pressure drop in cool part (Zo = 15 mbars in normal flow) function of mass air flow-rate at power 2
- pressure drop in hot part (Z'o = 10 mbars in normal flow) function of mass air flow-rate at power 1
- useful evacuating surface of a container: 2.1 m2
- heat transfer coefficient given by the Kern formula:

$$K = 0.027 \times \frac{C_0^{0,666} \times C_s^{0,333} \times v^{0,8} \times M_s^{0,8}}{D_e^{0,2} \times \mu^{0,466} \times 1,82}$$

ANNEX 9 (Cont.)

The equilibrium of flow is given by:

$$Z + Z' = (\rho_{s\,air} - \rho_{20°C}) \times g \times \frac{H}{100}$$

with:

Z and Z' function of mass air flow-rate

g = gravity coefficient

H = useful height of chimney
(assume 30 m underground
20 m outside)

The computing has been made with a spacing of time = 1 h

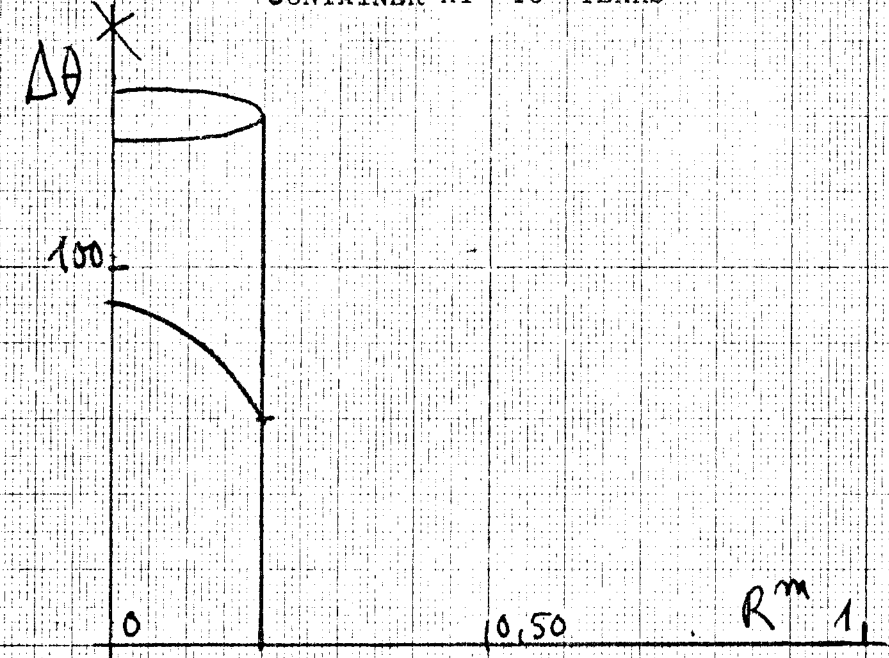
Other assumptions:

- volumic mean mass of container........................ 2.600 kg/m3
- mass heat capacity .... 0.18 kcal/kg°C

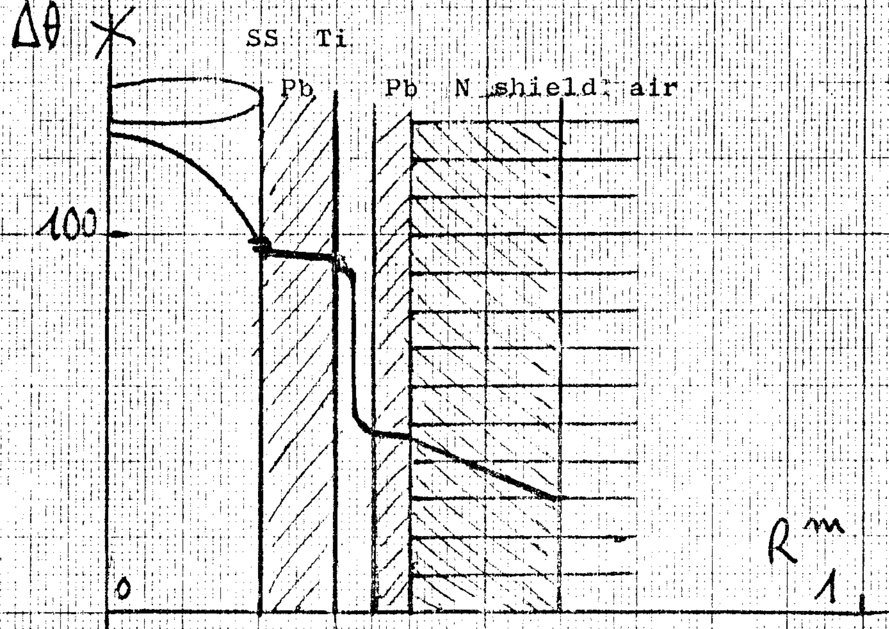
RESULTS : Annexed diagrams give the curves of temperature of:

- exit air
- mean container surface
- warmest container surface.

CONTAINER AT 40 YEARS



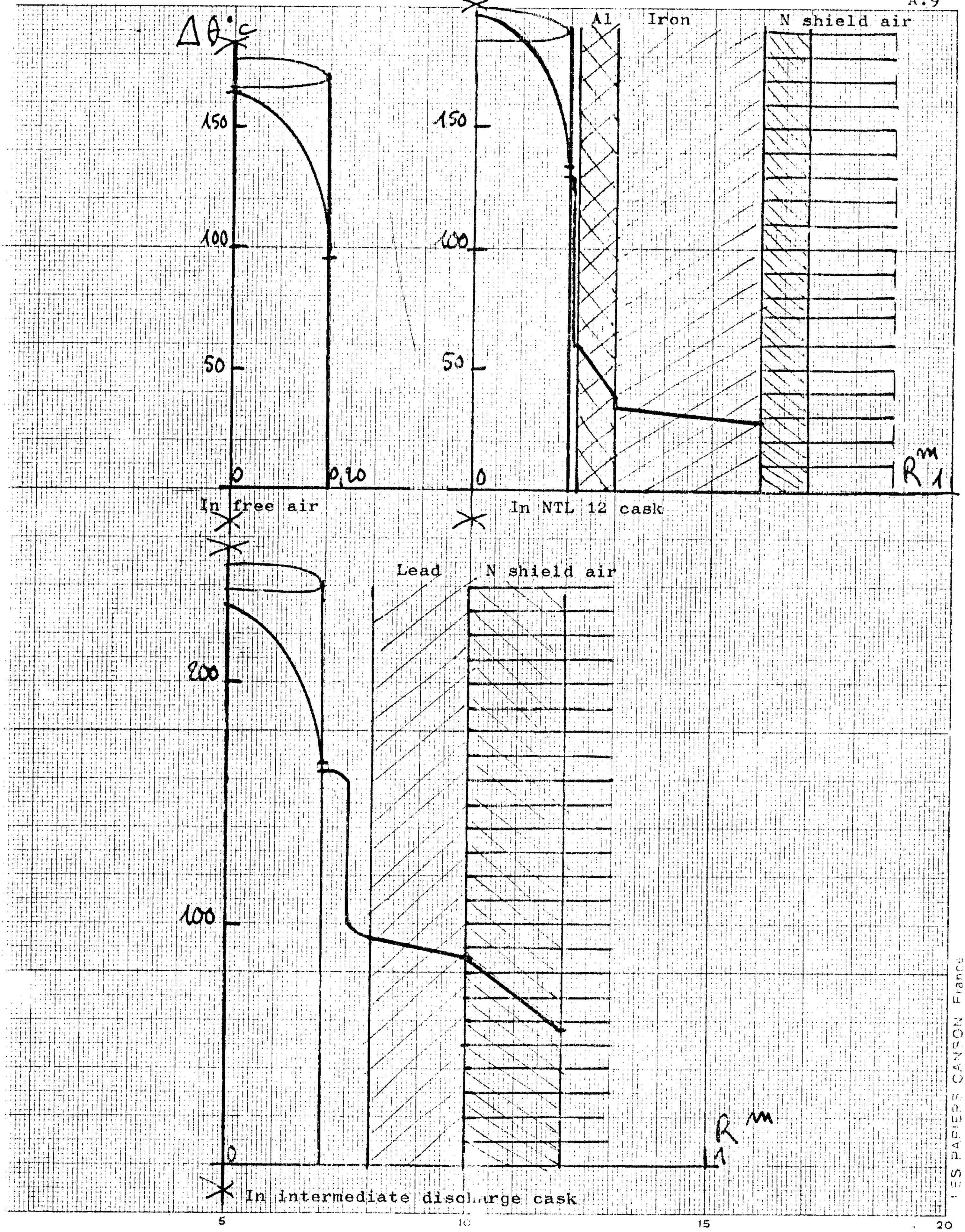
In free air

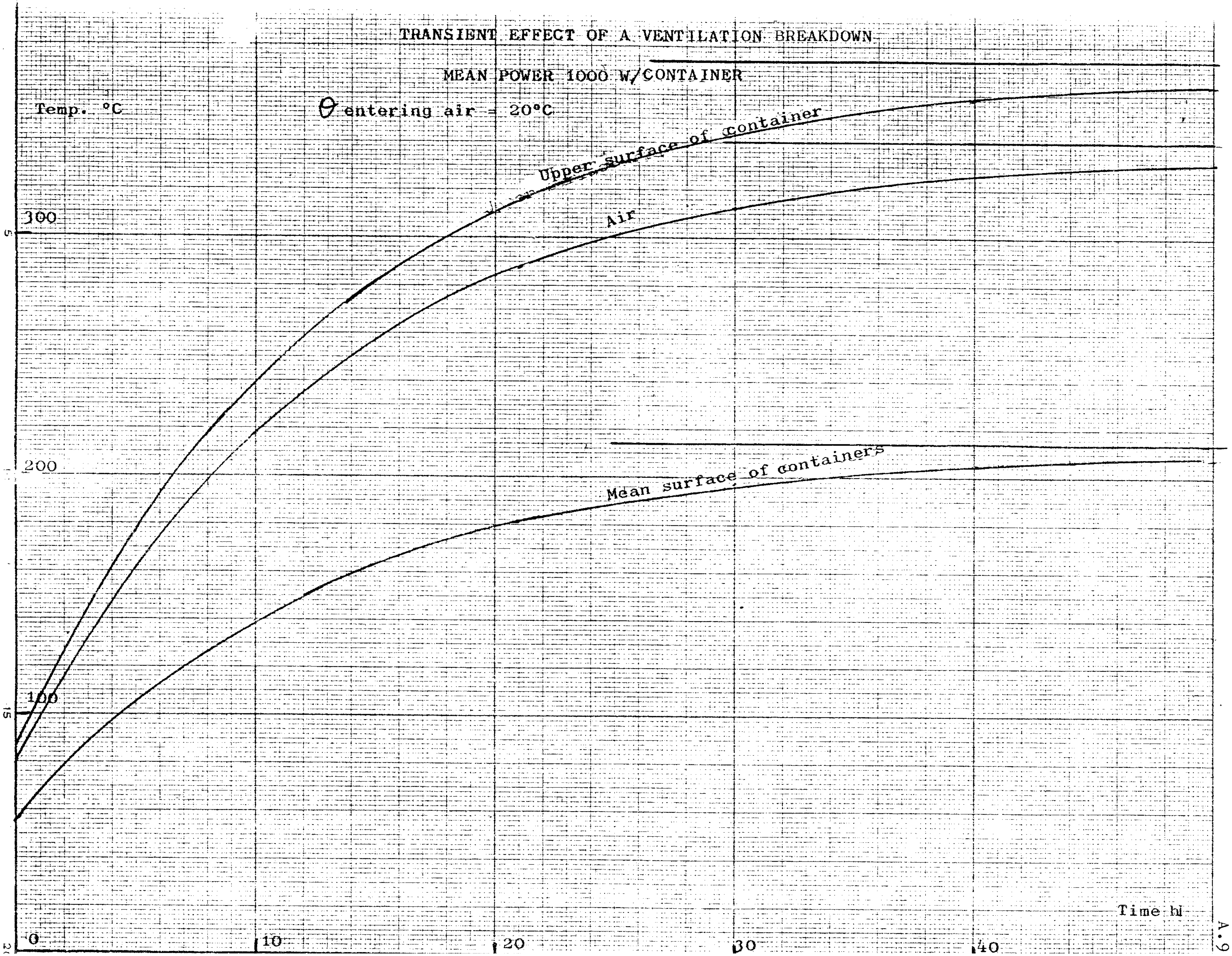


In underground transportation cask

CONTAINER AT 10 YEARS

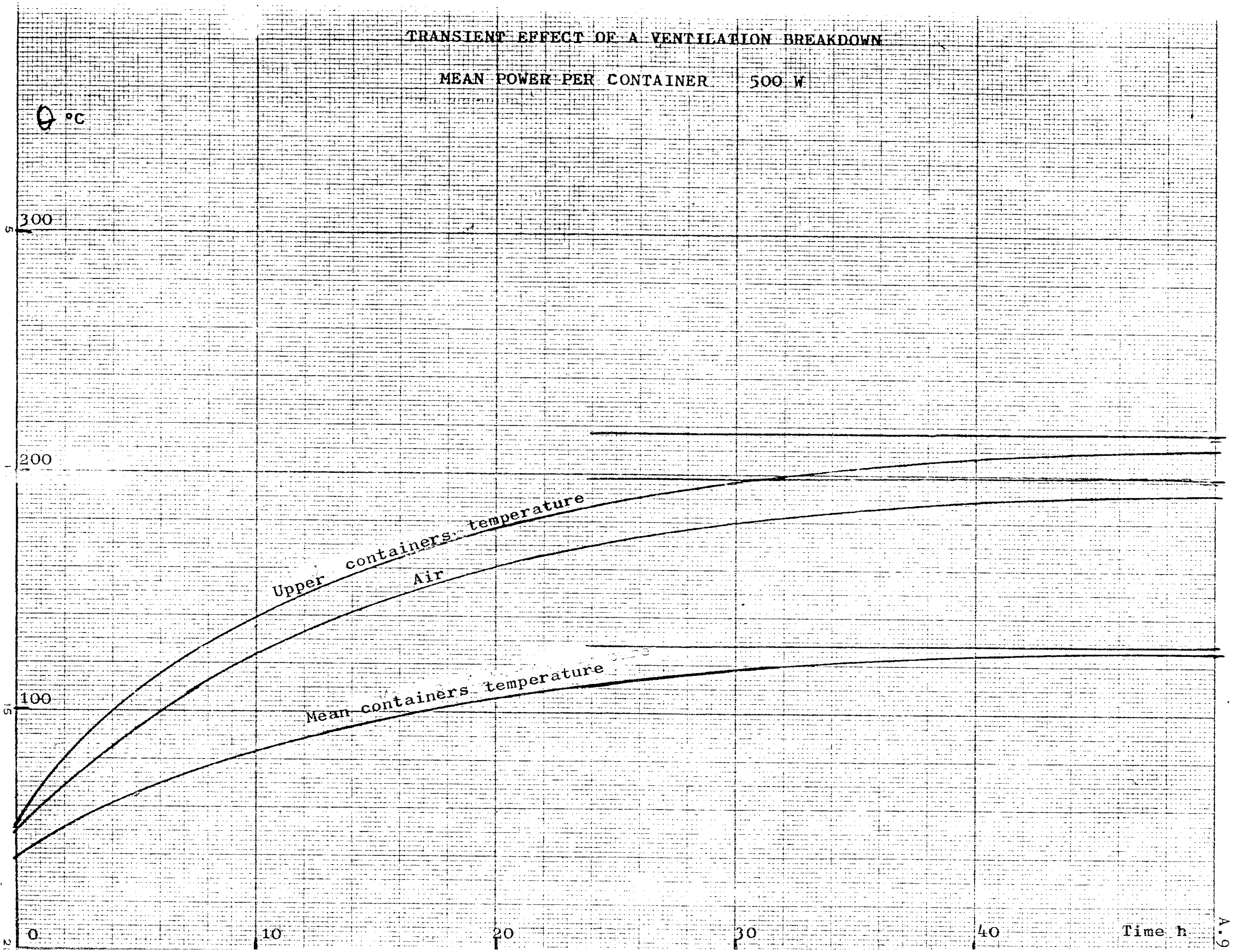
A.9




TRANSIENT EFFECT OF A VENTILATION BREAKDOWN
MEAN POWER 1000 W/CONTAINER
Temp. °C
θ entering air = 20°C
Upper surface of container
Air
Mean surface of containers
300
200
100
0
10
20
30
40
Time h

1055/77

A.9


TRANSIENT EFFECT OF A VENTILATION BREAKDOWN
MEAN POWER PER CONTAINER 500 W
θ °C
300
200
100
Upper containers temperature
Air
Mean containers temperature
0
10
20
30
40
Time h

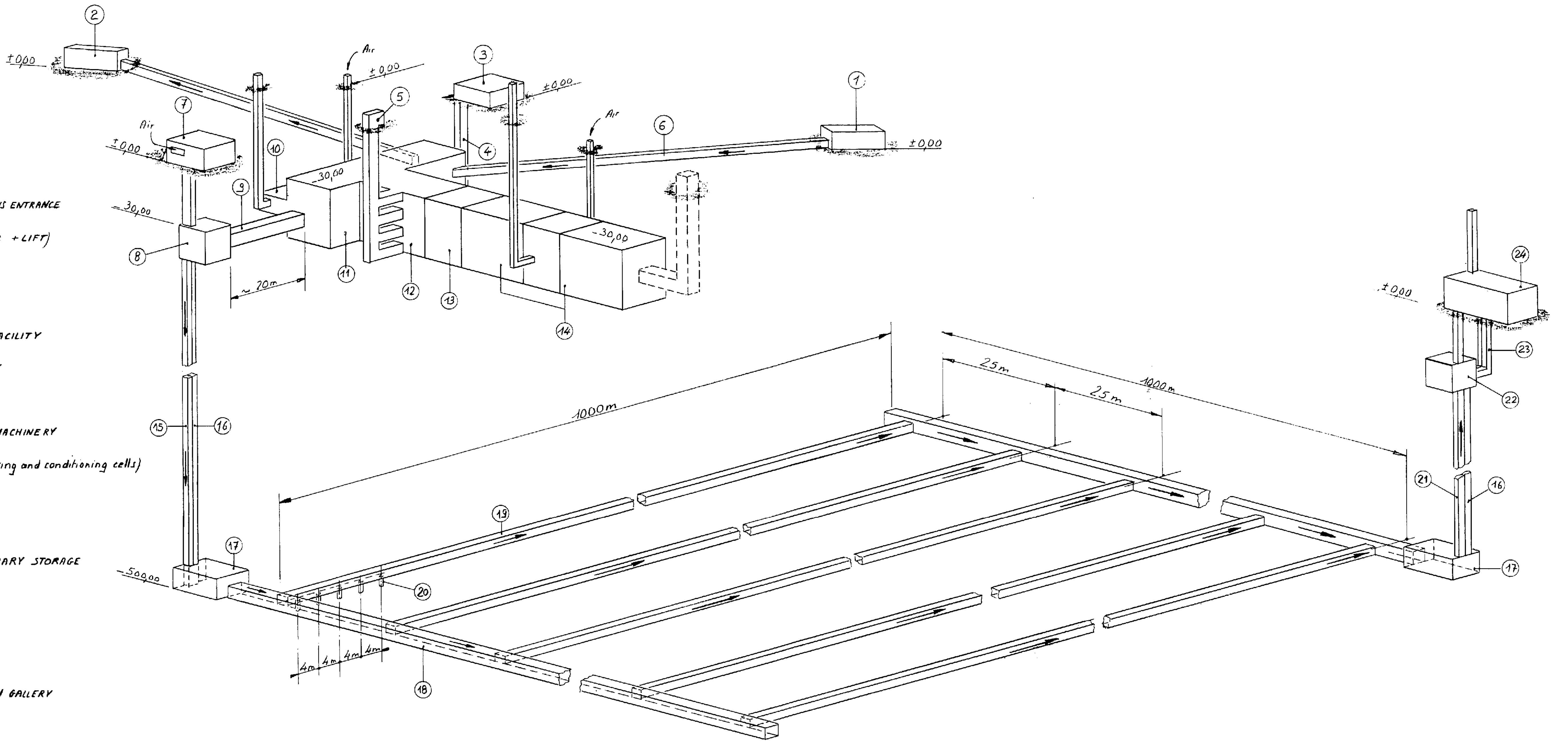
A.9

1055/77

A N N E X 10

DRAWINGS

Drawing no.	Title
1879 D 0010	General perspective
1879 D 0011	Lay-out of the incells installation
1879 D 0012/16	Containers receiving and temporary storage
1879 D 0013	Final conditioning and storage of canisters
1879 D 0014	Titanium container
1879 D 0015	Operations diagram
1879 D 0017	Temporary storage and encapsulation
1879 D 0020	Temporary storage ventilation
1879 D 0021	Air inlet filtration
1879 D 0022	Filtration and air exhaust room



1 — LORRY ENTRANCE
2 — LORRY EXIT
3 — BUILDING CHANGE. ROOMS ENTRANCE
4 — BUILDING ACCESS (STAIR + LIFT)
5 — EMERGENCY EXIT
6 — LORRY ACCESS GALLERY
7 — MINE VENTILATION FACILITY
8 — MINE LIFT MACHINERY
9 — CONNECTING GALLERY
10 — VENTILATION : BUILDING + MACHINERY
11 — MEAN BUILDING (Receiving and conditioning cells)
12 — TEMPORARY STORAGE
13 — STORAGE VENTILATION
14 — EXTENSION OF TEMPORARY STORAGE
15 — VENTILATION PIT
16 — MINE SHAFT
17 — WORKING AREA
18 — ACCESS and VENTILATION GALLERY
19 — STORAGE TUNNEL
20 — STORAGE PIT
21 — MINE AIR EXHAUST DUCT
22 — STAND BY MACHINERY
23 — ACCESS TO STAND BY MACHINERY
24 — AIR EXHAUST OF STAND BY MACHINERY AND MINE

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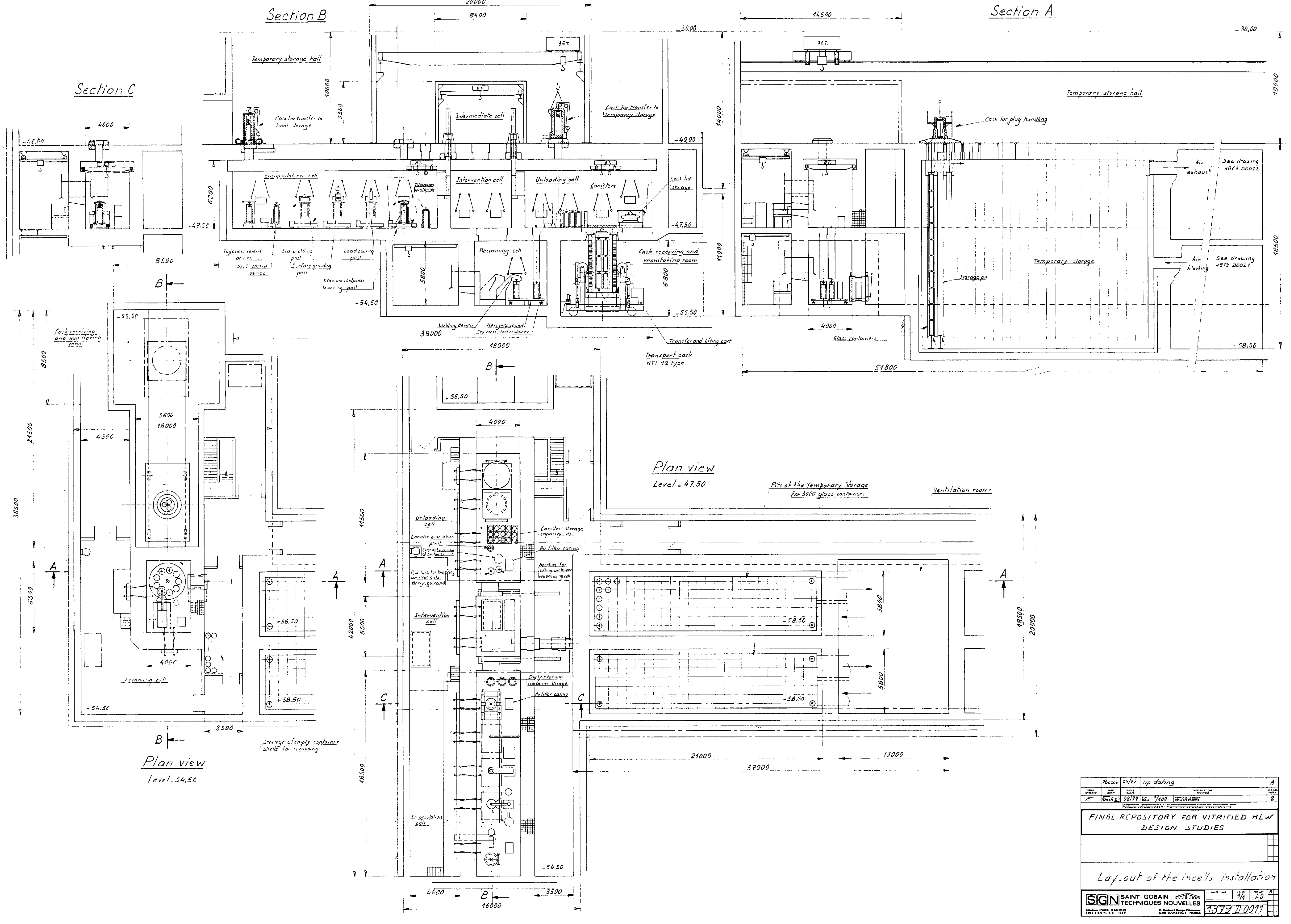
FINAL REPOSITORY FOR VITRIFIED HLW
DESIGN STUDIES

General perspective

SGN SAINT GOBAIN TECHNIQUES NOUVELLES
Téléphone : PARIS (1) 887.61.38 Telex : S.G.N. 616 - 129 F
23, Boulevard Georges Clémenceau 92400 COURBEVOIE FRANCE

UNITE UNIT — | FOLIO 1/1 | FORMAT A1 | A

1879 D 0010



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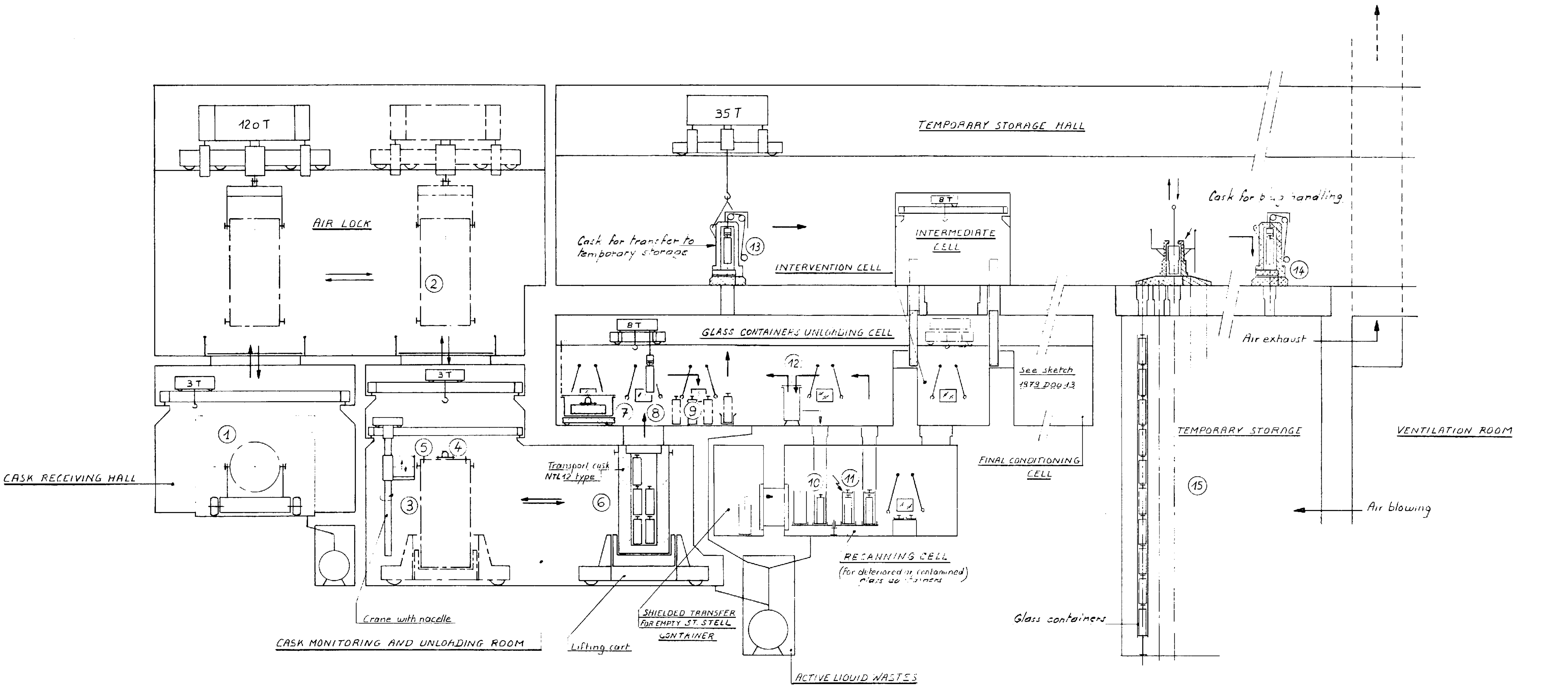
FINAL REPOSITORY FOR VITRIFIED HLW
DESIGN STUDIES

Lay-out of the incells installation

SGN SAINT GOBAIN TECHNIQUES NOUVELLES

FOLIO 1/1 — FORMAT A0 — A

1379 D 0011



1 Cask receiving (cask external washing, shock absorber dismouting)
2 Cask lay down on lifting cart
3 Monitoring of the internal activity of cask
4 Fixing of handling part on cask lid
5 Cask lid unbolting
6 Cask lifting and tight connection to glass containers unloading cell
7 Cask lid removal
8 Glass containers unloading
9 15 glass containers cooled storage
10 Putting glass containers into st. steel containers
11 Lid welding on st. steel containers
12 Possibility of st. steel container washing

(10–12: for contaminated glass containers only)

13 Transfer cask for glass container
14 Cask for glass container on the storage pit
15 Temporary storage

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FINAL REPOSITORY FOR VITRIFIED HLW
DESIGN STUDIES

OPERATIONS SKETCH
CONTAINERS RECEIVING AND TEMPORARY STORAGE

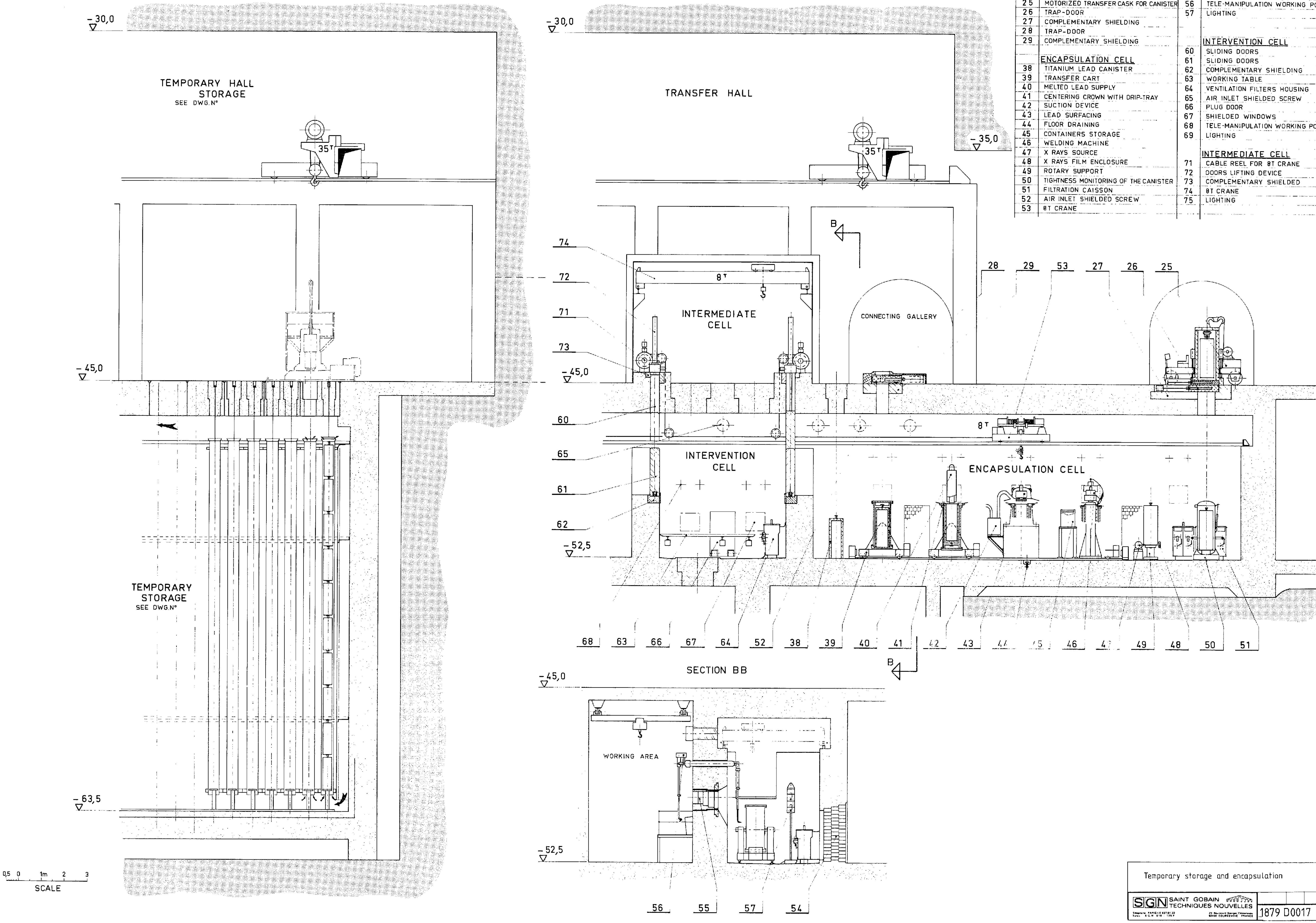
SGN SAINT GOBAIN TECHNIQUES NOUVELLES

FOLIO 1/1 — FORMAT A1 — A

1879 D 0012

ITEM	DESIGNATION
	TRANSFER HALL
21 TO 24	SEE DWG. N°
25	MOTORIZED TRANSFER CASK FOR CANISTER
26	TRAP-DOOR
27	COMPLEMENTARY SHIELDING
28	TRAP-DOOR
29	COMPLEMENTARY SHIELDING
	ENCAPSULATION CELL
38	TITANIUM LEAD CANISTER
39	TRANSFER CART
40	MELTED LEAD SUPPLY
41	CENTERING CROWN WITH DRIP-TRAY
42	SUCTION DEVICE
43	LEAD SURFACING
44	FLOOR DRAINING
45	CONTAINERS STORAGE
46	WELDING MACHINE
47	X RAYS SOURCE
48	X RAYS FILM ENCLOSURE
49	ROTARY SUPPORT
50	TIGHTNESS MONITORING OF THE CANISTER
51	FILTRATION CAISSON
52	AIR INLET SHIELDED SCREW
53	8T CRANE

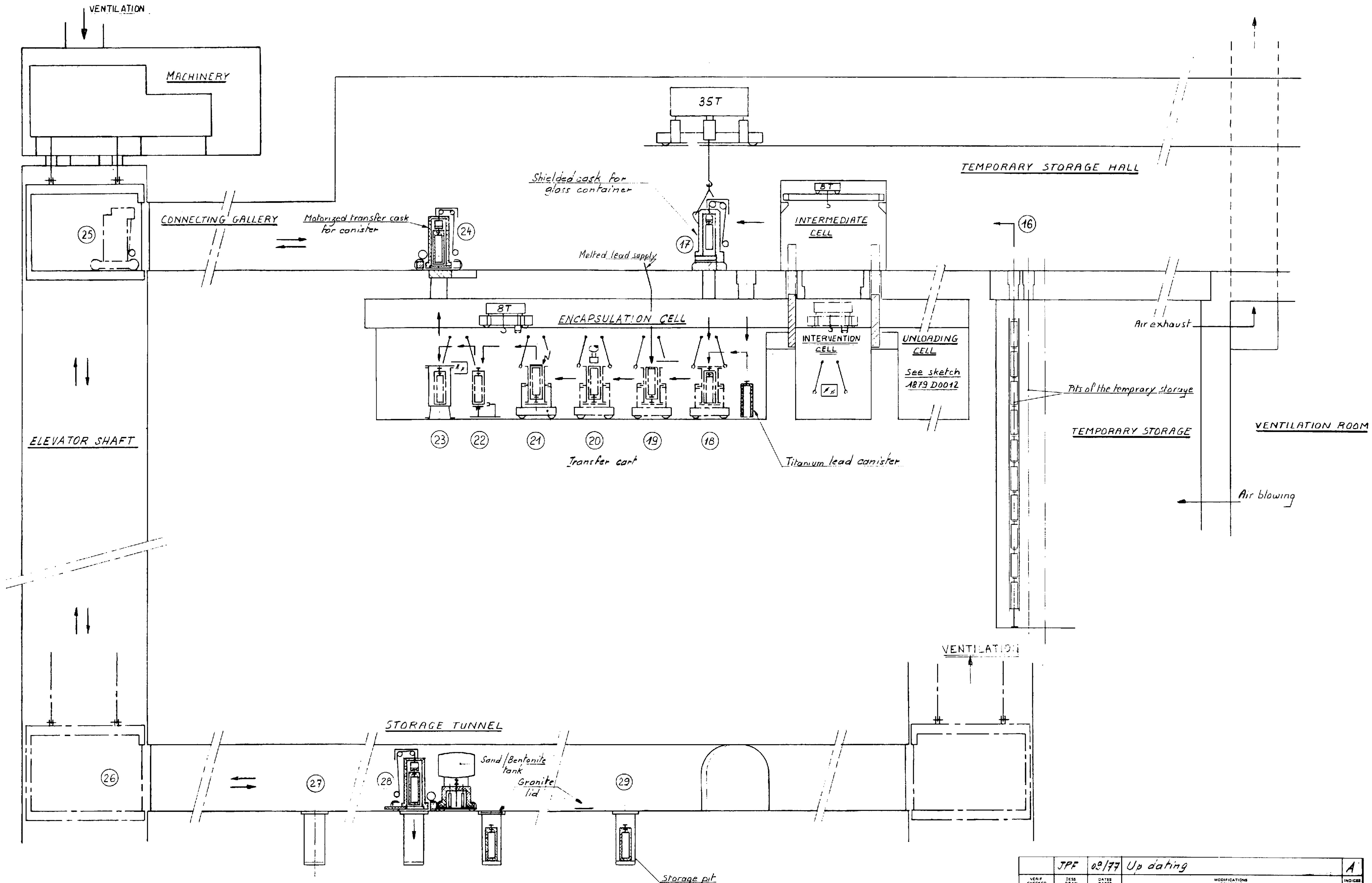
ITEM	DESIGNATION
54	WALL APERTURE CLOSED WITH REMOVABLE BRICKS
55	SHIELDED WINDOWS
56	TELE-MANIPULATION WORKING POINT
57	LIGHTING
	INTERVENTION CELL
60	SLIDING DOORS
61	SLIDING DOORS
62	COMPLEMENTARY SHIELDING
63	WORKING TABLE
64	VENTILATION FILTERS HOUSING
65	AIR INLET SHIELDED SCREW
66	PLUG DOOR
67	SHIELDED WINDOWS
68	TELE-MANIPULATION WORKING POINT
69	LIGHTING
	INTERMEDIATE CELL
71	CABLE REEL FOR 8T CRANE
72	DOORS LIFTING DEVICE
73	COMPLEMENTARY SHIELDED
74	8T CRANE
75	LIGHTING



Temporary storage and encapsulation

SGN SAINT GOBAIN TECHNIQUES NOUVELLES

1879 D0017



16. Loading of the transfer cask for glass container
17. Deposit of the glass container into the encapsulation cell
18. Deposit of the canister on the glass container
19. Complementary lead casting in the canister
20. Lead surfacing
21. Welding of the canister lid
22. Welding x rays monitoring
23. Tightness monitoring of the canister
24. Loading of the canister transfer cask

25. Canister transfer cask in the elevator
26. canister transfer cask at the repository level
27. Loading of the pit bottom with sand/Bentonite
28. Loading of the pit with a canister
29. pit filling with sand/bentonite and closing with a granite lid

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	JPF	09/77	Up dating	A
[illegible]	Fanchkein	08/77	ECH SCALE: – / REMPLACE LE DESSIN REPLACES DRAWING	Ø

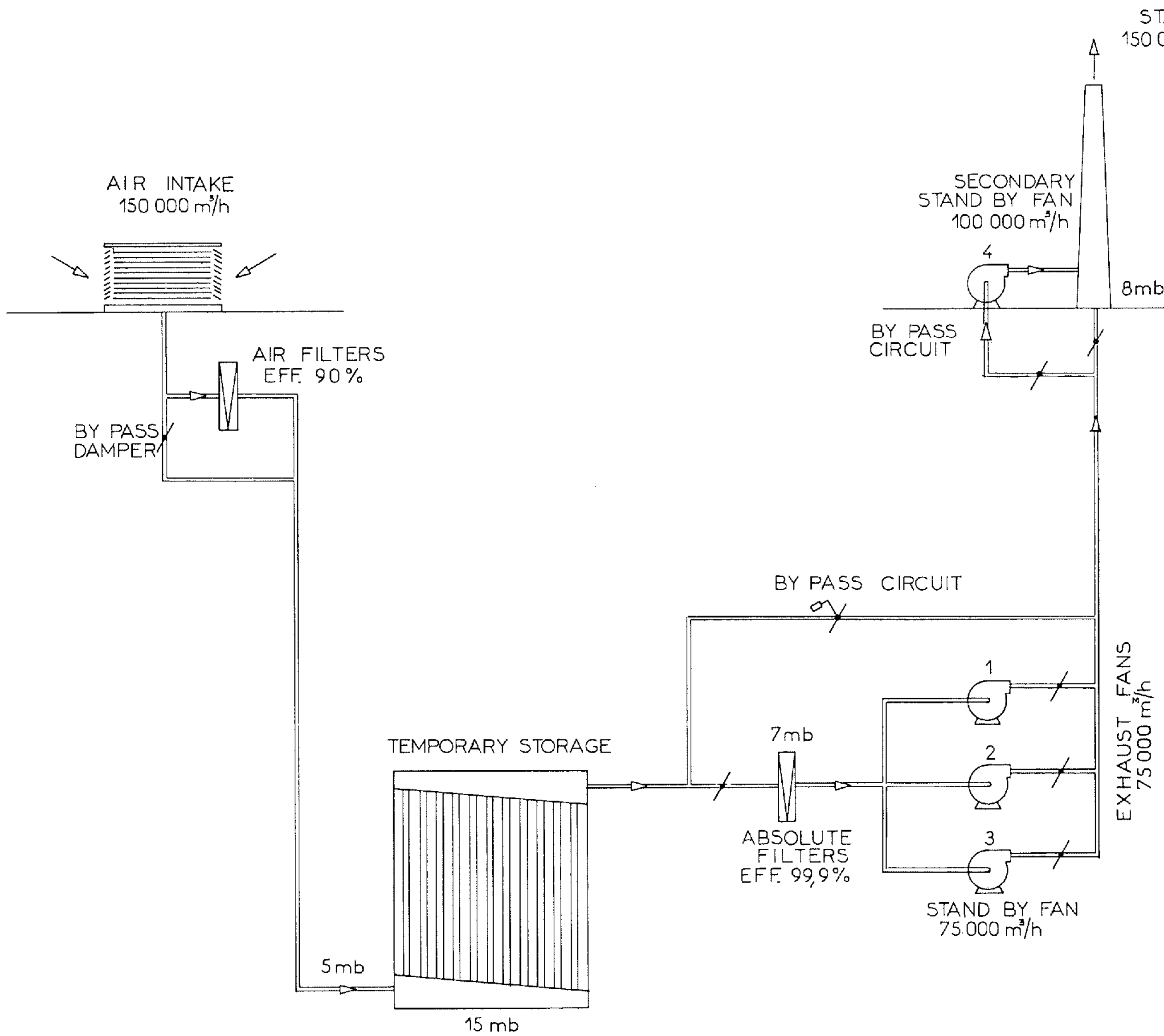
FINAL REPOSITORY FOR VITRIFIED HLW
DESIGN STUDIES

OPERATIONS SKETCH
FINAL CONDITIONING AND STORAGE OF CANISTERS

SGN SAINT GOBAIN TECHNIQUES NOUVELLES
Téléphone : PARIS (1) 637.01.30
Telex : S.G.N. 610 · 125 F
23, Boulevard Georges Clemenceau 92400 COURBEVOIE FRANCE

UNITE UNIT: – | FOLIO 1/1 | FORMAT A1 | A

1879 D 0013



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GEOLOGICAL STORAGE

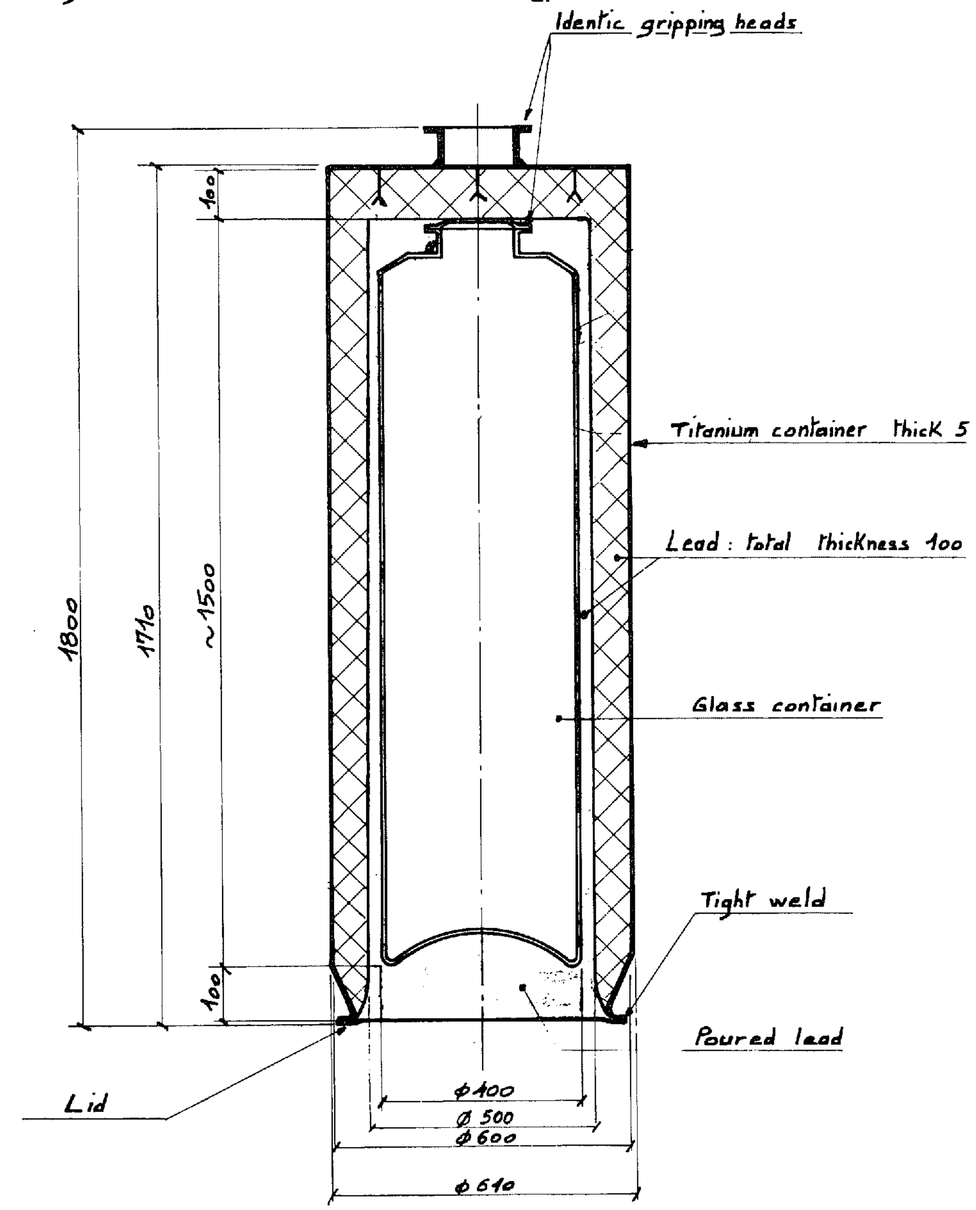
TEMPORARY STORAGE VENTILATION

SGN SAINT GOBAIN TECHNIQUES NOUVELLES
Téléphone : PARIS (1) 637.01.30 Telex : S.G.N. 610 - 125 F
23, Boulevard Georges Clémenceau 92400 COURBEVOIE FRANCE

UNITE UNIT — FOLIO 1/1 — FORMAT A3

1879 D00 20

Weight of container stainless steel + glass	500 Kgp
Weight of lead	3300 Kgp
Weight of Titanium container	87 Kgp
Total weight	3887 Kgp



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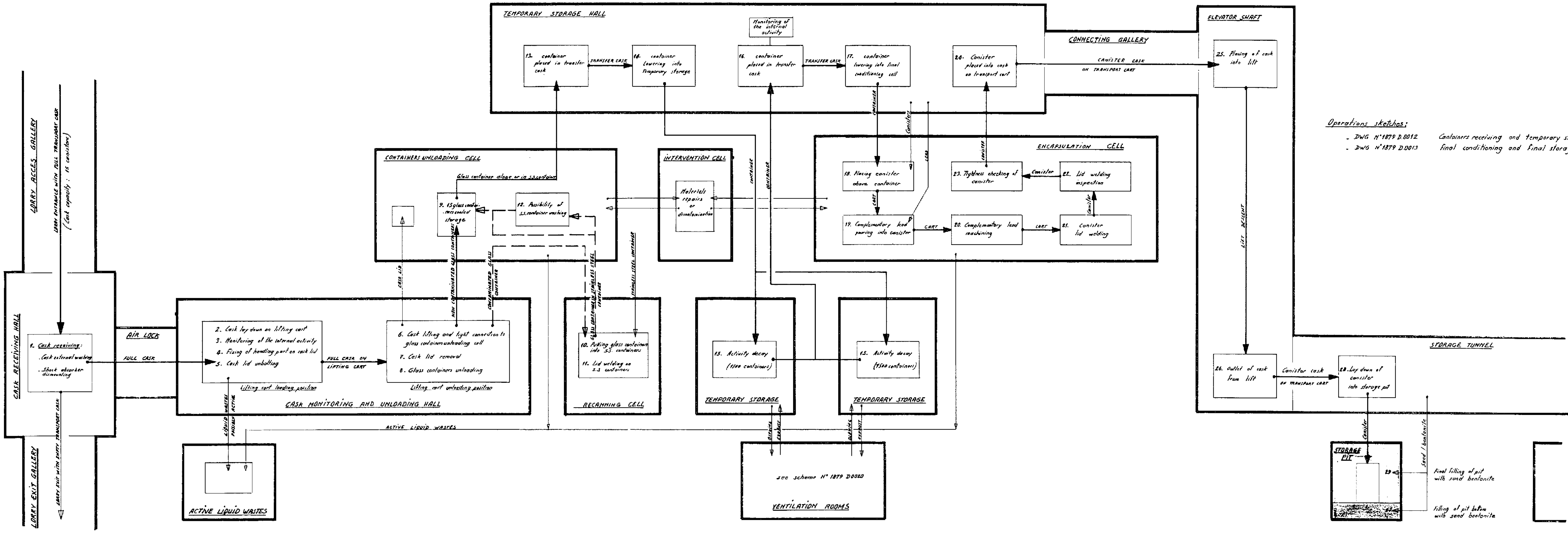
FINAL REPOSITORY FOR VITRIFIED HLW
DESIGN STUDIES

Titanium container

SGN SAINT GOBAIN TECHNIQUES NOUVELLES
Téléphone : PARIS (1) 637.01.30 Telex : S.G.N. 610 - 125 F
23, Boulevard Georges Clémenceau 92400 COURBEVOIE FRANCE

UNITE UNIT — FOLIO 1/1 — FORMAT A3 — A

1879 D 0014



Operations sketches:

- DWG N°1879 D0012 Containers receiving and temporary storage
- DWG N°1879 D0013 final conditioning and final storage.

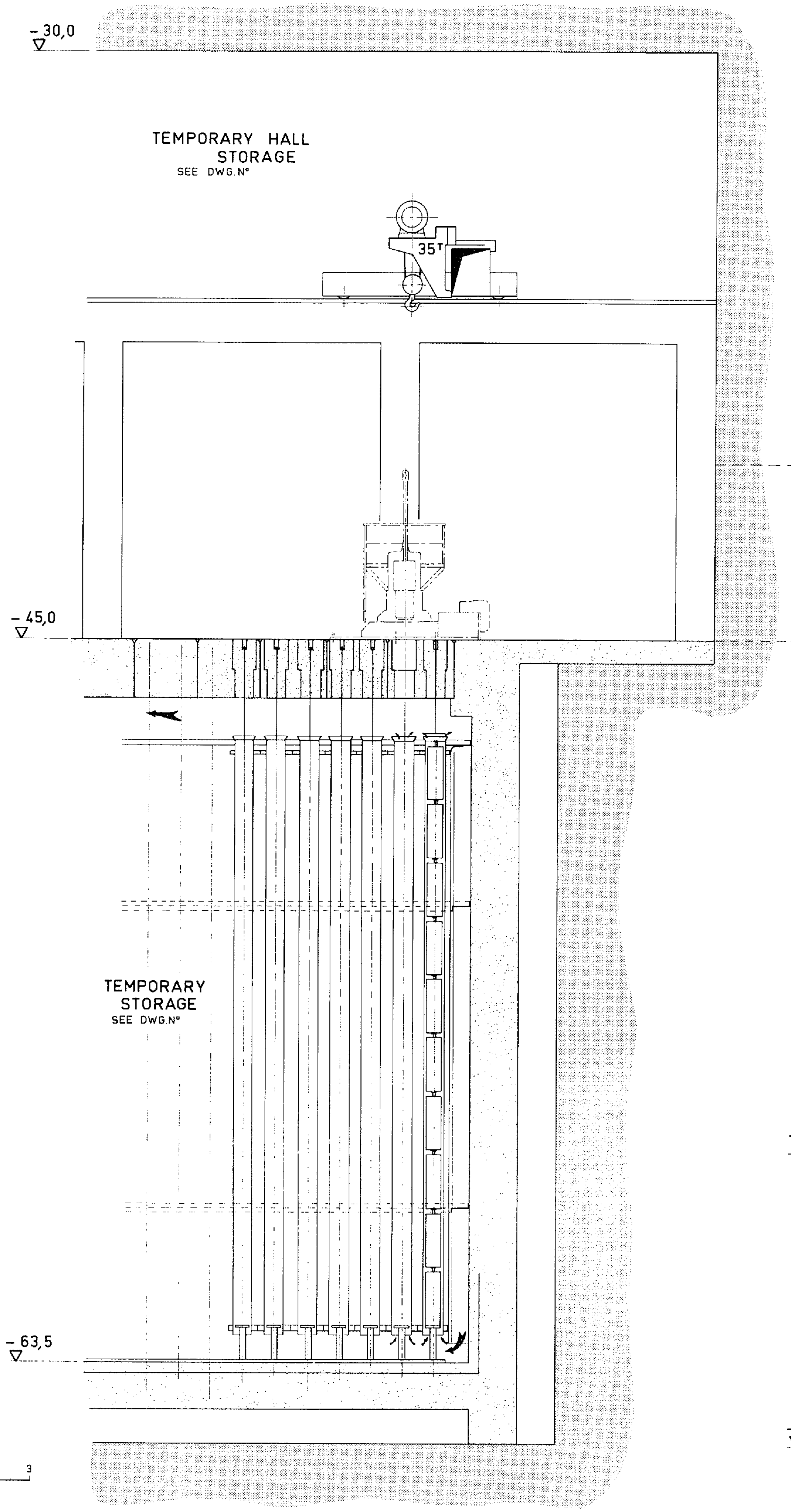
FINAL REPOSITORY FOR VITRIFIED HLW
DESIGN STUDIES

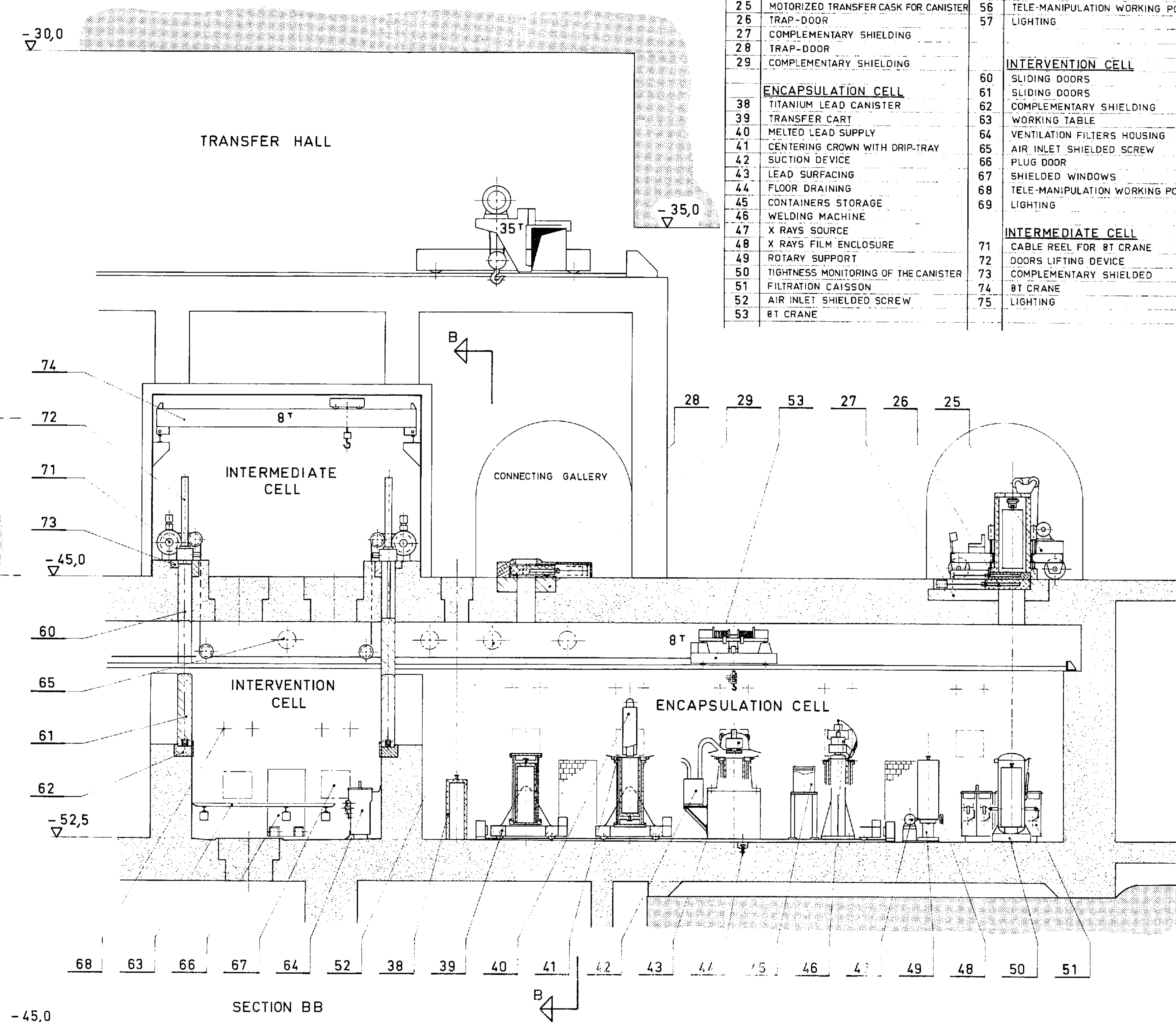
OPERATIONS DIAGRAM

SGN SAINT GOBAIN TECHNIQUES NOUVELLES

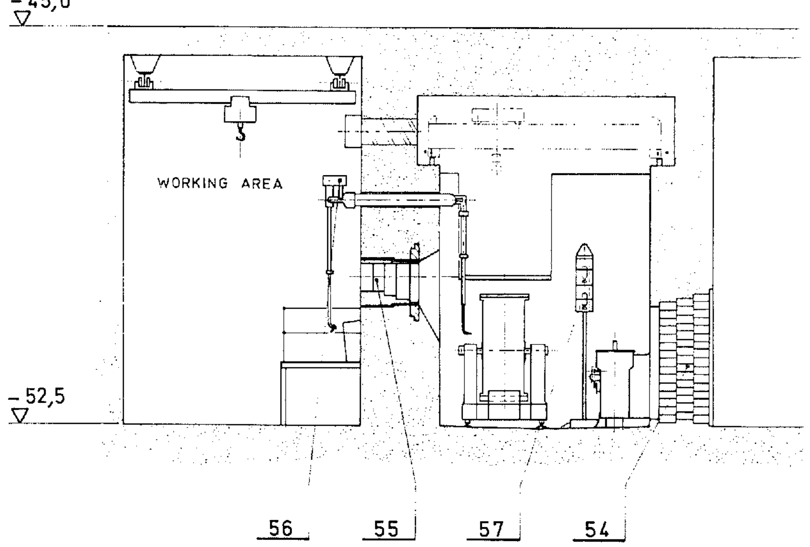
1879 D0015

ITEM	DESIGNATION	ITEM	DESIGNATION
	TRANSFER HALL	54	WALL APERTURE CLOSED WITH REMOVABLE BRICKS
21 TO 24	SEE DWG. N°	55	SHIELDED WINDOWS
25	MOTORIZED TRANSFER CASK FOR CANISTER	56	TELE-MANIPULATION WORKING POINT
26	TRAP-DOOR	57	LIGHTING
27	COMPLEMENTARY SHIELDING		
28	TRAP-DOOR		
29	COMPLEMENTARY SHIELDING		INTERVENTION CELL
		60	SLIDING DOORS
	ENCAPSULATION CELL	61	SLIDING DOORS
38	TITANIUM LEAD CANISTER	62	COMPLEMENTARY SHIELDING
39	TRANSFER CART	63	WORKING TABLE
40	MELTED LEAD SUPPLY	64	VENTILATION FILTERS HOUSING
41	CENTERING CROWN WITH DRIP-TRAY	65	AIR INLET SHIELDED SCREW
42	SUCTION DEVICE	66	PLUG DOOR
43	LEAD SURFACING	67	SHIELDED WINDOWS
44	FLOOR DRAINING	68	TELE-MANIPULATION WORKING POINT
45	CONTAINERS STORAGE	69	LIGHTING
46	WELDING MACHINE		
47	X RAYS SOURCE		INTERMEDIATE CELL
48	X RAYS FILM ENCLOSURE	71	CABLE REEL FOR 8T CRANE
49	ROTARY SUPPORT	72	DOORS LIFTING DEVICE
50	TIGHTNESS MONITORING OF THE CANISTER	73	COMPLEMENTARY SHIELDED
51	FILTRATION CAISSON	74	8T CRANE
52	AIR INLET SHIELDED SCREW	75	LIGHTING
53	8T CRANE		





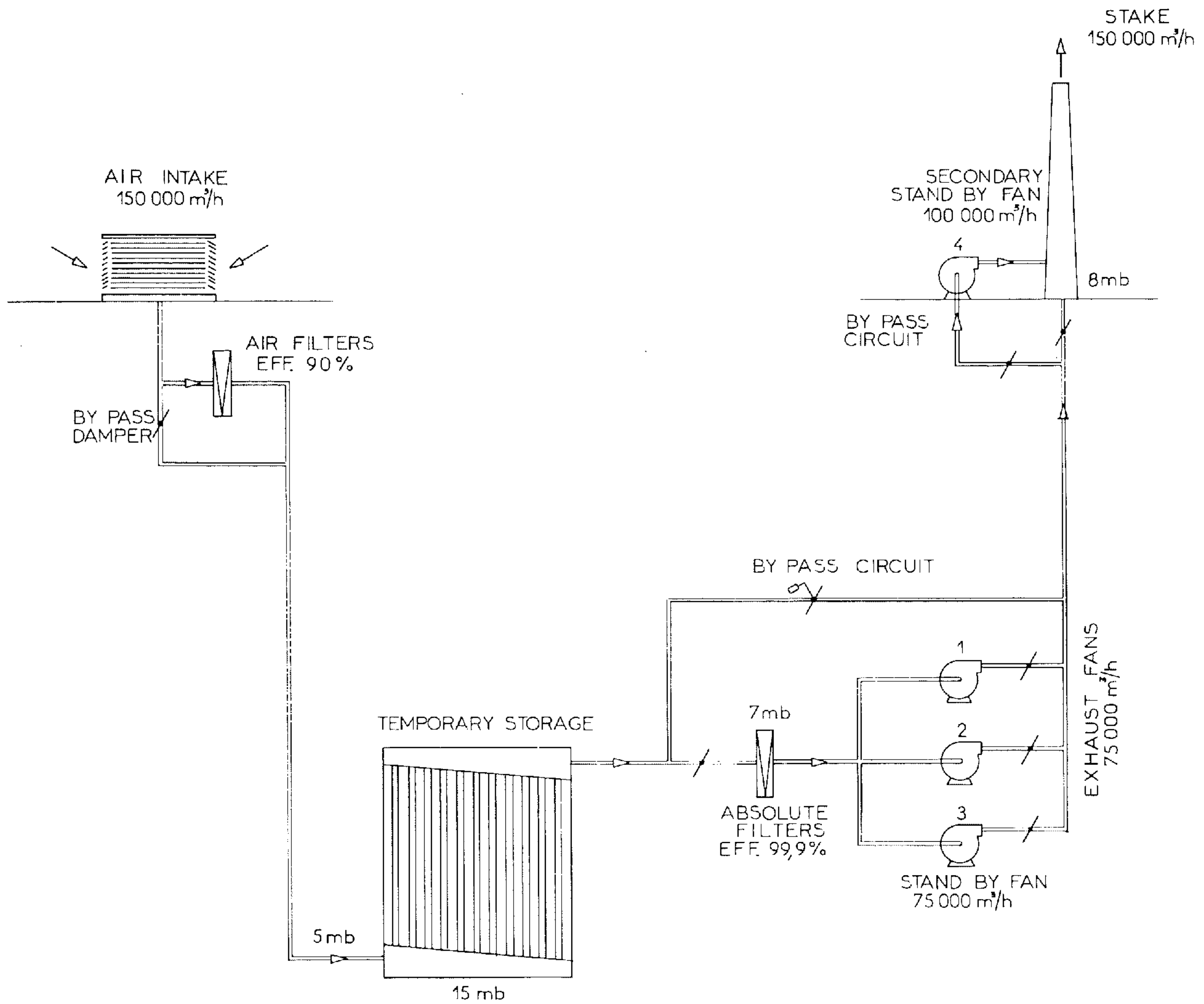
SECTION BB



Temporary storage and encapsulation

SGN SAINT GOBAIN TECHNIQUES NOUVELLES

1879 D0017



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GEOLOGICAL STORAGE

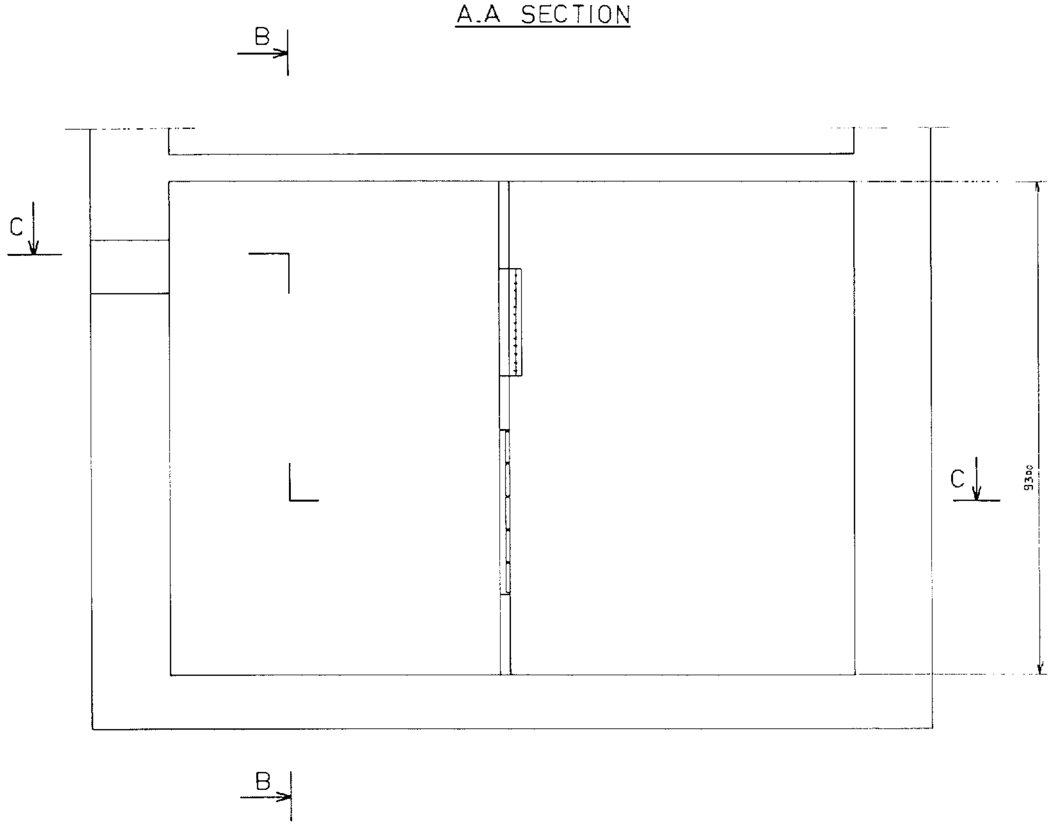
TEMPORARY STORAGE VENTILATION

SGN SAINT GOBAIN TECHNIQUES NOUVELLES

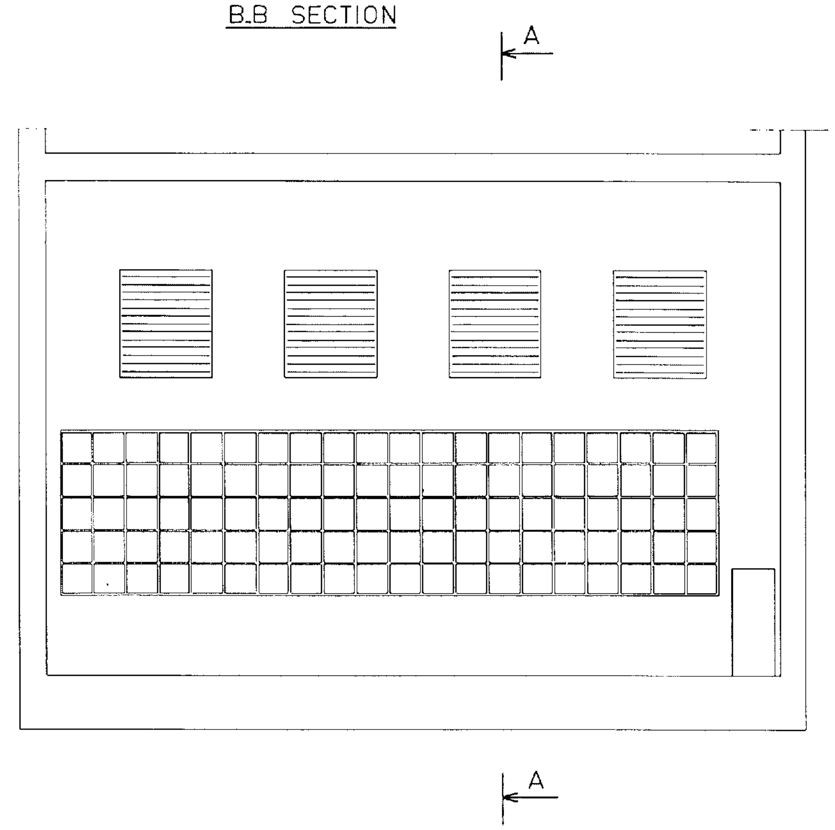
1/1 A3

1879 D00 20

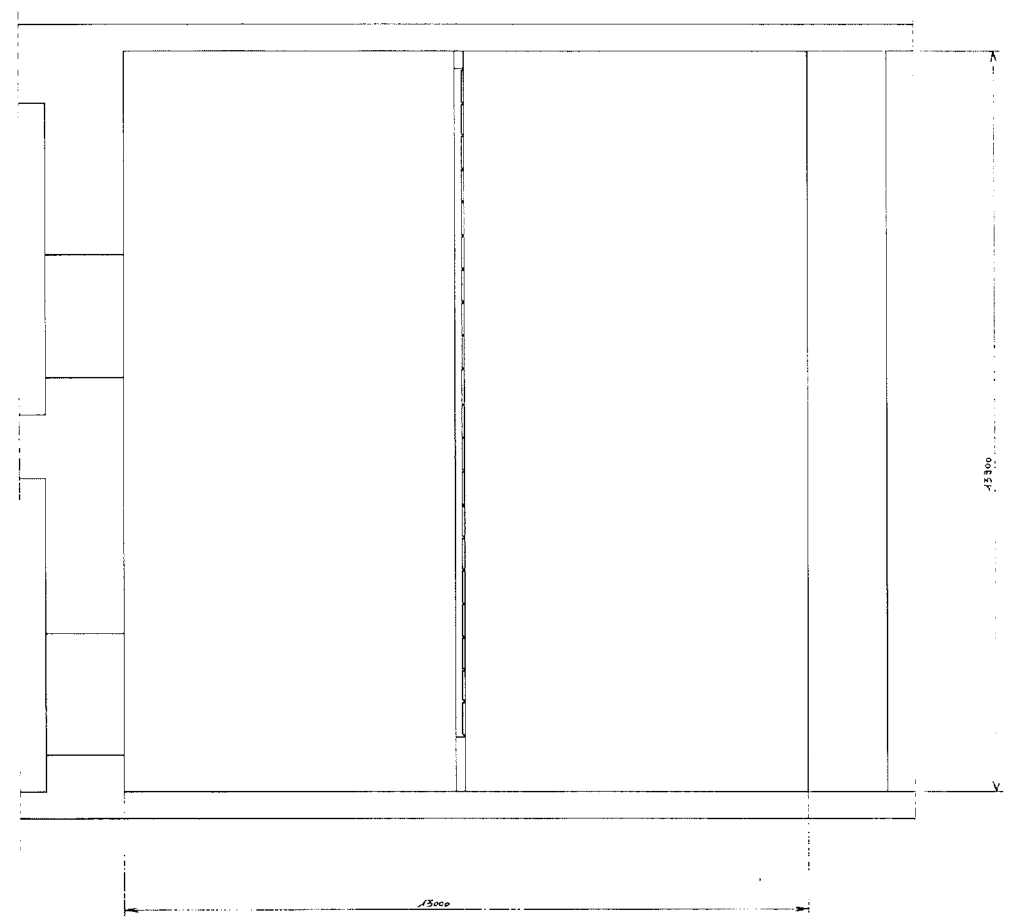
A.A SECTION



B.B SECTION



C.C SECTION



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GEOLOGICAL STORAGE

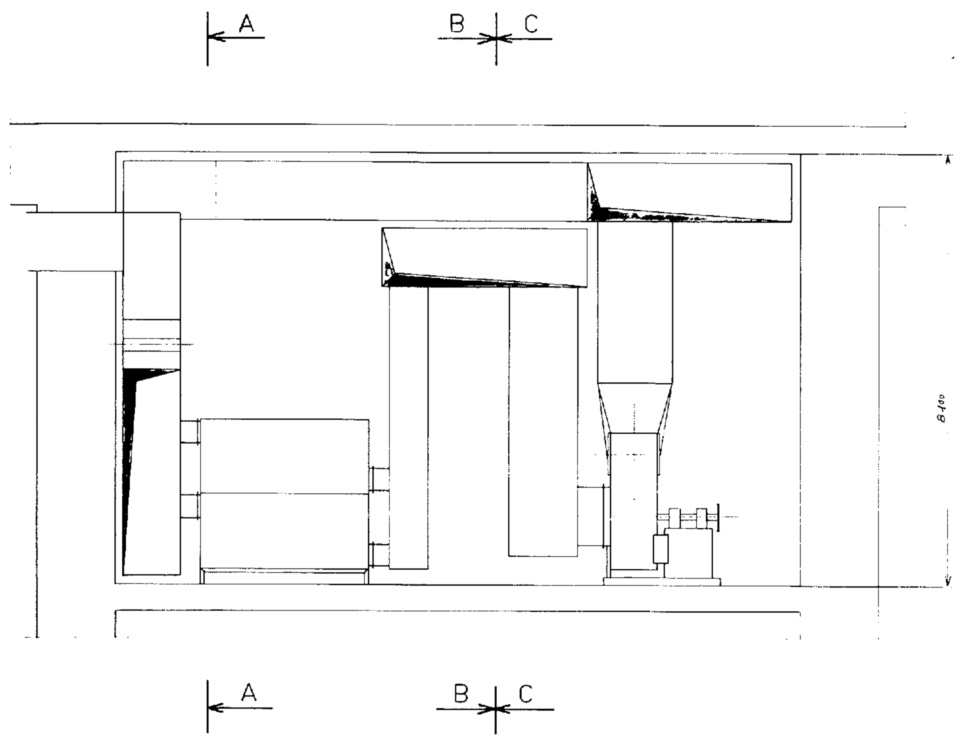
TEMPORARY STORAGE
AIR INLET FILTRATION

SGN SAINT GOBAIN TECHNIQUES NOUVELLES

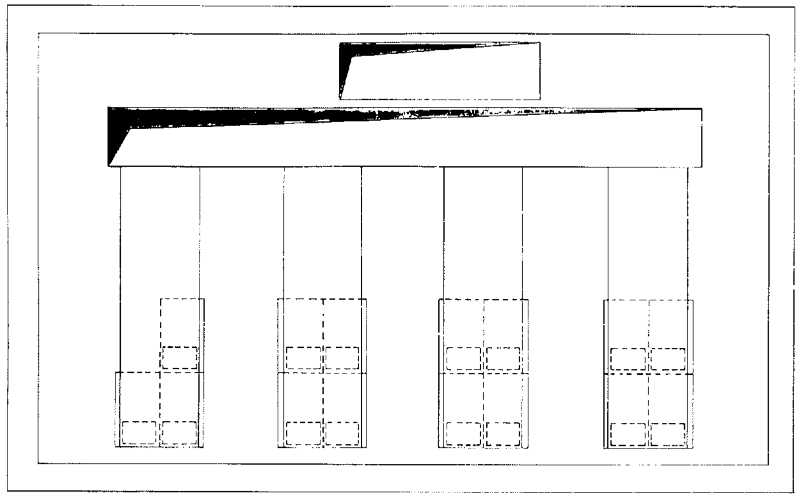
UNITÉ UNIT	FOLIO	FORMAT
	1/1	A0

1879D0021

D.D SECTION



C.C SECTION



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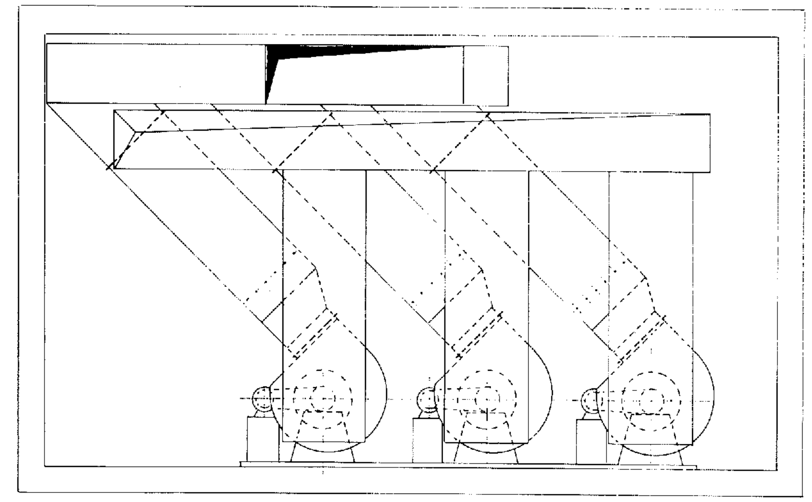
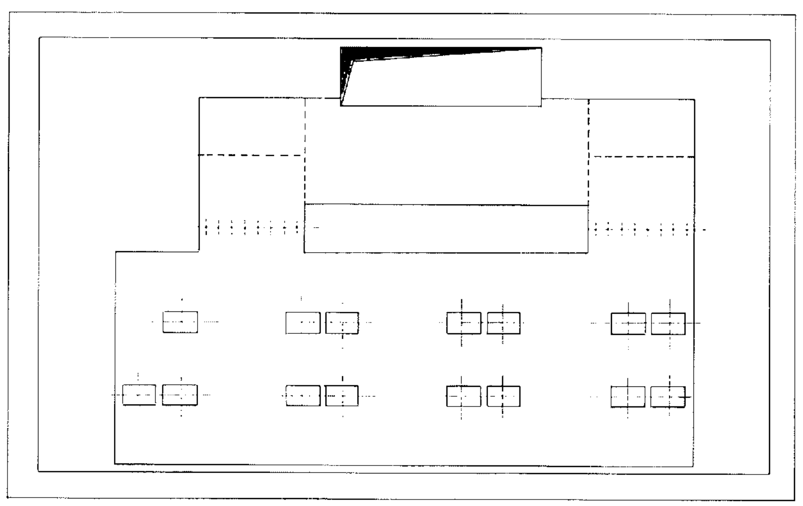
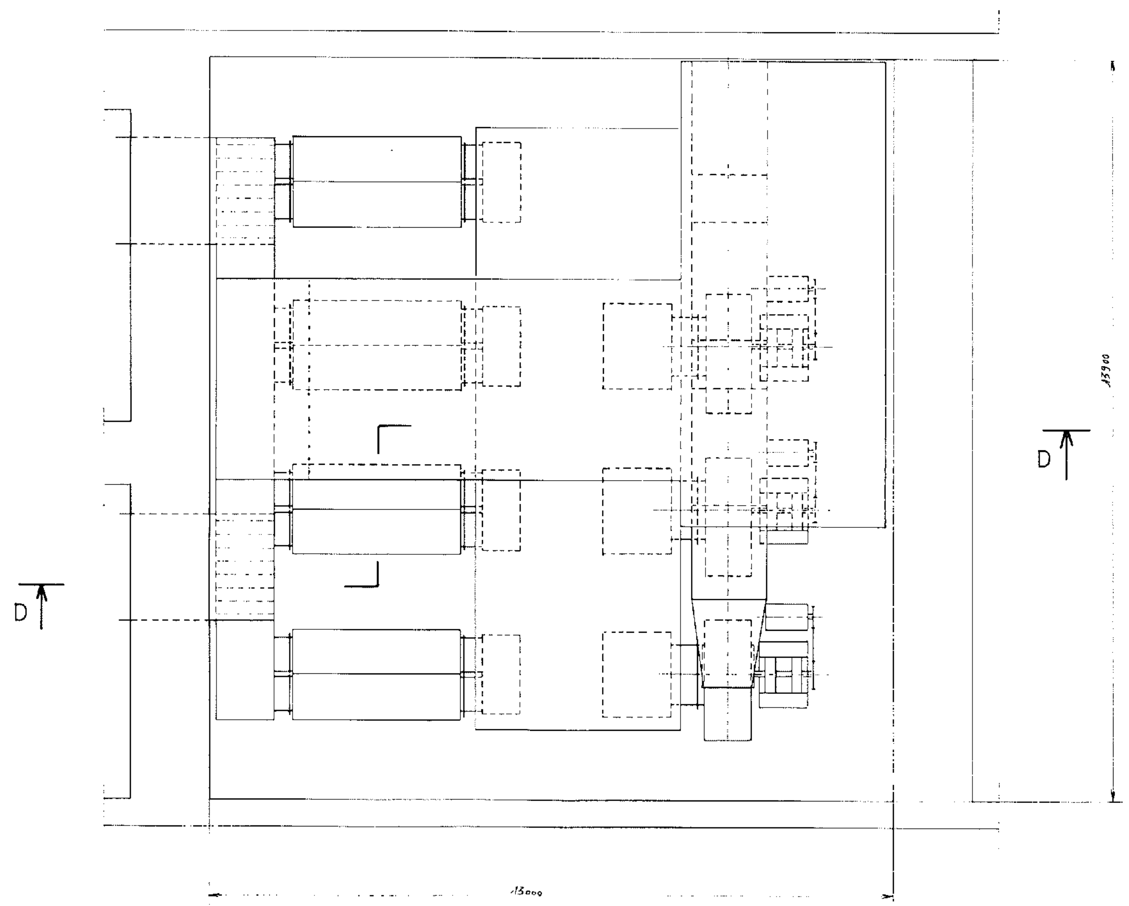


A.A SECTION



PLAN VIEW



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GEOLOGICAL STORAGE

TEMPORARY STORAGE

FILTRATION AND AIR EXHAUST ROOM

SGN SAINT GOBAIN TECHNIQUES NOUVELLES

UNITE UNIT	FOLIO	FORMAT
	1/1	A0

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FÖRTECKNING ÖVER KBS TEKNISKA RAPPORTER

01 Källstyrkor i utbränt bränsle och högaktivt avfall från en PWR beräknade med ORIGEN
Nils Kjellbert
AB Atomenergi 77-04-05

02 PM angående värmeledningstal hos jordmaterial
Sven Knutsson
Roland Pusch
Högskolan i Luleå 77-04-15

03 Deponering av högaktivt avfall i borrhål med buffertsubstans
Arvid Jacobsson
Roland Pusch
Högskolan i Luleå 77-05-27

04 Deponering av högaktivt avfall i tunnlar med buffertsubstans
Arvid Jacobsson
Roland Pusch
Högskolan i Luleå 77-06-01

05 Orienterande temperaturberäkningar för slutförvaring i berg av radioaktivt avfall, Rapport 1
Roland Blomqvist
AB Atomenergi 77-03-17

06 Groundwater movements around a repository, Phase 1, State of the art and detailed study plan
Ulf Lindblom
Hagconsult AB 77-02-28

07 Resteffekt studier för KBS
Del 1 Litteraturgenomgång
Del 2 Beräkningar
Kim Ekberg
Nils Kjellbert
Göran Olsson
AB Atomenergi 77-04-19

08 Utlakning av franskt, engelskt och kanadensiskt glas med högaktivt avfall
Göran Blomqvist
AB Atomenergi 77-05-20

09 Diffusion of soluble materials in a fluid filling a porous medium
Hans Häggblom
AB Atomenergi 77-03-24

10 Translation and development of the BNWL-Geosphere Model
Bertil Grundfelt
Kemakta Konsult AB 77-02-05

11 Utredning rörande titans lämplighet som korrosionshärdig kapsling för kärnbränsleavfall
Sture Henriksson
AB Atomenergi 77-04-18

12 Bedömning av egenskaper och funktion hos betong i samband med slutlig förvaring av kärnbränsleavfall i berg
Sven G Bergström
Göran Fagerlund
Lars Rombén
Cement- och Betonginstitutet 77-06-22

13 Urlakning av använt kärnbränsle (bestrålad uranoxid) vid direktdeponering
Ragnar Gelin
AB Atomenergi 77-06-08

14 Influence of cementation on the deformation properties of bentonite/quartz buffer substance
Roland Pusch
Högskolan i Luleå 77-06-20

15 Orienterande temperaturberäkningar för slutförvaring i berg av radioaktivt avfall
Rapport 2
Roland Blomquist
AB Atomenergi 77-05-17

16 Översikt av utländska riskanalyser samt planer och projekt rörande slutförvaring
Åke Hultgren
AB Atomenergi augusti 1977

17 The gravity field in Fennoscandia and postglacial crustal movements
Arne Bjerhammar
Stockholm augusti 1977

18 Rörelser och instabilitet i den svenska berggrunden
Nils-Axel Mörner
Stockholms Universitet augusti 1977

19 Studier av neotektonisk aktivitet i mellersta och norra Sverige, flygbildsgenomgång och geofysisk tolkning av recenta förkastningar
Robert Lagerbäck
Herbert Henkel
Sveriges Geologiska Undersökning september 1977

20 Tektonisk analys av södra Sverige, Vättern - Norra Skåne
Kennert Röshoff
Erik Lagerlund
Lunds Universitet och Högskolan Luleå september 1977

21 Earthquakes of Sweden 1891 - 1957, 1963 - 1972
Ota Kulhánek
Rutger Wahlström
Uppsala Universitet september 1977

22 The influence of rock movement on the stress/strain situation in tunnels or bore holes with radioactive consisters embedded in a bentonite/quartz buffer mass
Roland Pusch
Högskolan i Luleå 1977-08-22

23 Water uptake in a bentonite buffer mass
A model study
Roland Pusch
Högskolan i Luleå 1977-08-22

24 Beräkning av utlakning av vissa fissionsprodukter och aktinider från en cylinder av franskt glas
Göran Blomqvist
AB Atomenergi 1977-07-27

25 Blekinge kustgnejs, Geologi och hydrogeologi
Ingemar Larsson KTH
Tom Lundgren SGI
Ulf Wiklander SGU
Stockholm, augusti 1977

26 Bedömning av risken för fördröjt brott i titan
Kjell Pettersson
AB Atomenergi 1977-08-25

27 A short review of the formation, stability and cementing properties of natural zeolites
Arvid Jacobsson
Högskolan i Luleå 1977-10-03

28 Värmeledningsförsök på buffertsubstans av bentonit/pitesilt
Sven Knutsson
Högskolan i Luleå 1977-09-20

29 Deformationer i sprickigt berg
Ove Stephansson
Högskolan i Luleå 1977-09-28

30 Retardation of escaping nuclides from a final depository
Ivars Neretnieks
Kungliga Tekniska Högskolan Stockholm 1977-09-14

31 Bedömning av korrosionsbeständigheten hos material avsedda för kapsling av kärnbränsleavfall. Lägesrapport 1977-09-27 samt kompletterande yttranden.
Korrosionsinstitutet och dess referensgrupp

32 Long term mineralogical properties of bentonite/quartz buffer substance
Preliminär rapport november 1977
Slutrapport februari 1978
Roland Pusch
Arvid Jacobsson
Högskolan i Luleå

33 Required physical and mechanical properties of buffer masses
Roland Pusch
Högskolan Luleå 1977-10-19

34 Tillverkning av bly-titan kapsel
Folke Sandelin AB
VBB
ASEA-Kabel
Institutet för metallforskning
Stockholm november 1977

35 Project for the handling and storage of vitrified high-level waste
Saint Gobain Techniques Nouvelles October, 1977

36 Sammansättning av grundvatten på större djup i granitisk berggrund
Jan Rennerfelt
Orrje & Co, Stockholm 1977-11-07

37 Hantering av buffertmaterial av bentonit och kvarts
Hans Fagerström, VBB
Björn Lundahl, Stabilator
Stockholm oktober 1977

38 Utformning av bergrumsanläggningar
Arne Finné, KBS
Alf Engelbrektson, VBB
Stockholm december 1977

39 Konstruktionsstudier, direktdeponering
ASEA-ATOM
VBB
Västerås

40 Ekologisk transport och stråldoser från grundvattenburna radioaktiva ämnen
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Sverker Evans
AB Atomenergi

41 Säkerhet och strålskydd inom kärnkraftområdet.
Lagar, normer och bedömningsgrunder
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Siegfried F Johnson
Stig Rolandson
AB Atomenergi och ASEA-ATOM

42 Säkerhet vid hantering, lagring och transport av använt kärnbränsle och förglasat högaktivt avfall
Ann Margret Ericsson
Kemakta november 1977

43 Transport av radioaktiva ämnen med grundvatten från ett bergförvar
Bertil Grundfelt
Kemakta november 1977

44 Beständighet hos borsilikatglas
Tibor Lakatos
Glasteknisk Utveckling AB

45 Beräkning av temperaturer i ett envånings slutförvar i berg för förglasat radioaktivt avfall Rapport 3
Roland Blomquist
AB Atomenergi 1977-10-19

46 Temperaturberäkningar för använt bränsle
Taivo Tarandi
VBB

47 Teoretiska studier av grundvattenrörelser
Preliminär rapport oktober 1977
Slutrapport februari 1978
Lars Y Nilsson
John Stokes
Roger Thunvik
Inst för kulturteknik KTH

48 The mechanical properties of the rocks in Stripa, Kråkemåla, Finnsjön and Blekinge
Graham Swan
Högskolan i Luleå 1977-09-14

49 Bergspänningsmätningar i Stripa gruva
Hans Carlsson
Högskolan i Luleå 1977-08-29

50 Lakningsförsök med högaktivt franskt glas i Studsvik
Göran Blomqvist
AB Atomenergi november 1977

51 Seismotechtonic risk modelling for nuclear waste disposal in the Swedish bedrock
F Ringdal
H Gjöystdal
E S Hysebye
Royal Norwegian Council for scientific and industrial research

52 Calculations of nuclide migration in rock and porous media, penetrated by water
H Häggblom
AB Atomenergi 1977-09-14

53 Mätning av diffusionshastighet för silver i lera-sand-blandning
Bert Allard
Heino Kipatsi
Chalmers tekniska högskola 1977-10-15

54 Groundwater movements around a repository

54:01 Geological and geotechnical conditions
Håkan Stille
Anthony Burgess
Ulf E Lindblom
Hagconsult AB september 1977

54:02 Thermal analyses
Part 1 Conduction heat transfer
Part 2 Advective heat transfer
Joe L Ratigan
Hagconsult AB september 1977

54:03 Regional groundwater flow analyses
Part 1 Initial conditions
Part 2 Long term residual conditions
Anthony Burgess
Hagconsult AB oktober 1977

54:04 Rock mechanics analyses
Joe L Ratigan
Hagconsult AB september 1977

54:05 Repository domain groundwater flow analyses
Part 1 Permeability perturbations
Part 2 Inflow to repository
Part 3 Thermally induced flow
Joe L Ratigan
Anthony S Burgess
Edward L Skiba
Robin Charlwood

54:06 Final report
Ulf Lindblom et al
Hagconsult AB oktober 1977

55 Sorption av långlivade radionuklider i lera och berg
Del 1 Bestämning av fördelningskoefficienter
Del 2 Litteraturgenomgång
Bert Allard
Heino Kipatsi
Jan Rydberg
Chalmers tekniska högskola 1977-10-10

56 Radiolys av utfyllnadsmaterial
Bert Allard
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57 Stråldoser vid haveri under sjötransport av kärnbränsle
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Ulla Bergström
Lennart Devell
AB Atomenergi

58 Strålrisker och högsta tillåtliga stråldoser för människan
Gunnar Walinder
FOA 4 november 1977

59 Tectonic lineaments in the Baltic from Gävle to Simrishamn
Tom Flodén
Stockholms Universitet 1977-12-15