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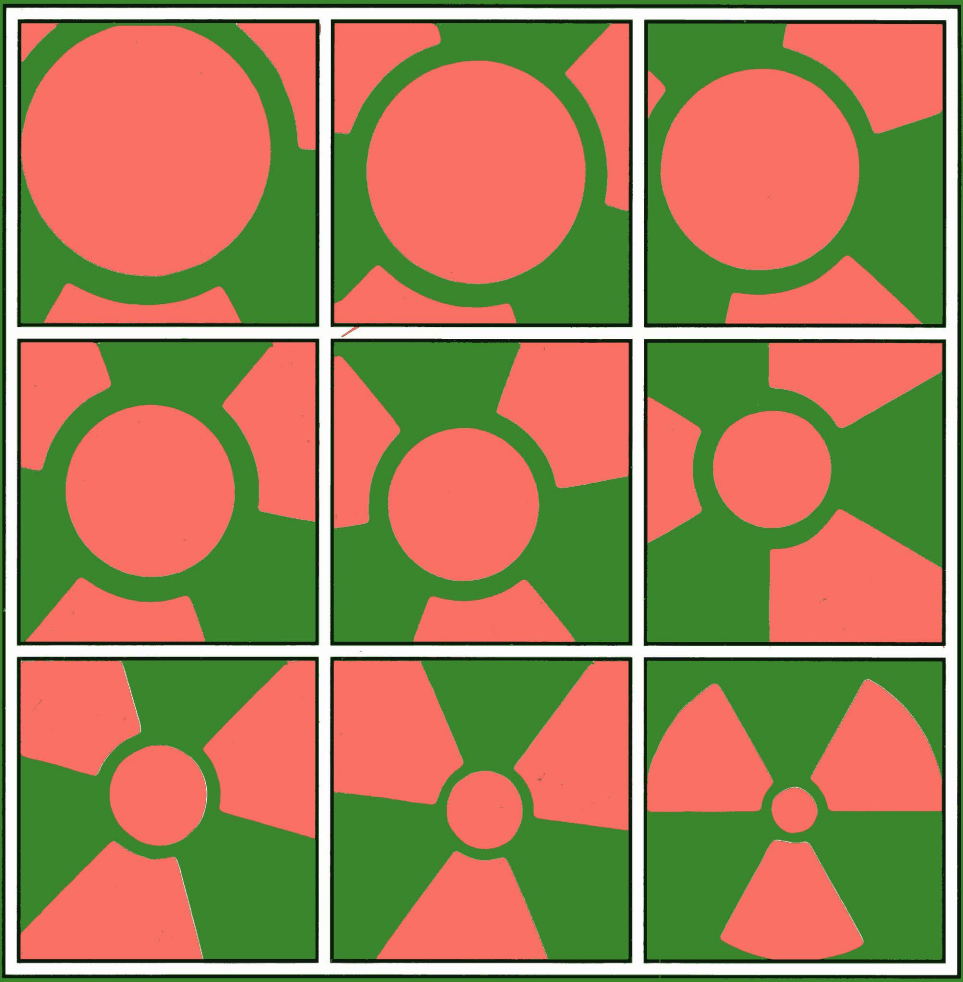
nuclear science
and technology

Assessment of management alternatives for LWR wastes

(Volume 1)

Main achievements of the joint study



Report

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nuclear science and technology

Assessment of management alternatives for LWR wastes

(Volume 1)

Main achievements of the joint study

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Final report

Work performed as part of the shared cost programme (1985-89) on management and disposal of radioactive waste of the European Communities

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SUMMARY

Within the framework of the 3rd E.C. Programme on Radioactive Waste Management and disposal a joint study was implemented to assess the different practices used to manage liquid, gaseous and solid radwastes arising from operation of Light Water Reactors (LWR).

The joint study was co-ordinated by the Commission of the European Communities and executed by 9 European organizations.

Practices refer to processes or technologies used in the late eighties by European countries for the power units and recent developments in radwaste disposal systems. Technical, economical and radiological aspects are considered in this evaluation with the main emphasis on three distinct European routes of PWR's.

On the technical level it has been shown that the three routes studied diverge considerably in the management of their gaseous and solid wastes. This reveals the major influence of the state of development of the disposal option for conditioned wastes on the strategy of management of LWR wastes.

In Germany and Belgium, where the final choice of a disposal system has not yet been made (open waste management alternative), volume reduction is a major objective. This involves the use of techniques of direct in-cask drying of wet wastes and incineration of dry wastes.

In France, where near-surface disposal is available and operates at relatively low cost, the volume reduction is achieved by compaction.

The incineration technique appears to be economically unfavourable in the different management routes analysed : increase of volume reduction (interim and final storage profits) does not counterbalance the investment and operation costs of this technique.

Finally, this comparative analysis of the radwaste management routes practiced in the four European countries has highlighted differences of efficiency which are paid for by differences in cost. But all three radwaste management chains studied lead to activities of airborne and liquid releases that are much lower than the safety requirement limits enforced by the national Safety Authorities.

TABLE OF CONTENTS

1. *INTRODUCTION*

During the past few years, management practices for low and intermediate level radioactive reactor wastes have taken advantage of many improvements in processes, organisation and safety.

Within the framework of the 3rd E.C. Programme on radioactive waste management and disposal, a joint theoretical study was implemented, whose main purpose was to assess selected management routes resulting from these new developments.

This study was concerned with Light Water Reactor with the main emphasis on Pressurized Water Reactors (PWRs). Boiling Water Reactors were only considered within the sensitivity studies.

Three distinct European alternatives were considered, namely :

- Route PWR1 - French practice
- Route PWR2 - German practice
- Route PWR3 - Belgian practice.

A description of each route is given for both Pressurized and Boiling Water Reactors.

For PWRs, an analysis and calculation of the cost of each route, and the radiological impact on the public were made. In addition, sensitivity studies examined the effect of varying the most important parameters influencing waste characteristics and quantities as well as total cost.
Within the framework of the sensitivity studies, an economic assessment of some operation units of the radwaste management route of BWR's and comparison with the corresponding one of the PWR's management route have been performed.

This joint study was co-ordinated by the Commission of the European Communities and executed by the following Companies and Organisations :

- ▸ Description of the reference management routes of LWR waste including the evaluation of the main cost element for treatment, conditioning packaging, transport : SGN(F) + EDF(F), GNS(D) + FRAMATOME (F), BELGATOM (B).
- ▸ Description of the disposal options including the cost evaluation for LWR packagages : INITEC (Spain) + CEA (F).
- ▸ Cost assessment of all the routes : TASK R&S (I) and KAH (D)
- ▸ Estimation of radiological impact of all the routes : BELGATOM (B) and Commission of the European Communities.

- Elaboration of the main achievements of the joint study BELGATOM. For this elaboration, a work of data harmonisation was performed. In some cases information provided by the Companies and organisations was modified for sake of consistency.

The whole study is published in a serie of EUR reports dated 1992, listed below :

VOLUME N°	MAIN AUTHORS	ORGANISATION	TITLE	EUR REPORT N°
1	R. Glibert	BELGATOM	Assessment of Management Alternatives for LWR Wastes : Main achievements of the joint study	14043 EN/Vol 1
2	E. de Saulieu C. Chary	SGN EDF	Assessment of Management Alternatives for LWR Wastes : Description of a French scenario for PWR waste	14043 EN/Vol 2
3	S. Santraille K. Janberg H. Geiser	FRAMATOME - GNS	Assessment of Management Alternatives for LWR Wastes : Description of German scenarios for PWR and BWR wastes	14043 EN/Vol 3
4	J. Crustin R. Glibert	BELGATOM	Assessment of Management Alternatives for LWR Wastes : Description of a Belgian scenario for PWR waste	14043 EN/Vol 4
5	B. Centner	BELGATOM	Assessment of Management Alternatives for LWR Wastes : Assessment of the radiological impact to the public resulting from discharges of radioactive effluents	14043 EN/Vol 5
6	G.M. Thiels S. Kowa	TASK R & S KAH	Assessment of Management Alternatives for LWR Wastes : Cost determination of the LWR waste management routes (Treatment/Conditioning/Packaging/ Transport Operations)	14043 EN/Vol 6
7	J. Malherbe	CEA	Assessment of Management Alternatives for LWR Wastes : Cost and radiological impact associated to near surface disposal of reactor waste (French concept)	14043 EN/Vol 7
8	N. Sanchez-Delgado	INITEC	Assessment of Management Alternatives for LWR Wastes : Cost and radiological impact associated to near surface disposal of reactor waste (Spanish concept)	14043 EN/Vol 8

2. *REFERENCE FRAMEWORK*

The following basic assumptions were defined :

- A 20 GWe nuclear park of Light Water Reactors was selected as reference scenario.
- Primary waste inventories related to each route were defined based to a large extent on national practices existing in the late eighties. The corresponding reference reactors have the respective capacities :
  - 0.9 GWe for route PWR1
  - 1.3 GWe for route PWR2
  - 0.9 GWe for route PWR3
  - 1.3 GWe for route BWR1
  - 0.975 GWe for route BWR2.

  Real values, including secondary wastes generated by the treatment systems and corresponding to the reactor design of each power unit were applied for the assessments.
- For the sake of harmonization a typical European inventory was established for evaluation of environmental impact associated with each national route.
- A management route is defined as each assembly of co-ordinated actions by which the management of LWR wastes from their production to their disposal is implemented. Usually, these actions comprise treatment, conditioning packaging, interim storage, transport and disposal operations as illustrated in Figure 3.1. for the PWR waste management route.
- The waste handling facility operation was envisaged for 30 years (mean life time period).
- The following waste treatment and conditioning processes were considered : demineralization, evaporation, centrifugation, flocculation, filtration, embedding, drying, supercompaction and incineration.
- Either mobile or fixed conditioning units were used.
- The packaged waste is placed in interim storage located on either the reactor site or on a centralized site (1 year duration).
- Near surface or deep disposal concepts were foreseen.

3. *METHODOLOGY*

The analysis of a waste management route mainly consists of:

- evaluating waste inventories, i.e. streams, volumes, activities, radionuclide compositions ;
- describing treatment systems and conditioning units ;
- defining the output characteristics: quantity, activity and radionuclide composition of effluents released, activity and volume of packaged wastes ;
- establishing the costs of equipment process materials and labour related to the treatment and conditioning units. This cost evaluation was performed for 3 routes of PWR. Some unit operations of the BWR routes were assessed within the sensitivity studies.

3.1. *COST ASSESSMENT PROCEDURE AND ECONOMIC ASSUMPTIONS*

In order to carry out the cost assessment of the various management options, a number of cost elements were defined (Figure 3.2.). These are generally utilised to determine the overall plant cost.

The 1988 capital cost is derived from the delivered material cost of the Major Equipment or "Base value" ; all other capital cost elements, except civil works, are expressed as a fraction of this Base value. The cost of the civil work is evaluated as a function of the volume of the buildings in which the waste effluents are treated and stored after conditioning.

For routes PWR1 and PWR3, the base values were calculated from the standard price values found in the chemical industry on the German market.

With the support of chemical block diagrams and engineered flow sheets, only available with enough details for PWR1 and PWR3 routes, the capital costs for these routes were established. Percentages are applied on the "base value" used to calculate the elements of the direct capital cost.

Economic assessment of the routes PWR2, BWR1, and BWR2 are partially based on costs directly provided by organisations and partially on estimation. This appraisal was performed without standardisation of the engineering data. However the cost elements displayed in Figure 3.2. and the general assumptions and criteria applied in PWR1 and PWR2 were taken into account.

3.2. *DEFINITION OF THE COST ELEMENTS OF THE PLANT*

Each management route is evaluated from the cost elements illustrated in Figure 3.2. and include capital and operating costs.

3.3. *GENERAL ASSUMPTIONS FOR PLANT COSTING*

The following main assumptions were made for the evaluation of all the routes :

- The owner's cost was omitted from the cost assessment since land purchase values and regulations concerning taxes licensing and insurance completely depend on the location proposed plant.
- Labour keeps to a normal weekly work schedule, i.e. 1 man-year = 8 $h.d^{-1}$ x 230 $d.a^{-1}$ = 1,840 h a^{-1}.
- Salary scales for operators : 17 ECU_{88} h^{-1} and higher labour categories = 35 ECU_{88} h^{-1}
- The LWR waste treatment and conditioning units are housed in a separate building on the reactor plant site ;
- The mobile conditioning units, where implemented in a route, are either rented or bought according to the practice of each country.
- The interim storage has a capacity for 1 year conditioned waste products.
- The utilities are calculated as being on 10% a^{-1} of the cost of the sum of [Process materials + maintenance materials+operators].
- The maintenance materials are estimated as 5% a^{-1} of the material cost of the sum of [Major Equipment + Bulk Materials].

3.4. *ASSUMPTION FOR COSTING OF INDIRECT CAPITAL COST*

The indirect capital cost (architectural and engineering services) is derived from the direct capital cost associated with <u>one</u> treatment conditioning facility (i.e. capacity 0.9 - 1.8 GWe using the following formula :

$a = 1.36 - (0.0687 \ln D)$ and $I = a.D$

where :

a = indirect capital cost factor ;
D = total direct cost for 1 module (ECU_{88}) ;
I = indirect capital cost (ECU_{88})

3.5. *ASSUMPTIONS FOR COSTING OF THE TRANSPORT*

The transport is organized either by road or rail. The capital cost for the transport reflects the acquisition of the casks at the start-up of the plant, whereas the annual operating cost consists of the freight cost, custom duties and insurance.

A transport journey, unless otherwise specified, is defined as the transport of the casks to the disposal site and their return to the waste treatment plant, each covering a distance of 500 km.

3.6. *ADJUSTMENT OF COSTS TO 20 GWe CAPACITY*

3.6.1. *Direct Capital Cost*

A 20 GWe nuclear park is assumed as reference scenario. With the exception of the interim storage, the plant capacity of the LWR waste management routes refers to power stations ranging between 0.9 and 1.8 GWe with the LWR waste treatment corresponding to one or maximum 2 reactors (i.e. 1 module). To arrive at a 20 GWe nuclear park, a linear approach was used for the scaling of the treatment/conditioning plant (on the basis of the costs for 1 module) and the transport.

In contrast, the costs related to the interim storage building were directly calculated for the amount of the conditioned wastes produced by a 20 GWe nuclear park.

3.6.2. *Indirect Capital Cost*

The indirect capital cost obtained for one treatment conditioning module (0.9 GWe - 1.3 - 1.8 GWe) is scaled to a reactor park size of 20 GWe using the following equation :

$$In = I\left[\frac{Rn}{Ro}\right]^{0.6}$$

I = indirect capital cost for one module (ECU_{88})
In = indirect capital cost for new plant capacity (= 20 GWe) (ECU_{88})

Rn = capacity of new facility (= 20 GWe)
Ro = capacity of reference facility (0.9, 1.3 or 1.8 GWe)

3.6.3. *Annual Operating Cost*

The elements of the operating cost were derived from the information provided for one module. These annual expenditures were these linearly adjusted to a nuclear reactor park size of 20 GWe.

3.7. ***ACTUALISATION OF COSTS***

A cost projection for all the management routes was also performed. The date of actualisation of the cost corresponds to the start-up of the plants.

3.7.1. *General Assumptions*

The following assumptions were made for the actualisation :

- The date of actualisation is the start-up of the plant, which corresponds to 01.01.92 for all the LWR waste management routes.
- The plant construction requires 4 years starting from 01.01.88 for all the LWR waste management route. A bar chart, showing the different steps in the plant construction and the corresponding investments, is given in figure 3.3.
- Annual rate of interest (ECU) = 8.3% a^{-1}
- Annual rate of inflation (ECU) = 2.2% a^{-1}.
- Duration of plant of operation = 30 a.

3.7.2. *Actualisation Method*

Many methods have been developed to actualize the capital and annual operating costs. The "Present Worth" method was selected by TASK R & S - KAH (see vol. 6 of the joint study).

The following expressions are applied to the main cost elements.

Direct capital cost

$$Cj = Pj. (1+e)^{x}. (1+i)^{n-x}$$

where

Cj = actualized total cost of jth element (ECU)
Pj = nominal total cost of the the cost element with reference to the year 1988 (ECU_{88})
x = time duration between the start of plant construction and the middle of the activity of the jth cost element
e = annual rate of inflation (2.2% a^{-1})
i = annual rate of interest (8.3% a^{-1})
n = total duration of plant construction (4 y)

Example for major equipment and bulk materials

x = 2.25 (see bar chart)
$n-x$ = 1.75
$Cj = Pj\ (1.022)^{2.25}\ (1.083)^{1.75}$

$$\boxed{Cj = Pj \times 1.207}$$

Indirect capital cost

The indirect capital cost, which represents the architectural and engineering services, is actualized as follows :

$$Ia = In.(1+e)^{x}.(1+i)^{n-x}$$

where :

Ia = actualized indirect capital cost (ECU)
In = indirect capital cost of the plant (ECU_{88})
e = 2.2% a^{-1} // i = 8.3%a^{-1}
n = 4 years.

Annual operating cost

The cost elements of the annual operating cost are actualized using the expression :

$Cj = Pj(1+e)^n$
$e = 2.2\%\ a^{-1}$
$n = 4$ years

$$\boxed{Cj = 1.090\ Pj}$$

3.7.3. *Conversion of annual operating cost into total operating cost*

$$O = O_a \left[\frac{1+e}{i-e} \right] \left[1 - \left[\frac{1+e}{1+i} \right]^L \right]$$

for $i \neq e$ and $L > 0$

where :

O = actualized total operating cost (ECU)
Oa = actualized annual operating cost (ECU a^{-1})
L = duration of plant operation (30 a)

$$\boxed{O = Oa \times 13.81}$$

3.8. *SCALING OF COSTS*

It has been shown that the "sixth-tenth" rule satisfactorily describes the correlation between cost and plant capacity :

$$Cn = Co \left[\frac{Rn}{Ro} \right]^m$$

where :

Cn = cost of new facility (ECU88)
Co = cost of reference facility (ECU88)
Rn = capacity of new facility (GWe)
Ro = capacity of reference facility (GWe).
m = scaling factor.

Experience in the chemical industry has demonstrated that a value of 0.6 for m generally results in a good correlation between cost and plant capacity, presuming an identical process.

However, some problems were encountered in the application of this procedure to the LWR waste management routes. It assumes that the reference data correspond to a plant capacity of 20 GWe. However, in the case of the LWR waste management routes the basic data, with the exception of those for the interim storage, refer to a plant capacity ranging between 0.9 and 1.8 GWe. From these data the results for a 20 GWe capacity plant were derived using a modular approach. This was selected, because it was agreed that the LWR waste treatment would be performed on each reactor site, consisting of 1 or maximum 2 reactors (i.e. 1 module) and that the number of modules would be adjusted to arrive at a 20 GWe capacity. The interim storage building, however, was immediately calculated for the amount of conditioned wastes produced by a 20 GWe nuclear park.

In view of the above, the application of the scaling methodology to the derived costs for a 20 GWe plant capacity might lead to an overestimation for smaller plant capacities and an underestimation for larger plant capacities.

To stay in line with the overall philosophy adopted for the LWR waste management routes, a linear approach was used for the scaling of the capital and operating costs for the treatment/conditioning plant (on the basis of the costs for 1 module) and the transport. For the interim storage, the following equations were employed to obtain the data for the new plant capacity

- Base value for the interim storage :

  Application of the equation given above, using a value of 0.6 for m.

- Interim storage building volume :

$$Vn = \left[Vs . \frac{Rn}{Ro} \right] + Vw . \left[\frac{Rn}{Ro} \right]^{m}$$

with $m = 0.2$ for $Rn > 20$ GWe
$m = 0.05$ for $Rn < 20$ GWe
$m = 0$ for $Rn = 20$ GWe

where :

Vn = total volume of the interim storage of new facility (m^3);
Vs = volume of storage area of the interim storage for reference facility (m^3).
Vw = volume of work area of the interim storage for reference facility (m^3)

Finally, the indirect capital cost was re-calculated using the equations detailed in Par. 3.4 and 3.6.2.

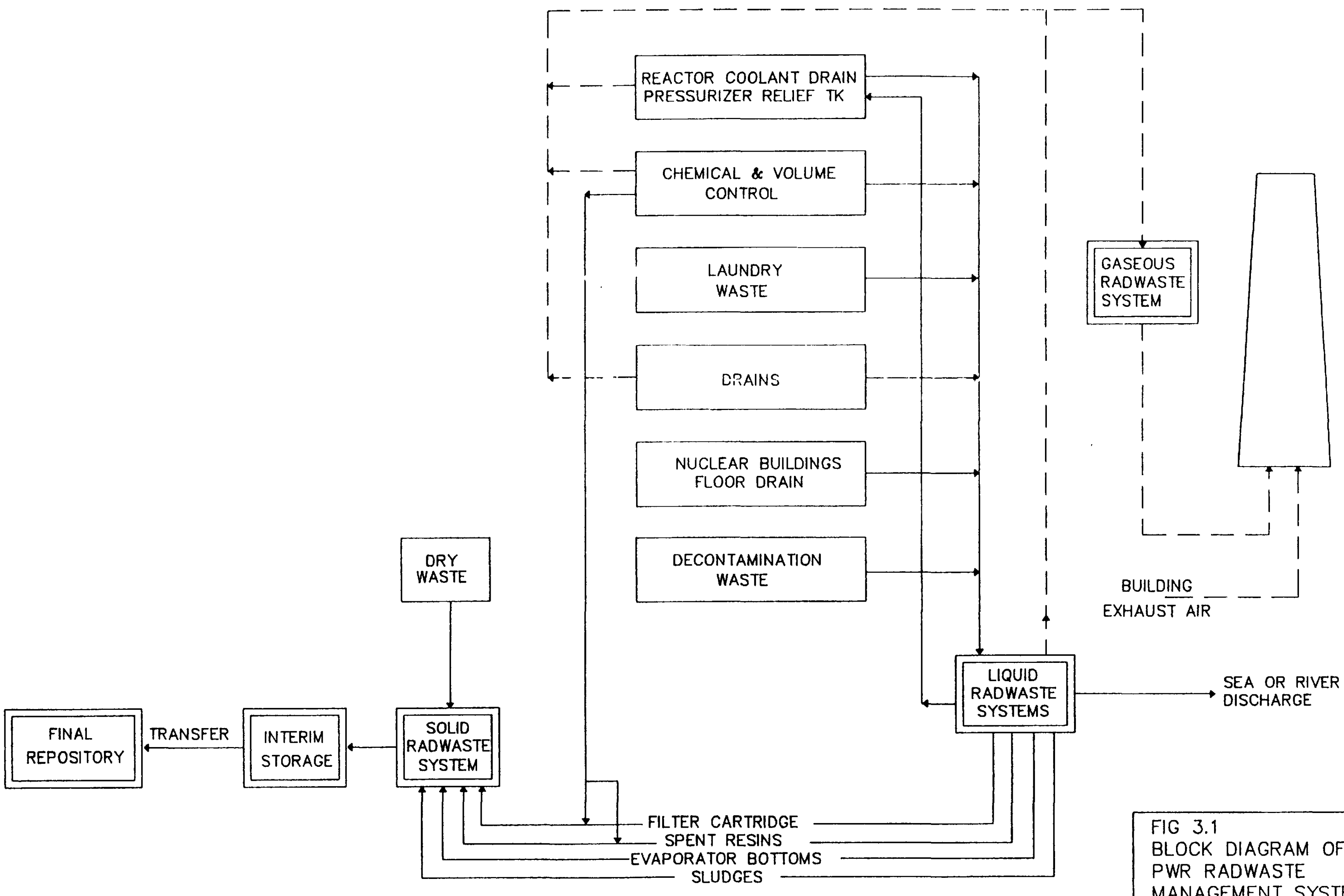


FIG 3.1
BLOCK DIAGRAM OF A
PWR RADWASTE
MANAGEMENT SYSTEM.

FIGURES\TEU4

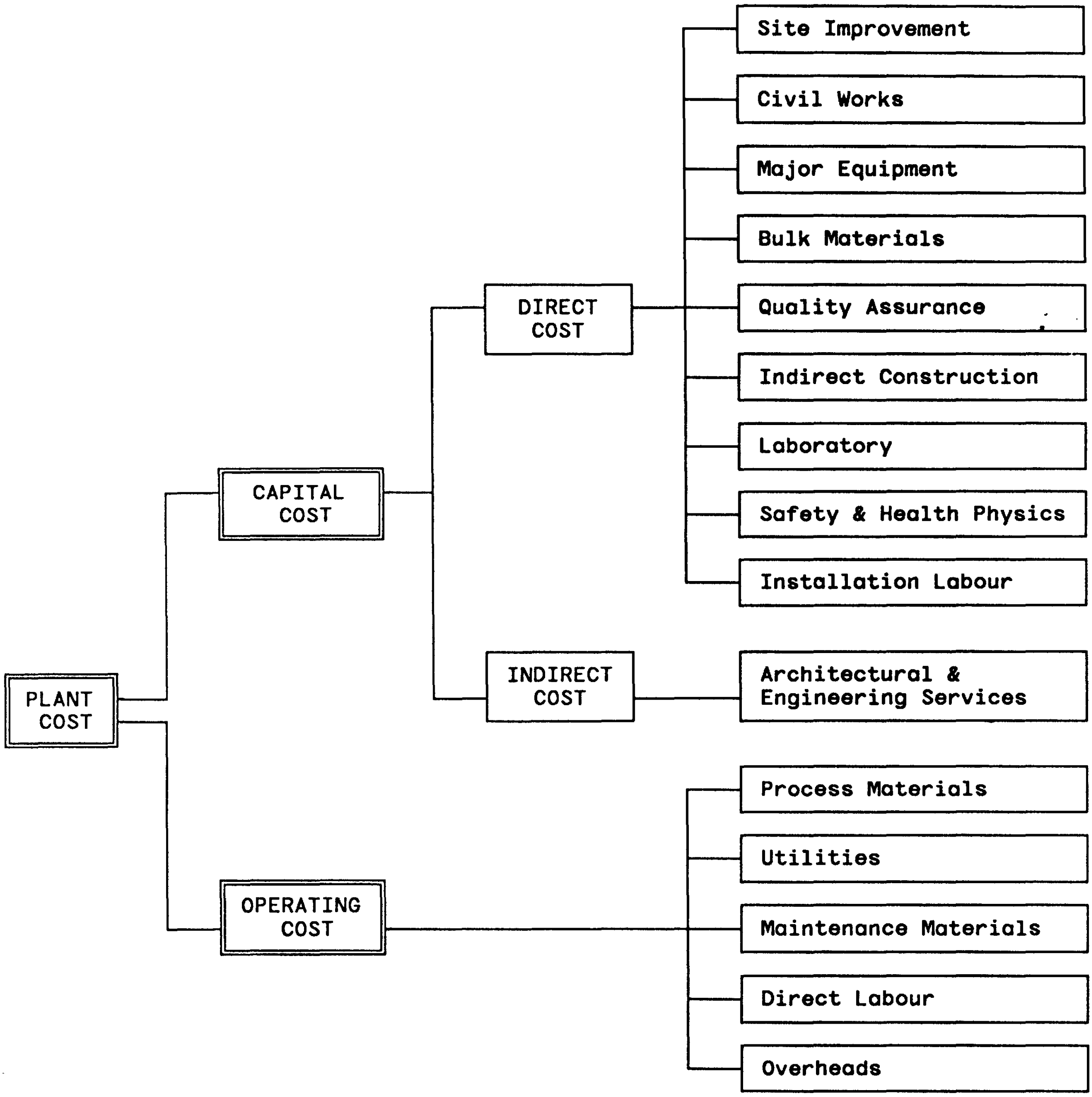
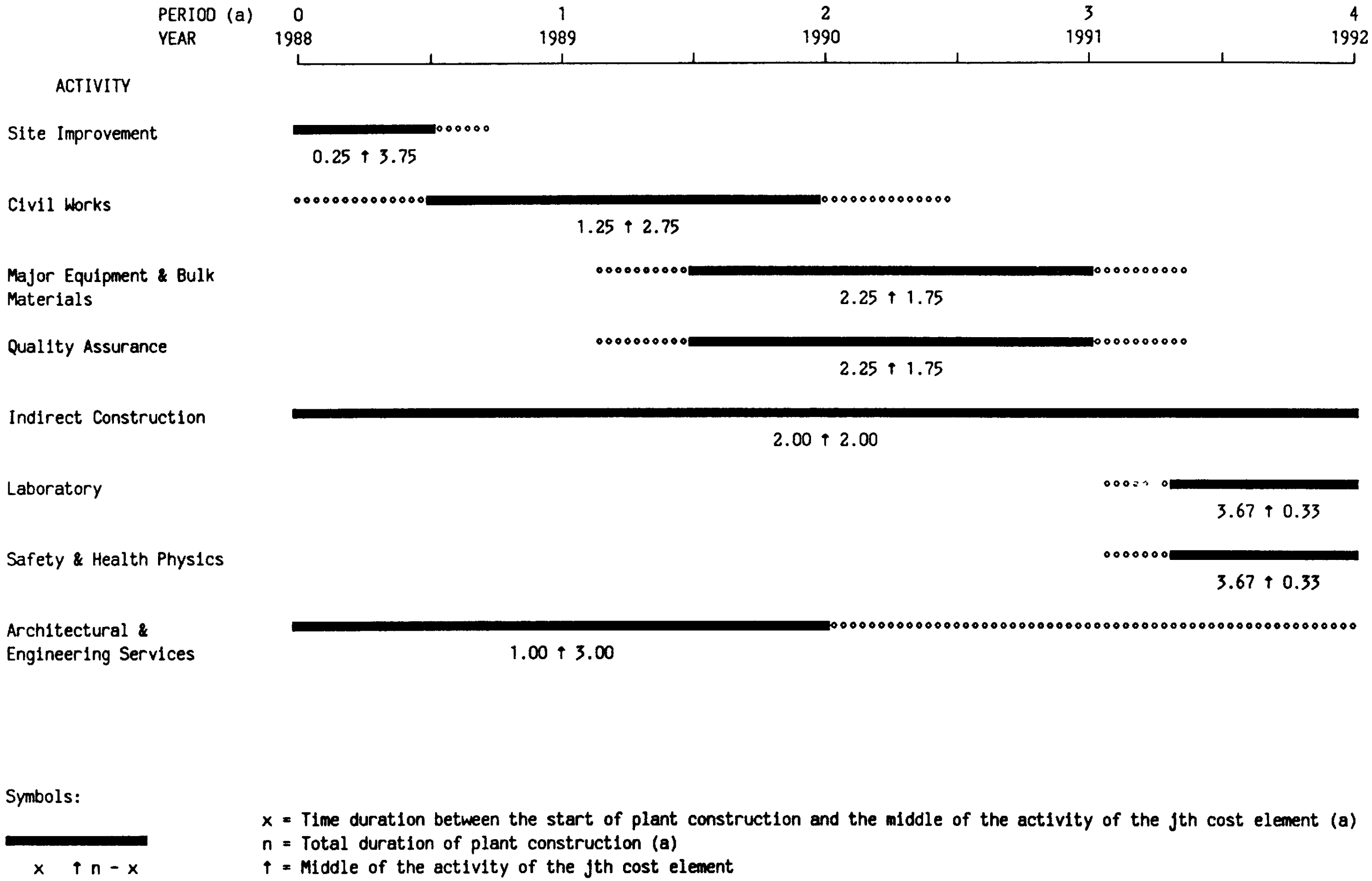


FIGURE 3.2. Elements considered for the evaluation of the plant cost.



x = Time duration between the start of plant construction and the middle of the activity of the jth cost element (a)
n = Total duration of plant construction (a)
↑ = Middle of the activity of the jth cost element

Figure 3.3. Bar chart applicable to routes PWR1, PWR2 and PWR3

4. *GENERAL RADWASTE MANAGEMENT SCHEMES DESCRIPTION*

Normal reactor operation generates gaseous and liquid effluents as well as primary solid wastes. The main categories and the way they are managed and treated are schematically represented in figure 3.1. These are generally managed as follows :

- Gaseous and liquid effluents are fed to treatment systems in which they are purified, controlled before release into the environment or recycled ; such processes produce secondary solid wastes ;
- Primary and secondary solid wastes are collected and sent to conditioning units for subsequent packaging ;
- Packaged wastes are conveyed from the interim storage site to the disposal site.

4.1. *PRESSURIZED WATER REACTOR*

4.1.1. *Gaseous Effluent Treatment*

Two types of gaseous effluent are considered :

- Aerated effluents from the effluent treatment building which are directly sent to the ventilation treatment system ;
- Hydrogenated effluents from tanks and degassers which are purified in a gaseous treatment system.

4.1.1.1. *Ventilation*

The ventilation system ensures the control of activity releases in the event of a radioactive leak in the building. This control is performed by absolute filters for aerosols and charcoal filters, impregnated with silver sorbent for iodine (only in the case of route PWR2). Treated effluents are then monitored before release through the stack.

4.1.1.2. *Gaseous Treatment*

The gaseous treatment system aims at the decay of short-lived radionuclides (Xe, Kr, I, etc..) mainly present in the hydrogenated effluents and allows the removal of the hydrogen from the gaseous waste treatment circuits. This hydrogen control is only ensured in routes PWR2 and PWR3.

The decay of the short-lived radionuclides takes place in decay tanks (routes PWR1 and PWR3) or on active charcoal delay beds (route PWR2). In the first case, the gaseous effluent is compressed and stored in gas decay tanks. After the decay period, it is vented to the stack. In the second case, the gaseous effluent is dried (the moisture content of the active charcoal affects the noble gas adsorption) using a cooler-condenser together with a dessicant dryer. It is then passed through an active charcoal bed, where the noble gas molecules are selectively delayed.

4.1.2. *Liquid Effluent Treatment*

The liquid effluents fall in two separate categories :

- ▸ Hydrogenated, recoverable effluent from the primary coolant system. Normal and accidental leaks of primary water are collected with discharge of the excess water produced during temperature rise and boron content modification of the primary coolant system. These effluents are sent to the boron recycling system.
- ▸ Aerated non-recoverable effluents comprising secondary and floor drains, chemical and laundry effluents. These effluents are sent to the liquid waste treatment system.

The purification processes used for both types of liquid effluent generate secondary solid wastes.

4.1.2.1. *Boron Recycling*

For the treatment of recoverable effluents, the following sequence of processes is implemented as shown on figure 4.1. :

- filtration (solids),
- demineralization of dissolved ions,
- gas stripping for H_2 and fission products,
- separation by evaporation of water/boric acid solutions for future re-use.

A small part of the effluent stream is sent to the liquid discharge system so as to decrease the primary tritium content.

4.1.2.2. *Liquid Waste Treatment*

Non-recoverable effluents are treated to reduce their activity before discharge. They are stored according to their origin or characteristics ; their purification is carried out by means of a relevant process, such as evaporation, filtration, centrifugation, demineralization or flocculation.

The various steps of a typical treatment are shown on the block diagram given in Figure. 4.2.

4.1.2.3. *Liquid Discharge*

This system provides storage capacity and monitors the activity of purified liquid effluent before discharge into the environment. Discharges are performed through a dilution device, when external conditions are favourable.

4.1.3. *Solid Waste Treatment*

Two groups of solid wastes can be distinguished:

- ▸ Wet wastes from the water purification processes. This type of waste mainly consists of concentrates, sludges, ion exchange resins and filters,

- ▸ Dry wastes generated during routine operation of the reactor.

Tools, papers, vinyl bags and contaminated clothes are collected and sorted (combustible, non-combustible, compactable, non-compactable). As opposed to wet wastes, dry solid wastes are characterized by a low activity level.

Wet and dry solid wastes are treated and packaged into fixed or mobile conditioning units. Packages are stored in an appropriate interim storage building and then transported to the final disposal site.

4.1.3.1. *Wet Solid Wastes*

Apart from the conditioning operations, each route comprises storage capacity for wet wastes.

- *ROUTE PWR1*

  Spent ion exchange resins are embedded together with a polystyrene matrix in concrete casks. This operation is performed in the mobile facility, which can handle the waste output from the 20 GWe nuclear park.
  Concentrates, sludges and filters are cemented in concrete casks utilising fixed conditioning facilities.

- *ROUTE PWR2*

Direct disposal of wet wastes in casks is practised in this route. The objective is to completely dry the wastes to obtain the formation of a solid block inside special cast iron packages called MOSAIK. Five mobile facilities are required per 20 GWe (2 FAFNIR units for resins and filters, 3 FAVORIT units for concentrates and sludges).

- *ROUTE PWR3*

Wet wastes are conditioned in fixed cementation facilities.

4.1.3.2. Dry Solid Wastes (Mixed Solid Wastes)

- *ROUTE PWR1*

Mixed wastes are first sorted in compactable and non-compactable batches. The compactable wastes are precompacted (volume reduction factor = 3) and put into metallic drums. They are further supercompacted (VR=3) at disposal site. The non-compactable wastes are directly placed in metallic drums.

- *ROUTE PWR2*

Mixed wastes are first sorted in compactable and non-compactable batches. The compactable wastes are then precompacted in a fixed facility (VR=3) and then supercompacted (VR=3) by means of the FAKIR mobile unit. Two such conditioning units are required per 20 GWe. Non-compactable combustible wastes are incinerated in a fixed centralized facility.
Both processed and unprocessed wastes are first put into metallic drums and then into parallelepipedic containers. Shielding depends on the activity level.

- *ROUTE PWR3*

Mixed wastes are conveyed to a central conditioning site, where they are sorted into combustible and non-combustible types. Combustible wastes are incinerated and the resulting ashes are immobilised into cement and put into metallic drums. The remaining compactable wastes are first precompacted (mean volume reduction factor = 3 and then supercompacted (VR=3). The processed wastes are covered with concrete in metallic drums.

4.2. *BOILING WATER REACTOR*

The general description of Radwaste Management of a BWR is given in Figure 4.3

4.2.1. Gaseous Effluent Treatment

Two types of gaseous effluents are considered :

- Aerated effluents from the effluent treatment building which are directly sent to the ventilation system,
- A gas mixture containing fission gases air inleakage, which is extracted from the main condenser (off-gas)

  Remark : Gas leakages originating from gland of valves of the primary steam system and sweping gases of all tanks of the liquid and solid radwaste systems whose liquid content can produce a high gaseous nuclides concentration are collected together and treated in the case of the BWR1 route.

4.2.1.1. Building Ventilation

The building ventilation ensures the control of activity releases in the event of a radioactive leak in the building. This control is performed by absolute filters for aerosols and, only for BWR1, iodine filter in case of escape of iodine in the building. Treated effluents are then monitored before release through the stack.

4.2.1.2. Off-gas Treatment

The off-gas treatment system aims at the decay of trace quantities of fission and activation gases (Xe, Kr, N_2, O_2,..) and allows the recombination of free hydrogen and oxygen which originate from the radiolytical decomposition of the water coolant.

The off-gas mixture composed of fission and activation gases, non-condensable gases from the main condenser (air leaks), H_2 and O_2, water vapour from the steamjet air ejectors are introduced into a catalytic recombiner where radiolytically produced H and O are recombined. The gases then pass to the system condensor and the water evaporator. From there, uncondensable gases are delivered to the delay line where the decay of a part of the radioactive products occurs.

After passage through the delay line, the gases are cooled and filtered in a high-efficiency particulate air filter. Gases are next put through a drier to reduce the dew point of the mixture, and, after a further cooling, they are directed through activated carbon beds which selectively and dynamically adsorb and delay the radioactive products of the carrier gas.

Upon leaving the activated carbon beds, and after passage through another high-efficiency particulate air filter, the gases are exhausted into the atmosphere.

- Leak off systems (tank + gland)

The air volumes of the tanks containing gaseous nuclides are interconnected in series and in the order of increasing radioactivity.
A continuous small purge air stream flows through the tanks from low activity to high activity and is then routed to the off-gas system.
The tank leak-off system contains a charcoal delay line which operates, in case of liquid volume modification by treating the equivalent amount of air.

The leakages which are picked up in the stuffing boxes and in the shaft sealing arrangements are carried away in pipes. Leakages consist of steam with small quantities of inert gas, H_2, O_2 and N_2 and radioactive gas such as iodine, xenon and krypton. The gland leak-off system provides condensation and delay for this gaseous effluent.

4.2.2. *Liquid Effluent Treatment*

Liquid effluent is distributed among the following three categories :

- Low conductivity effluent : water leakage from the primary system and the connected systems having a very low content of ional and solid impurities.

- High conductivity effluent : floor drain water, laboratory and decontamination drains having a very low content of ional and solid impurities.

- Detergent effluent : laundry and showers effluents which are slightly radioactive but contain light levels of solid and ional impurities.

Remark : Reactor water which is treated in the clean-up system has not been considered as a liquid effluent.

4.2.2.1. *Low Conductivity System*

The low conductivity effluent undergoes the following treatments:

- Filtration through a pre-coat filter to remove undissolved impurities ;

- Demineralization of dissolved ions.

The treated water is collected in a clean water storage tank. If the water has a sufficient low conductivity level it can be re-used in the reactor coolant system.

4.2.2.2. *High Conductivity System*

Effluent water which conductivity and solids contents are relatively high is chemically neutralized if required and concentrated in an evaporator. The distillate is demineralized depending on the quality in contaminants and can be re-used in the reactor coolant system.

4.2.2.3. *Detergent System*

The detergent effluents are treated in an evaporator and discharged as steam (BWR2).
As it regards the BWR1 route, the detergent effluents are passed through a pre-coat filter to remove undissolved impurities and then discharged with cooling water.

4.2.3. *Solid Waste Treatment*

Two groups of solid wastes are generated during waste management operations:

- Wet wastes (concentrates, sludges, ion exchange resins and filters),
- Dry wastes generated during routine operation of the reactor (tools, papers, vinly bags and contaminated clothes).

4.2.3.1. *Wet Solid Wastes*

- *ROUTE BWR1*

  Direct disposal of wet wastes in casks is practised in this route. The objective is to completely dry the wastes to obtain the formation of a solid block inside special cast iron packages called MOSAIK. Mobile facilities are used : FAFNIR units for resins and filters, FAVORIT units for concentrates and sludges.

- *ROUTE BWR2*

  Wet wastes are conditioned in fixed cementation facilities.

4.2.3.2. *Dry Solid Wastes (Mixed Solid Wastes)*

- *ROUTE BWR1*

  Mixed wastes are first sorted in compactable and non-compactable batches. The compactable wastes are then precompacted in a fixed facility (VR=3) and then supercompacted (VR=3) by means of the FAKIR mobile unit.

Non-compactable combustible wastes are incinerated in a fixed centralized facility. The non-compactable and non-combustible wastes are put into metallic drums.

The same metallic drums are used as package for the processed mixed solid wastes (compacted and incinerated wastes). The packagings are then introduced into parallelepipedic containers.

- *ROUTE BWR2*

  The compactable wastes such as rags, air filters, papers or small tools are compressed in a drum which is closed for transfer to the solid waste interim storage. Non-compactable waste is packaged manually in suitable containers.

4.3. *PACKAGES TRANSPORT*

- *ROUTE PWR1*

  Packages are assumed to be conveyed by truck to the final disposal site. The French Centre de l'Aube concept was considered for near surface disposal.

- *ROUTES PWR2 and BWR1*

  Packages are transported by train to the disposal site (Konrad iron mine).

- *ROUTES PWR3 and BWR2*

  Transport by truck to a disposal site based on the Spanish near surface disposal site concept was chosen.

4.4. *DISPOSAL SYSTEM DESCRIPTION*

Each management route is closed with the disposal of the conditioned packages. Two main reference systems have been retained :

- near surface disposal system for the routes PWR1 and PWR3 ;
- the deep repository system for routes PWR2 and BWR1.

4.4.1. Near Surface Disposal

Two systems of near surface disposal for low level wastes have been considered. The first system is operating in France collecting the low level wastes from reactor and fuel reprocessing plants (The Aube Centre).
The second one is a Spanish concept reported by INITEC similar to the French system.

4.4.1.1. *Design Criteria*

Two main performance objectives are aimed at for a LLW disposal facility namely :

- To ensure the immediate protection of people and environment. Immediate means during facility operating period.

- To ensure the deferred protection of people and environment. Deferred protection concerns the institutional control period which extends from the closure of the facility to the moment the site is free of access.
  The institutional control period must not exceed 300 years. To ensure these objectives, the following design criteria are applied :

- Limitation of the initial activity of radionuclides which are present in the wastes packages.

- Use of a multibarrier system which prevents the adverse agents mainly man and water to reach the radionuclides. These barriers are three in number :

  - the waste form including the physical form of the waste itself, the matrix, the package and the possible overpack
  - the engineered structures
  - the disposal sites's natural characteristics in case of an accident.

  All these provisions prevent water to reach the waste in normal situation and limit the quantity of radioactive substances carried away by water in case of accidental infiltration.

4.4.1.2. *Aube Centre Description*

The waste packages are disposed off either in tumulus or in cell depending of their intrinsic safety. Waste packages offering by themselves an intrinsic safety are stocked on a pad in a module. This module consists of ordinary concrete walls placed on a slab and marking out the enclosure inside which the packages are stacked .The space between the packages is filled with gravel allowing a good stability while giving a free way to water, should water infiltrate the tumulus. Generally, the packages are low medium level activity waste immobilized in concrete containers or very low level activity waste package stabilized in metallic containers.

The waste packages which do not offer by themselves a sufficent intrinsic safety with regard to the safety requirements are disposed of in cell.

The cell is a disposal structure consisting of concrete bottom and walls forming an alveole. The difference with module lies in the construction of the alveole floor and walls which trough the quality of these provide leaktighness and radiation protection not given by the package.

The space between the packages is filled with concrete.
Generally the wastes immobilized in a perishable container or non immobilized waste are placed into cell or alveole. A side section view of a disposal module is given in Figure 4.4.
A leachate collection gallery is built below the disposal module and collects any water that may have infiltrated the module.

This water goes to a monitoring tank in an underground gallery. The modules are built in rows. When in operation the module is covered with a movable Buttler-type shelter which incorporates handling equipment. The following main operations are conducted in sequential order :

- Unloading and disposal of packages.
  The truck carrying the packages is brought inside the mobile shelter. The packages are unloaded and their location in the module is recorded in the computerized radwaste tracking system of the site.

- Backfilling of the modules.
  The space between packages is filled with gravel (tumulus system) or concrete (alveole system).

- Placement of the disposal module roof and cover.
  Concrete slabs are put in place on top of the packages and the entire closed disposal module is covered with a waterproof synthetic material. This cover will be left in place when the final earthen cap is placed over the disposal unit.

Besides all the means to receive and to dispose off all the packages the site is equipped with the following facilities :

- Inspection system of the packages and decontamination room ;
- Overpacking system for some packages which are not in conformity with the specifications ;
- Temporary storage (buffer) of the packages ;
- Service and buildings (laboratories, health and radiation protection,... ;
- Administrative buildings.

4.4.1.3. *Spanish Concept Description*

The packages are directed to two kinds of disposal structure :

- Below-ground vault made in reinforced concrete with parallelipipidic form formed by a lower slab and peripheral walls.

- Special below-ground vault, identical to single vault but with thicker shielding walls than standard below-ground vault.
  Low activity package wastes (surface dose rate < 200 mr/h) are disposed of in standard vaults.
  High activity waste packages (average surface dose rate +/- 3 R/h) are stored in special vaults.
  The drums (200 or 400 l metallic drum) are placed into the vaults in successive layers by means of a gantry crane located in a movable roof (see Figure 4.5.). One completed a layer of drums, the free spaces between then will be filled with concrete in two phases. In the first phase, the drums are immobilized with a half-height layer of concrete. The surface obtained by a second pouring of concrete is used as a base for the next drum layer. Once the vault is filled, it is covered by a concrete slab and an impermeable protectived membrane is placed. Soil is added above to allow the development of vegetation and fix the slopes.
  All the vaults are provided with an infiltration water collection system designed to control any defects in the disposal structure.

The site included the following facilities :

- Conditioning building which performs the functions of reception and unloading of trucks transporting the packages, identification and control, temporary storage, compacting the 200 l drums containing the compactable waste, immobilization for the compacted wastes, etc.

- General Services building which accomodates the radiological laboratory and radiation protection services, the medical service, the laundry.

- Technical Services building which provide the utilities for all the buildings of the site.

- Administrative buildings.

4.4.2. *Deep Repository System*

The disposal of the low level radioactive packages arising from route PWR2 is considered to be performed in a deep repository system.

This respository is a former iron mine (Konrad - Germany) which is suitable for radioactive waste disposal. A conceptual outline of the underground areas of the repository is shown in figure 4.6. Two pit head gear buildings are located above two shafts. Packages are introduced via shaft 2 and the conventional personnel/material movements are carried out through shaft 1.

Storage chambers will be escavated at predeterminated levels from a main access tunnel. Transport wagon will take packages to the designated storage chamber and will be positioned in their final storage location by a storage vehicle. The full chambers will be sealed by an approx. 25 m long closure constructed in the chamber access tunnel.

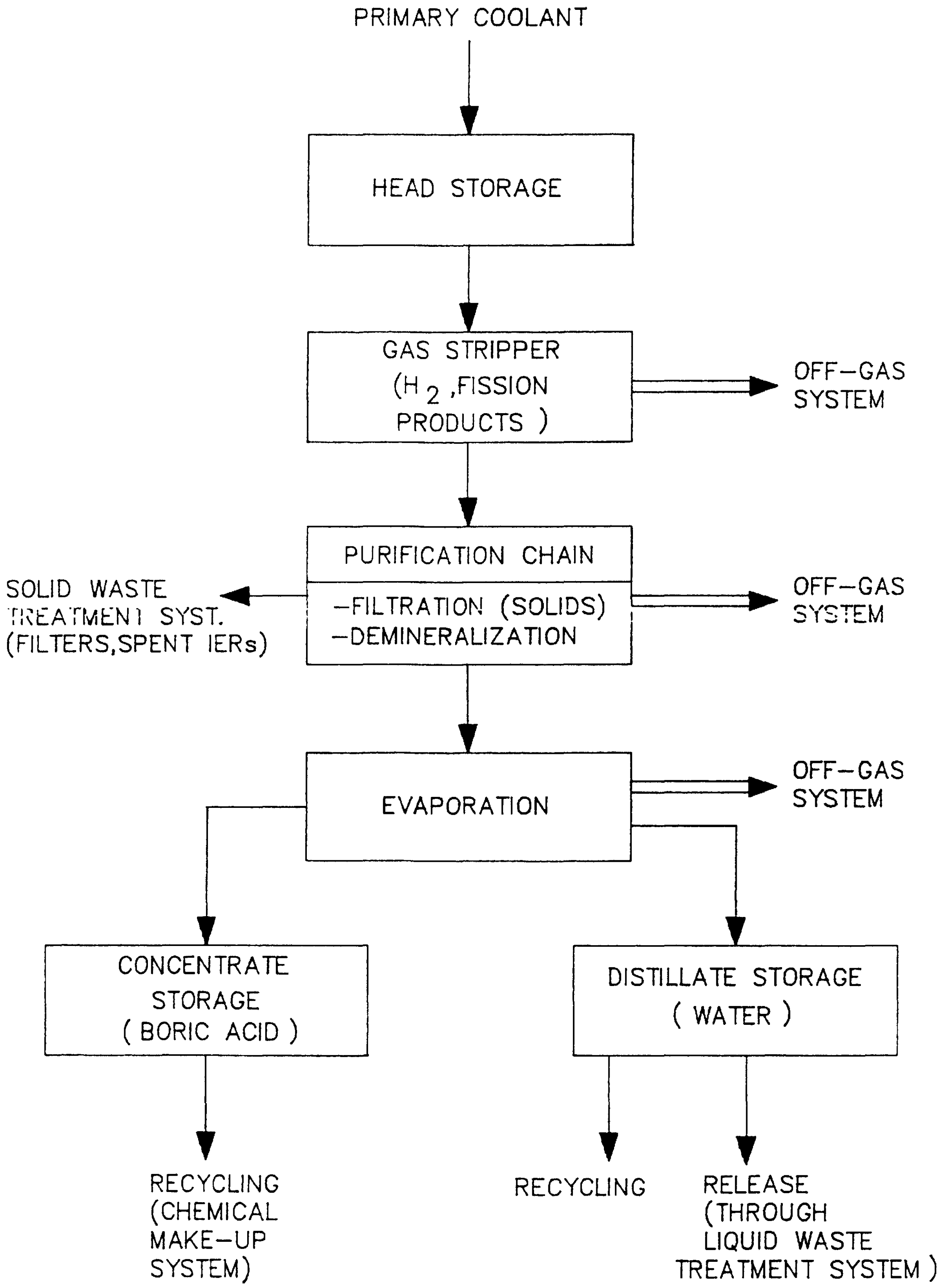
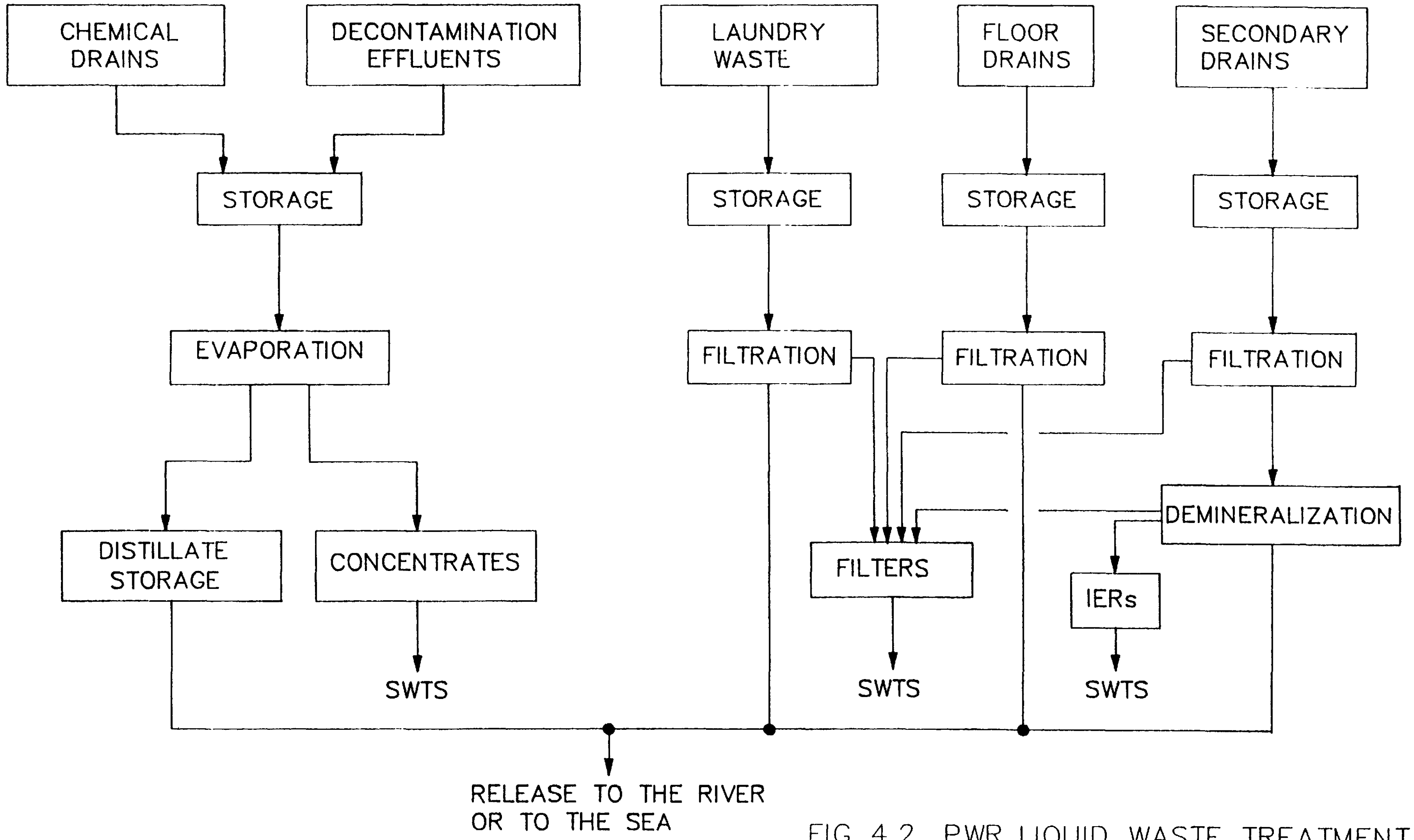


FIG 4.1 PWR PRIMARY COOLANT TREATMENT BLOCK DIAGRAM



SWTS(SOLID WASTE TREATMENT SYSTEM)

FIG 4.2 PWR LIQUID WASTE TREATMENT BLOCK DIAGRAM

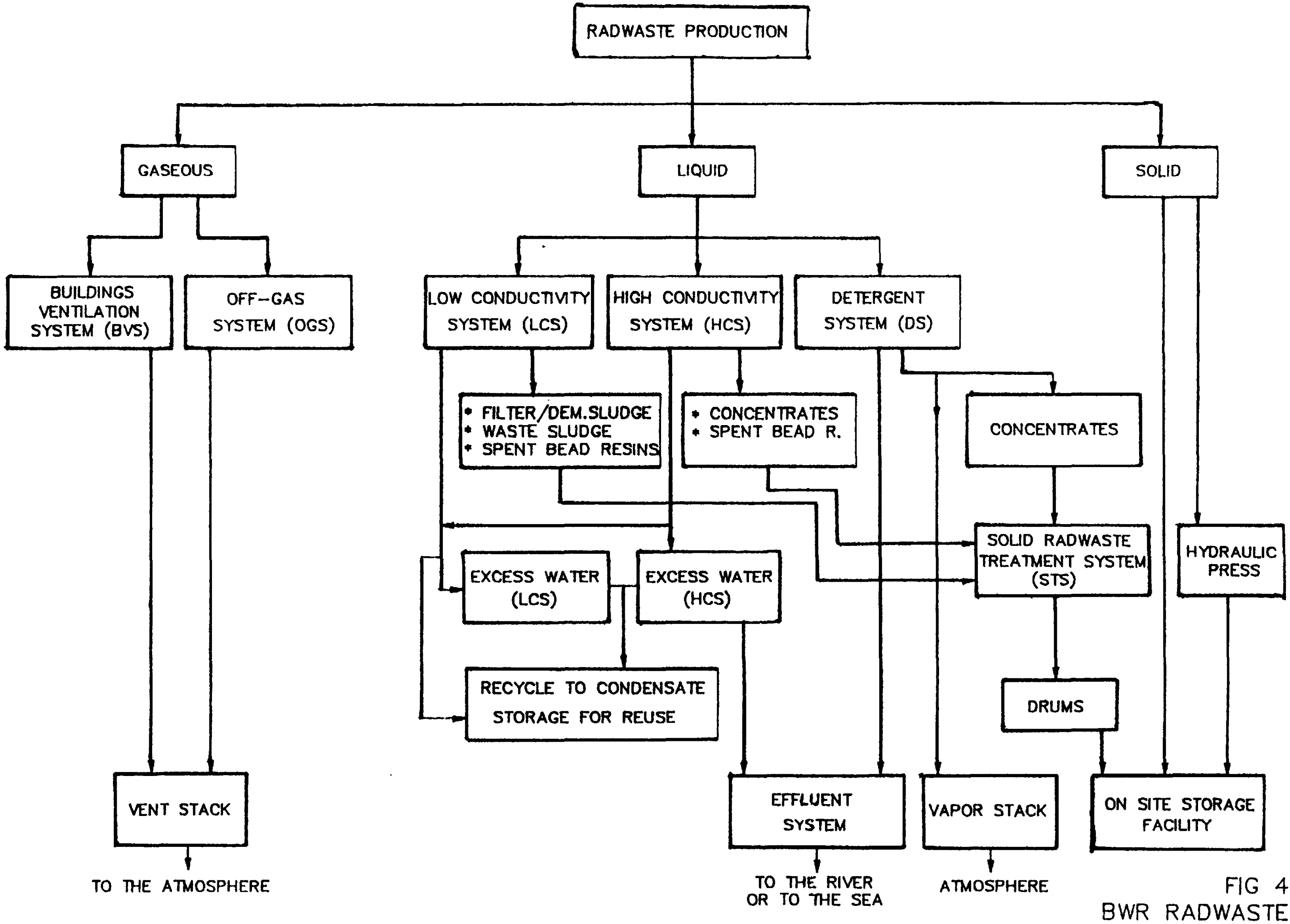


FIG 4.3
BWR RADWASTE MANAGEMENT
BLOCK DIAGRAM

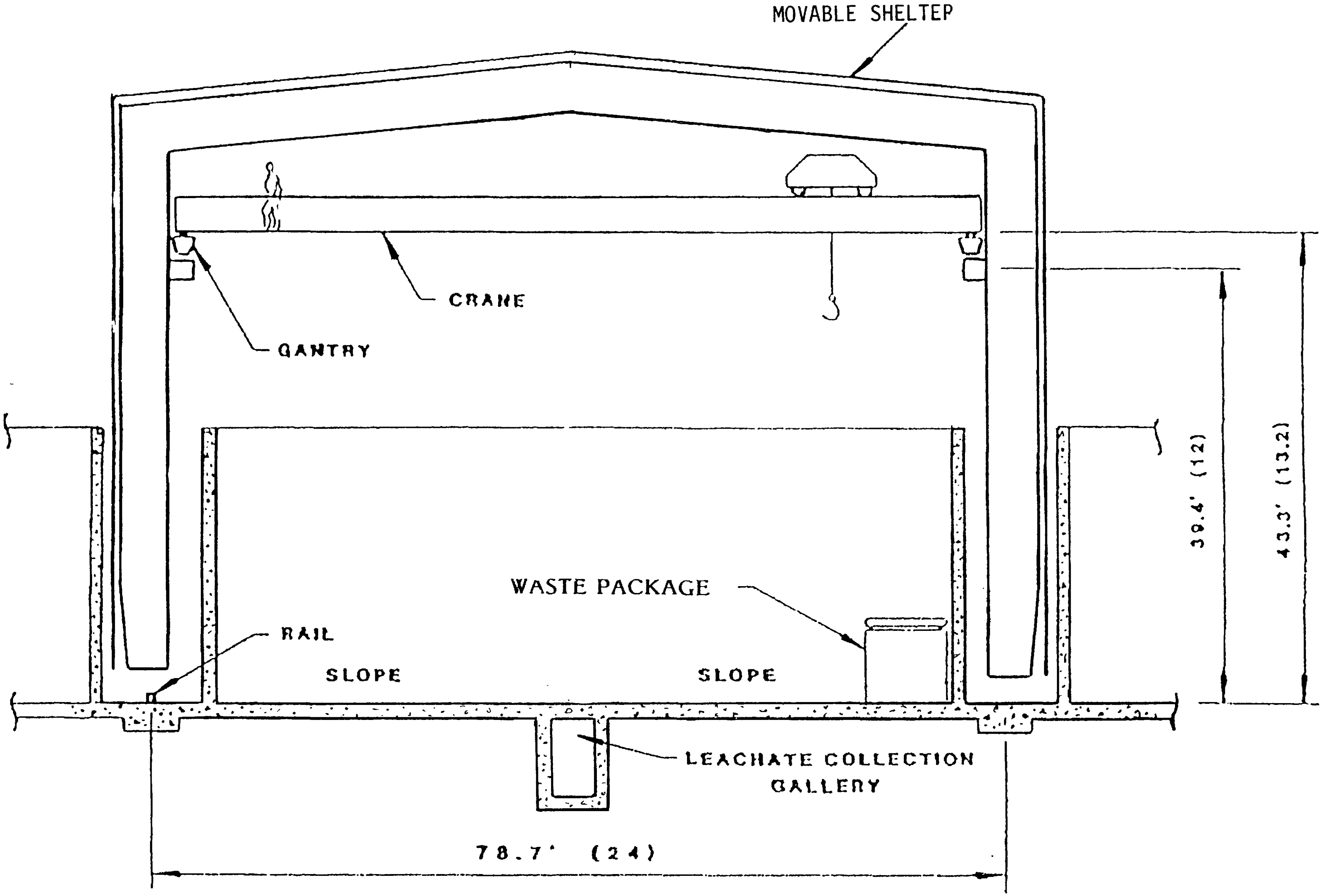


FIGURE 4.4 : DISPOSAL MODULE SIDE SECTION VIEW (near surface disposal)

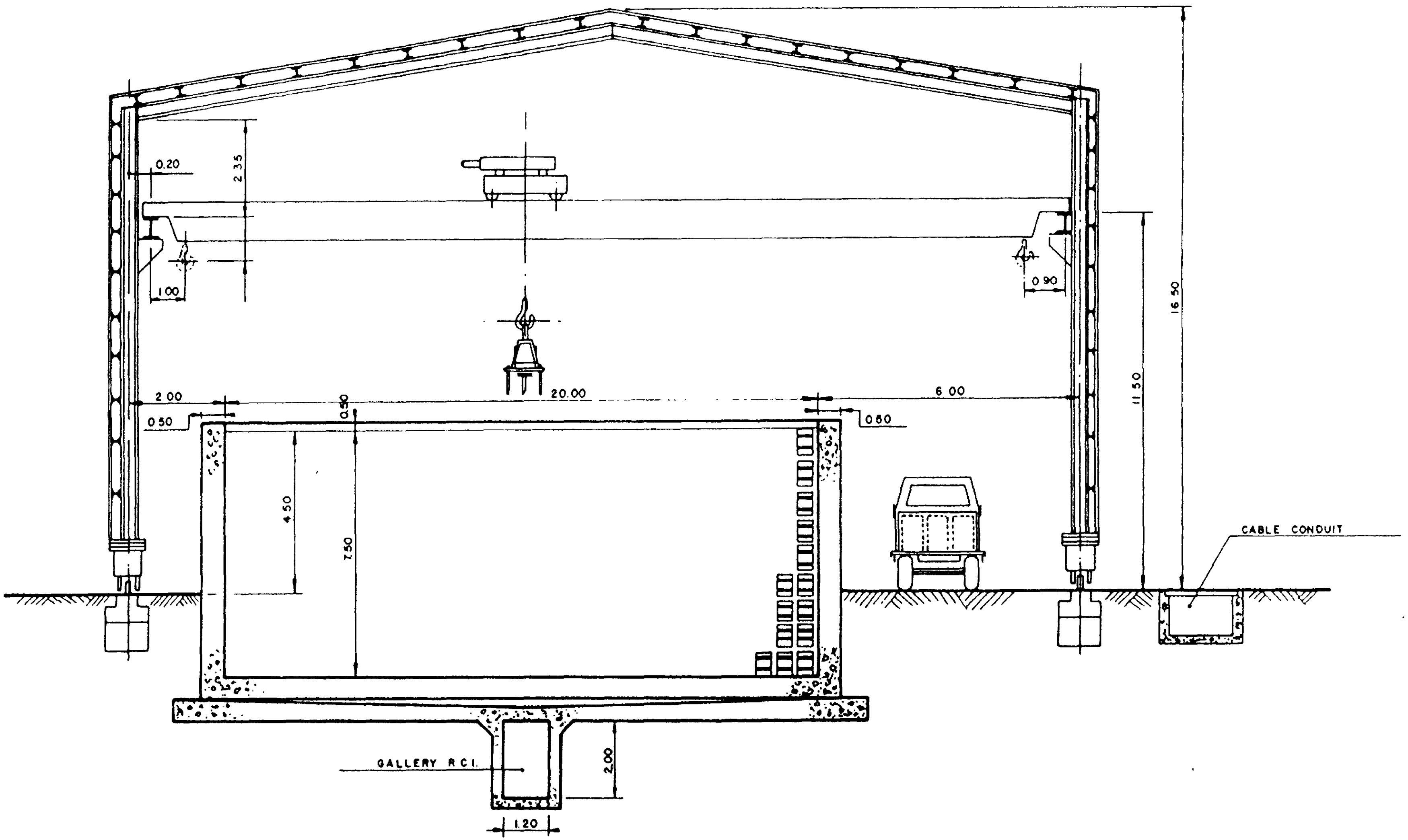
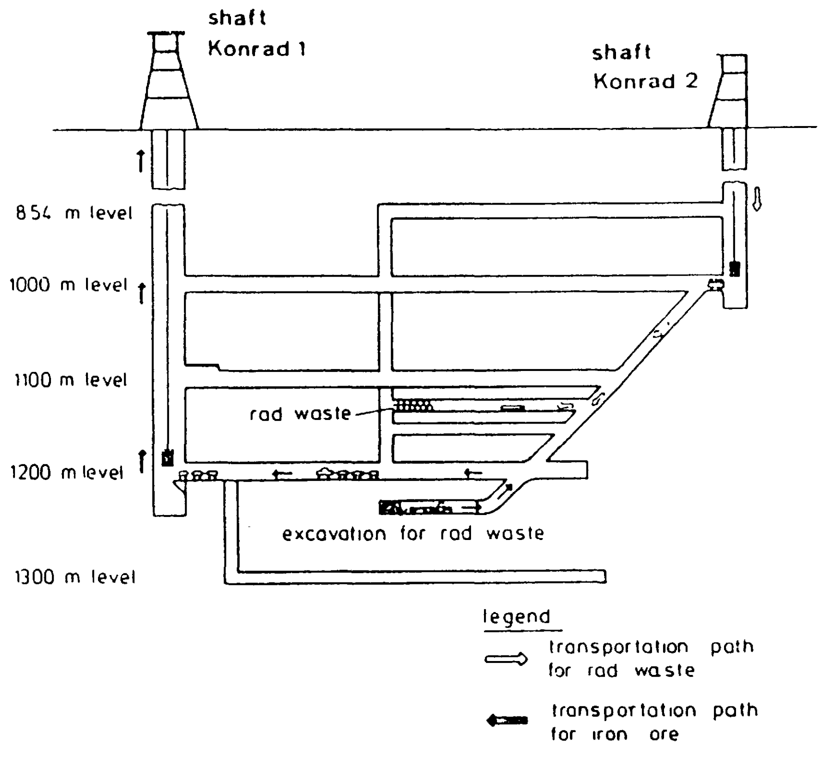


FIGURE 4.5. Below-ground vault Section View



Source: PTB

FIGURE 4.6 Conceptual outline of underground areas and movement of material

5. *SOURCE AND DISCHARGE RADWASTE INVENTORIES*

Common source inventories of liquid and gaseous effluents were established for each type of light water reactor. These common source inventories called primary are theoretical and correspond to a mean capacity of reactor unit of 1 GWe. They give a good picture of the amounts of gaseous and liquid effluents and their characteristics involved in the treatment of these effluents under normal operation. There is a good agreement between the real and the oretical values of the liquid effluents for the 3 PWR and 2 BWR routes. Discrepancies mainly exist for the gaseous effluents. It must be noted that the cost assessment study has considered the real figures of the effluents corresponding to each routes. The associated discharge inventories expressed in Ci/year are real figures and are thus given for each route. These inventories are detailed in Chapter VII.

Solid wastes generated in each management route were established for a 20 GWe nuclear park from the amounts produced by each reference reactor unit of the various routes.

5.1. *PRESSURIZED WATER REACTOR*

5.1.1. *Gaseous and Liquid Waste Inventories*

Common primary inventories of liquid and gaseous effluents from normal reactor operation were defined.

The European gaseous and liquid radwaste inventories for routes PWR1, PWR2 and PWR3 are quoted in Table 5.1.

TABLE V.1 : EUROPEAN GASEOUS AND LIQUID WASTE INVENTORIES FOR ROUTES PWR1, 2 and 3 (1 unit)

Origin	Primary inventory		Discharge inventory	
	Flow rate	Main characteristic	Flow rate	Main characteristic
- Off-gas treatment	10,000 Nm^3/a	3 x 10^4 Ci/a	10,000 Nm$_3$/a	1.11x10^3 Ci/a (Route 1) 22.43 Ci/a (Route 2) 70 Ci/a (Route 3)
- Ventilation	150,000 Nm^3/h	657 Ci/a 150 Ci/a (H3)	150,000 Nm^3/h	807 Ci/a
- Boron recycling system				
* Primary liquid	10,000 m^3/a	0.1 Ci/m^3	1,000 m^3/a	2 x 10-6 Ci/m^3 (released through liquid waste treatment
* Liquid waste treatment	11,010 m^3/a	29.676 Ci/a	11,010 m^3/a	Release (mean value)
* Chemicals	1,500 m^3/a	10-3 Ci/m^3		H3 excluded :
* Drains	2,500 m^3/a	10-2 Ci/m^3		3.15 Ci/a (Route 1)
* Building waste	3,000 m^3/a	10-3 Ci/m^3		0.985 Ci/a (Route 2)
* Laundry waste	4,000 m^3/a	10-4 Ci/m^3		0.416 Ci/a (Route 3)
* Decontamination	10 m^3/a	10-2 Ci/m^3		

5.1.2. *Solid Waste Inventories*

The management strategies applied to solid wastes vary strongly from one country to another.

Figures 5.1 and 5.2 show the annual volumes of solid waste (primary and secondary) generated in each management route, before and after conditioning.

As far as the wet solid wastes are concerned, the observed differences can be explained as follows:

- Route PWR1 generates a smaller volume of waste than the other routes mainly because of the use of the demineralization technique. This technique is preferentially applied in place of the purification by evaporation for the liquid waste effluent of route PWR1. It results less generation of concentrates which is not compensated by the generation of spent resins.
- Drying methods (route PWR2) are more efficient than embedding methods (routes PWR1 and PWR3), when volume reduction is sought. The drying into shielded cask of concentrates and spent resins gives volume modification factor compared to the solidification technique varying from 20 to 2.7. See detailed explanation in chapter 8.
- The use of concrete containers (route PWR1) instead of metallic drums (400 l) (route PWR3) results in doubling the volume. The external volumes of C1 and C4 concrete containers are respectively 2 and 1.235 m^3 (wall thickness of +/- 150 mm). In addition, C4 container can be equipped with steel liners and internal depending on the level of radioactivity of the wastes reducing its capacity.

In contrast to the wet solid wastes, the volume of packaged dry solid wastes is lower than the volume of generated wastes for the following reasons:

- The maximum volume reduction factor (5x) is obtained in route PWR1,
- Compaction and incineration applied in routes PWR2 and PWR3 decrease the volume by 9 and 40 respectively. However, using additional storage containers (route PWR2) and concreting the resulting ashes of the incineration (route PWR3) partially cancel the high volume reduction factors.
  So, the overpacking by containers of the 200 l metallic drums produced by the route PWR2 involves a volume increase factor of 3.
  In the same way, the addition of cement to the resulting ashes involves a volume increase factor of about 2.

5.2. *BOILING WATER REACTOR*

5.2.1. *Gaseous and Liquid Waste Inventories.*

Typical gaseous and liquid radwaste inventories for routes BWR1 and BWR2 are quoted in Table V.2. Flow rates of the various primary effluents originating from the various systems are identical. However, the corresponding characteristics differ for the two routes according to the real situation existing for the two reference BWR reactors. In the same way the discharge inventories correspond to the real situation.

In order to include all the liquid effluent in this inventory, the regenerated water effluent produced in the case of route BWR2 has been added. This effluent has to be considered as a secondary waste and results of the treatment of spent resins in order to reduce their radioactivity level in view of subsequent conditioning.

5.2.2. *Solid Waste Inventories*

The management strategies applied to solid wastes vary strongly from one route to another.

Figures 5.3 and 5.4 show the annual volumes of solid waste generated in each management route, before and after conditioning.

Regarding the wet solid wastes, both routes generate roughly the same volume of waste. The conditioned waste volume difference between route BWR1 and BWR2 is due to the efficiency of the drying method (route BWR1) compared to the embedding technology.

In contrast to the wet solid waste, the volume of packaged dry solid wastes of BWR1 route is greater than the corresponding one of the BWR2 route. Despite the application of two volume reduction techniques (compaction + incineration) for BWR1 route against one for BWR2 route, the use of additional storage containers cancels the resulting higher volume reduction factor (see par. 5.1.2.).

TABLE V-2 : European gaseous and liquid waste inventories for routes BWR 1 and 2 (1 unit).

ORIGIN	PRIMARY INVENTORY		DISCHARGE INVENTORY	
	Flow rate	Main characteristics	Flow rate	Main characteris.
- Off gas treatment	200,000 Nm^3/a	4.38 x 10^6 Ci/a (BWR 2) 4.38 x 10^5 Ci/a (BWR1)	200,000 Nm^3/a 20,000 Nm^3/a	876 Ci/a (BWR2) 263,6 Ci/a (BWR1)
Ventilation	200,000 Nm^3/h	175 Ci/a	200,000 Nm^3/h	175 Ci/a
Low conductivity effluent	15,000 m^3/a	5 x 10^{-2} Ci/m^3 (BWR1) 0.2 x (10^{-3}-10^{-1}) Ci/m^3 (BWR2)	5500 m^3/a (BWR1) 800 m^3/a (BWR2)	4.8 x 10^{-4} Ci/a (H_3 excluded) (BWR1) 1.13 x 10^{-5} - 5.42 x 10^{-3} Ci/a (BWR2)
- Building drains	5,000 m^3/a	10^{-3}Ci/m^3 5 Ci/a (BWR1) 10^{-6} 10^{-4} Ci/m^3 (BWR2)		
- Laboratory/Decontamination		10^{-3}Ci/m^3/0.5 Ci/a (BWR1) 10^{-5} - 10^{-2} Ci/m^3 (BWR2)		
- Decantation/Filtration		10^{-4}Ci/m^3 0.2 Ci/a (BWR1) 10^{-5} - 10^{-3} Ci/m^3 (BWR2)		
- Laundry/showers	5,000 m^3	10^{-5} 10^{-4} Ci/m^3/0.32 Ci/a (BWR1) 10^{-6} 5 x10-4 Ci/m^3 (BWR2)		
SECONDARY INVENTORY				
Regenerated water condensate cleaning (mixed bed resins)	2,000 m^3 (BWR2)	10^{-5} - 10^{-3} Ci/m^3	This effluent results from an additional treatment of the spent resins aiming at reducing their level of radioactivity	

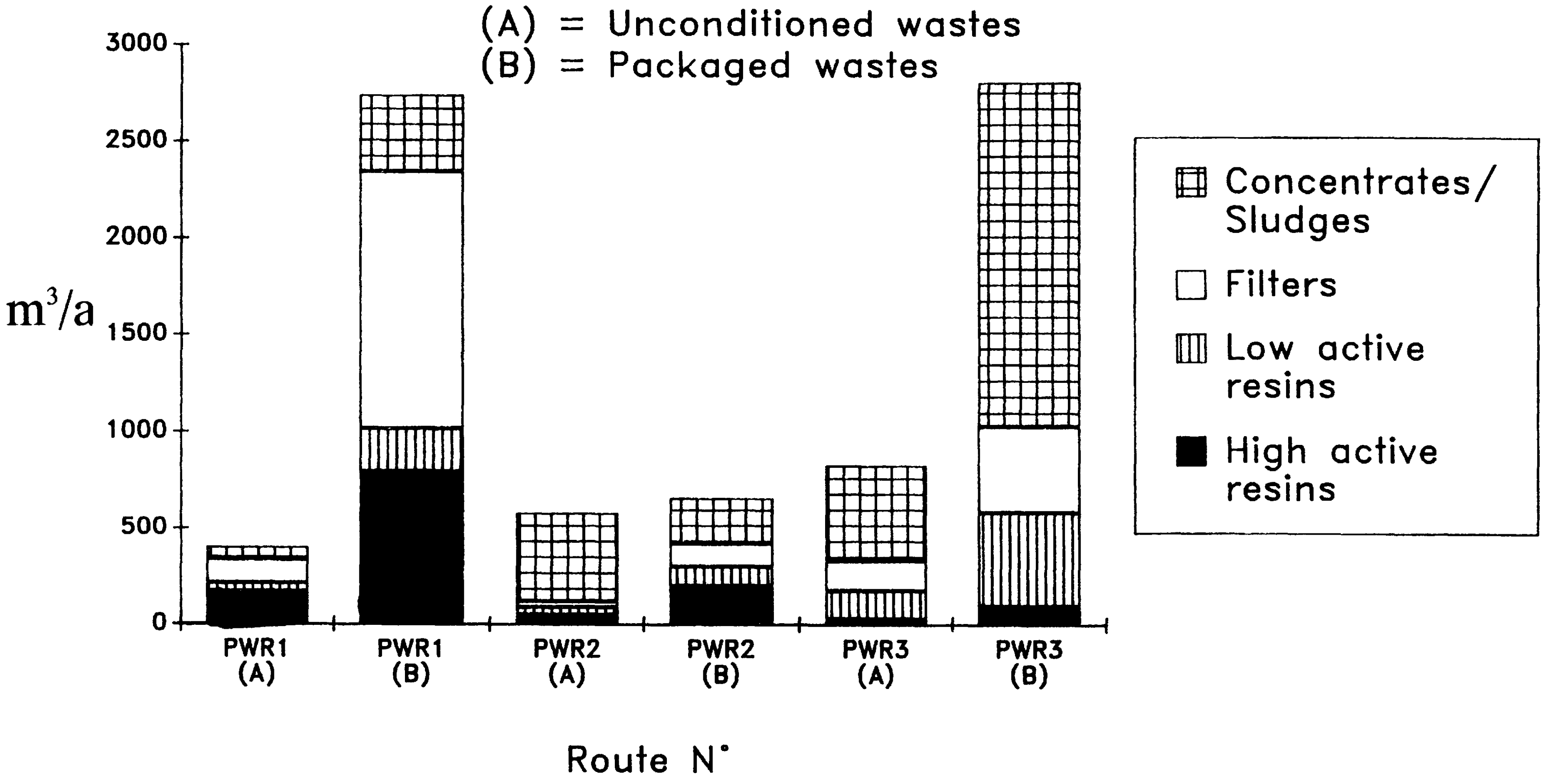


Fig 5.1 : ANNUAL WET SOLID WASTES GENERATION (20 GWe NUCLEAR PARK)

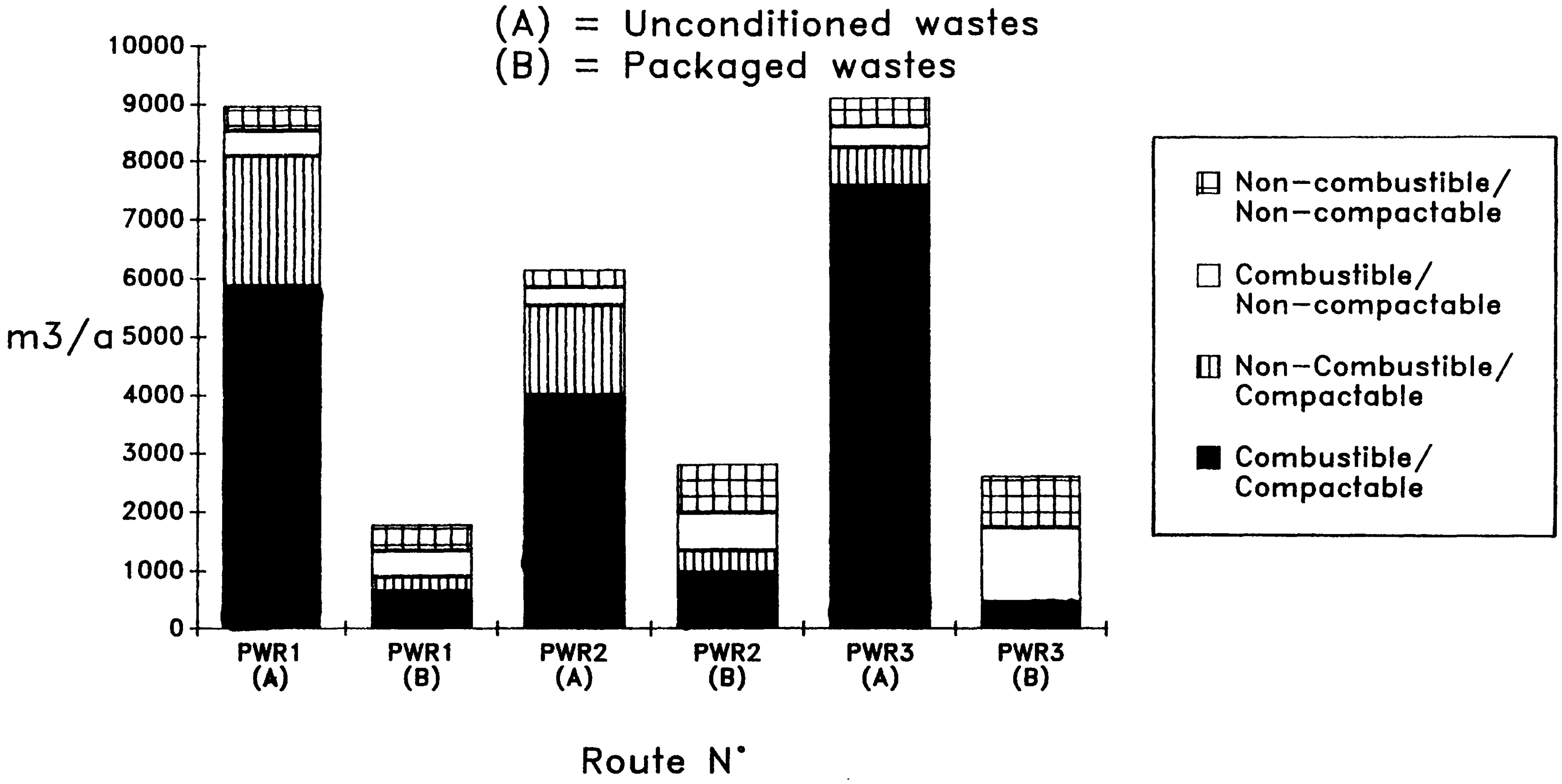


Fig 5.2 : ANNUAL DRY SOLID WASTES GENERATION (20 GWe NUCLEAR PARK)

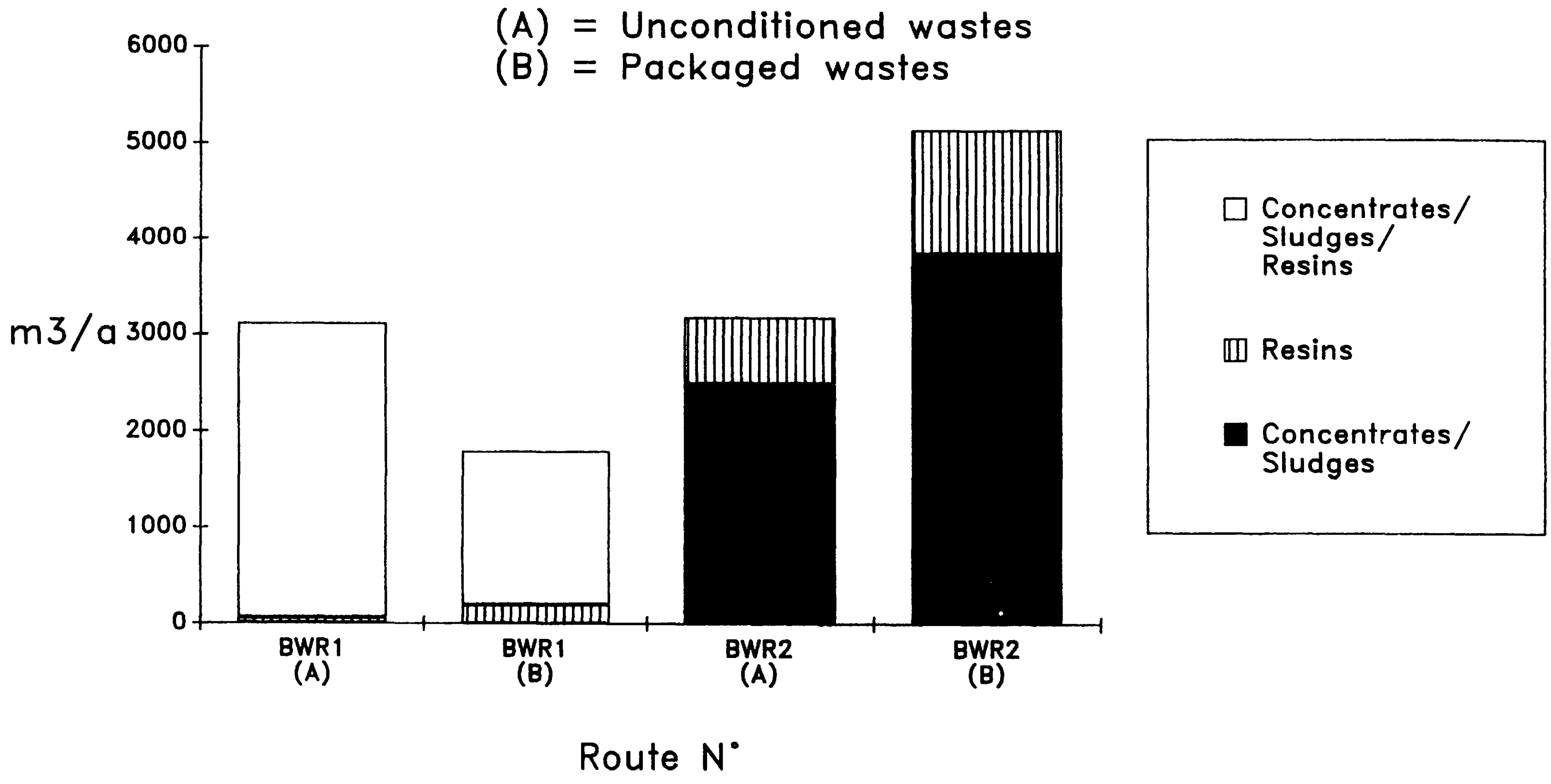


Fig 5.3 : ANNUAL WET SOLID WASTES GENERATION (20 GWe NUCLEAR PARK)

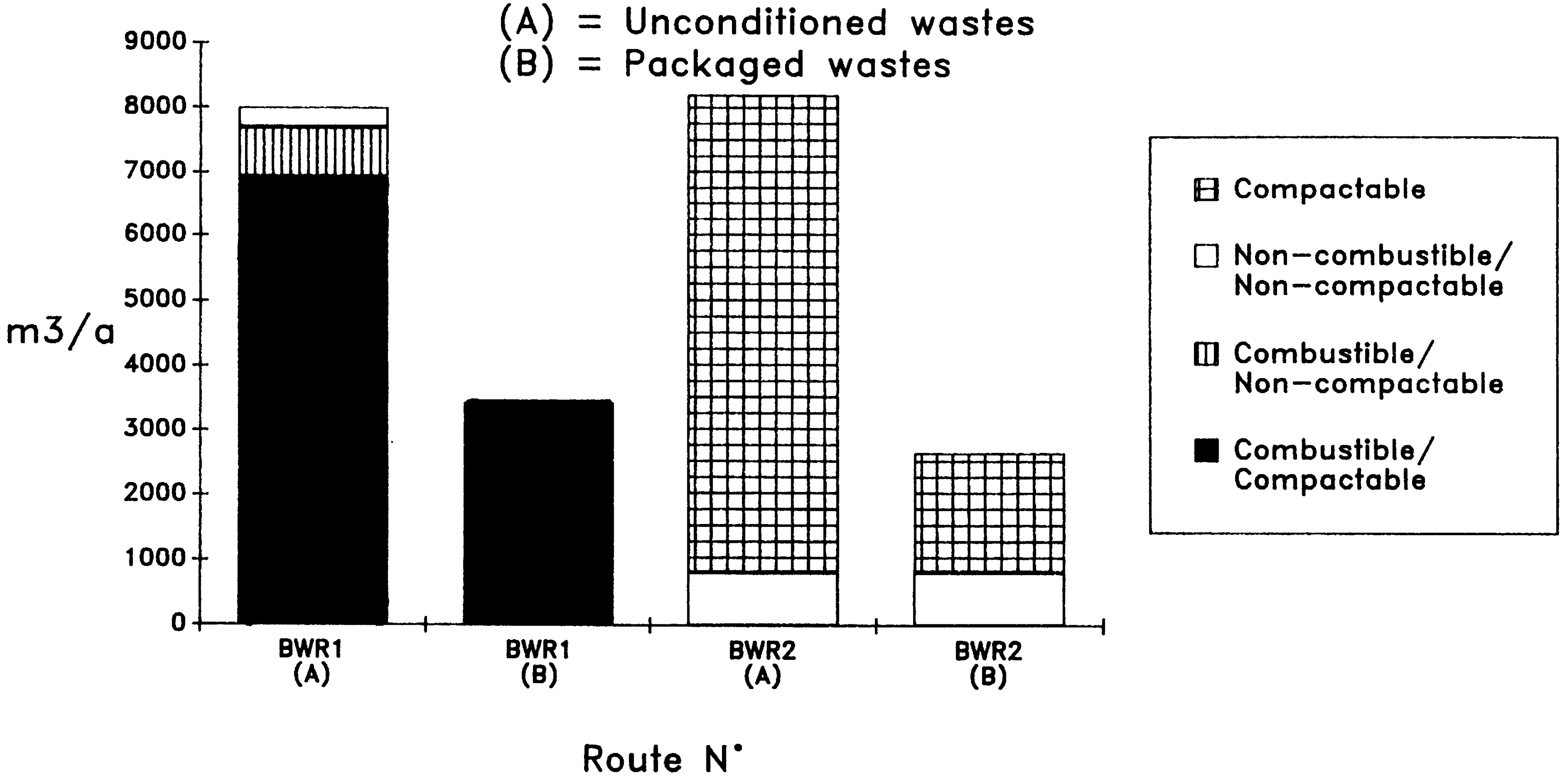


Fig 5.4 : ANNUAL DRY SOLID WASTES GENERATION (20 GWe NUCLEAR PARK)

6. *COSTING OF THE RADWASTE MANAGEMENT ROUTES*

The cost estimates of the PWR waste management routes refer to the treatment of the radioactive effluents arising from a 20 GWe nuclear park of standard PWR's, the interim storage and transportation to the disposal site of the conditioned radwastes.

6.1. *SITE MANAGEMENT COST FOR 30 YEARS*

The cost estimates of the treatment and conditioning plants located on each reactor site (single or twin) and the interim storage with one year capacity were evaluated with the support of the cost assessment procedure and assumption defined previously.

The total cost for 30 years operation was evaluated for the three PWR routes and expressed in actualized MECU 92 (million ECU 92). In order to compare the respective economic weight of the operation unit in each route, the cost elements not directly related to the operation units were distributed among these units as follows

- The capital cost of the Civil Works corresponding to the building housing the treatment/conditioning operation units has been distributed among these units proportionally to their respective capital cost.
- The capital cost of the civil works of the interim storage was added to the interim storage unit.
- The sum of the capital costs, civil works excluded, of the cost elements not directly related to the operation units was distributed among the latter proportionally to their respective capital costs.
- In the same way , the sum of operating costs of the cost elements not directly related to the operation units has been distributed among the operation units proportionally to their respective operating cost.

Figure 6.2 illustrates the costs associated with the processing/conditioning of waste handled by the three management routes (transport and disposal excluded). The total cost (i.e. investment and operating costs) is given for each processing system. Appreciable differences are observed in the following systems : boron recycling, liquid waste treatment, gaseous treatment and dry solid waste (mixed solid wastes) treatment.

Generally speaking, the cost divergences result from the design criteria applied in the reference reactors of the three management routes :

1. Thus, for routes PWR1 and PWR3, the waste processing facilities are common to two 900 MWe units (except for the gas treatment system in route PWR3). On the other hand, in route PWR2 each 1300 MWe power reactor has its own processing/conditioning facility.
2. The level of equipment redundancy in the processing / conditioning facilities varies from route to route.
3. The functions performed by the processing systems are not exactly the same in the three routes. In certain cases, the design of the systems covers possible accident conditions.

To illustrate the design criteria which lead to the cost differences, two processing systems are described in more detail :

- Off-gas treatment
- Conditioning of dry solid waste.

6.1.1. *Off-gas Treatment*

The technical comparison of the off-gas systems employed in the three routes can be summarized as follows (table 6.1) :

- The gaseous effluent treatment system is designed to handle gaseous effluents from two 0.9 GWe units in route PWR1, from one 1.3 GWe unit in route PWR2 and from one 0.9 GWe unit in route PWR3.
- The processing capacities of the delay line facilities for noble gases with short half lifes of route PWR3 are twice those of routes PWR1, whereas those of route PWR2 are about 10 times higher as compared to route PWR1.
- The gaseous waste systems of routes PWR2 and PWR3 permit the removal of hydrogen from the circuits during normal operation via a recombiner.
- The hydrogen recombiner system of management route PWR2 is designed to treat the hydrogen released in the reactor confinement under abnormal conditions (loss of coolant accident, etc).

Table VI.1 : Technical comparison between the off-gas systems designed for the three routes

ROUTE N°	1	2	3
DESIGNED FOR (GWe)	2 x 0.9	1 x 1.3	1 x 0.9
FLOW-RATE m3/a	10,000	90,000	10,000
H2 CONTROL (NORMAL)	NO	YES	YES
H2 CONTROL (ABNORMAL)	NO	YES	NO

6.1.2. *Conditioning of Dry Solid Waste*

The dry solid wastes are handled in a different manner in the three routes (table 6.2.) :

- Route PWR1 : the dry solid wastes are compacted
- Route PWR2 : the dry solid wastes are processed using compaction and incineration, the emphasis being placed on the former. The processed wastes are packaged.
- Route PWR3 : the dry solid wastes are also compacted and incinerated with the emphasis on the latter. Moreover, the ashes from incineration and the compacted waste are encapsulated in cement.

Table VI.2 : Technical comparison between the treatment options considered in the three routes for dry solid wastes

ROUTE N°	1	2	3
COMPACTION	YES	YES	YES
INCINERATION	NO	YES	YES
EMBEDDING	NO	NO	YES
OVERPACKING	NO	YES	NO

Concerning the cost differences observed among the three management routes, it must be noted that incineration leads to the high costs of dry waste processing in routes PWR2 and PWR3.

6.2. *TOTAL MANAGEMENT COST FOR 30 YEARS OPERATION*

The disposal costs corresponding to the reference sites selected for the three routes namely the Aube Centre for route PWR1, Konrad former iron mine for route PWR2 and the Spanish concept for route PWR3 were considered. The transportation costs originated from figures proposed by the various partners were added.

6.2.1. Disposal Costs

The disposal costs refer to the disposal systems applied in the routes. The volumes of radwaste packages to be disposed of are the following :

TABLE VI.3 : Generation of radwastes packages of a nuclear park of 20 GWe (30 years operation)

	PWR1	PWR2	PWR3
Volume of packages (m3)	135,800	104,000	162,700

6.2.1.1. Aube Centre

The Aube Centre has been designed to store the LLW packages originating from fuel reprocessing and power plants.

Cost estimate is based on the cost of the disposal site having a capacity of 9,320 m^3 (before supercompaction) per year of both types of packages-reactor and low level activity technological reprocessing wastes.

The annual volume before compaction of packages corresponding to a park of nuclear power plants producing 20 GWe is 6,309 m^3.

Scaling equations from TASK R & S - KAH and assumptions transmitted by CEA result in the following cost factors :

- **INVESTMENT COST : 39.1 MECU88**
- **ANNUAL OPERATING COST : 5.4. $MECU_{88}$/Y**

6.2.1.2. *Spanish concept*

The Spanish concept is designed to accomodate 120,000 m^3 of LLW packages for a period of 30 years distributed among 64 vaults of 3,750 m^3 each.

The cost estimation was performed with the support of TASK R & S - KAH methodology and the following main assumptions :

- 20% of civil works in vault construction is carried out before the start up date of the site . The remaining 80% is performed along the life of the facility (operating costs).

- Salaries are respectively 13 and 25 ECU/h for operator and overhead (against 17 and 35 ECU_{88}/h for the general assumptions).
  The evaluation of the following two main costs items was performed by INITEC :

INVESTMENT COST : 107.9 $MECU_{92}$
ANNUAL OPERATING COST : 6.34 $MECU_{92}$/y

6.2.1.3. *KONRAD Mine Repository*

The KONRAD mine would have an available void volume of up to 1,000,000 m^3. Considering a filling factor of 0.65, 650,000 m^3 could effectively be used.

The total costs for construction, operation during 40 years and sealing of the shafts after filling were estimated by NUKEM as follows :

Construction	635.5 MECU
40 years operation ...	936
2 shaft sealings	72.8
4 years operation	93.6
TOTAL c.a.	1,730 MECU

From this cost estimation an averaged actualised disposal cost of 2,600 ECU_{92}/m^3 was proposed by NUKEM and GNS.

6.2.2. *Costing of the Transport*

The economic assessment of the transport corresponding to each route is based on national practices. It results the figures (20 GWe) given in Table VI.4.

Table VI.4 : Total transport costs associated with the PWR routes for 30 years of operation (20 GWe)

ROUTE	COST ($MECU_{92}$)
Route PWR1	14.565
Route PWR2	18.513
Route PWR3	43.284

The more important cost for the route PWR3 is explained by the restricted amount of packages transported per truck (7 or 14 drums transported by road in a special cask).

6.2.3. *Complete Cycle Radwaste Management Cost*

The cost of the complete cycle of radwaste management from the generation to disposal was evaluated for 30 years of operation and expressed in actualised $MECU_{92}$ (Figure 6.1).

The actualised operating and capital cost for the treatment/conditioning operation units directly related to the power stations are represented separately, whereas those for transport and disposal have been grouped.

The total management costs thus obtained indicate that :

1. Appreciable differences exist between the costs of the various management routes (the difference between the maximum (route PWR2) and the minimum (route PWR1) is 40%. These are mainly due to the treatment and conditioning operation.

2. The cost of disposal constitutes a relatively minor part (about 10%) of the overall management cost of the three routes.

3. The transport costs remain below 3%.

4. As regards processing and conditioning operating cost, the ratio varies between 1.15 and 1.48.

The variation in the disposal cost associated with each management route can be explained in terms of :

- The type of disposal envisaged : deep repository (Konrad mine) for route PWR2 and near surface sites for routes PWR1 and PWR3.
- The volume of conditioned waste to be disposed of
- Differences in the economic evaluation of the reference disposal sites chosen for the calculations (Aube centre for route PWR1/Spanish model for route PWR3). For this last model, site works are a major contributor to the higher costs associated with the PWR3 disposal option, representing 50% of the capital cost and 17% of the total cost.

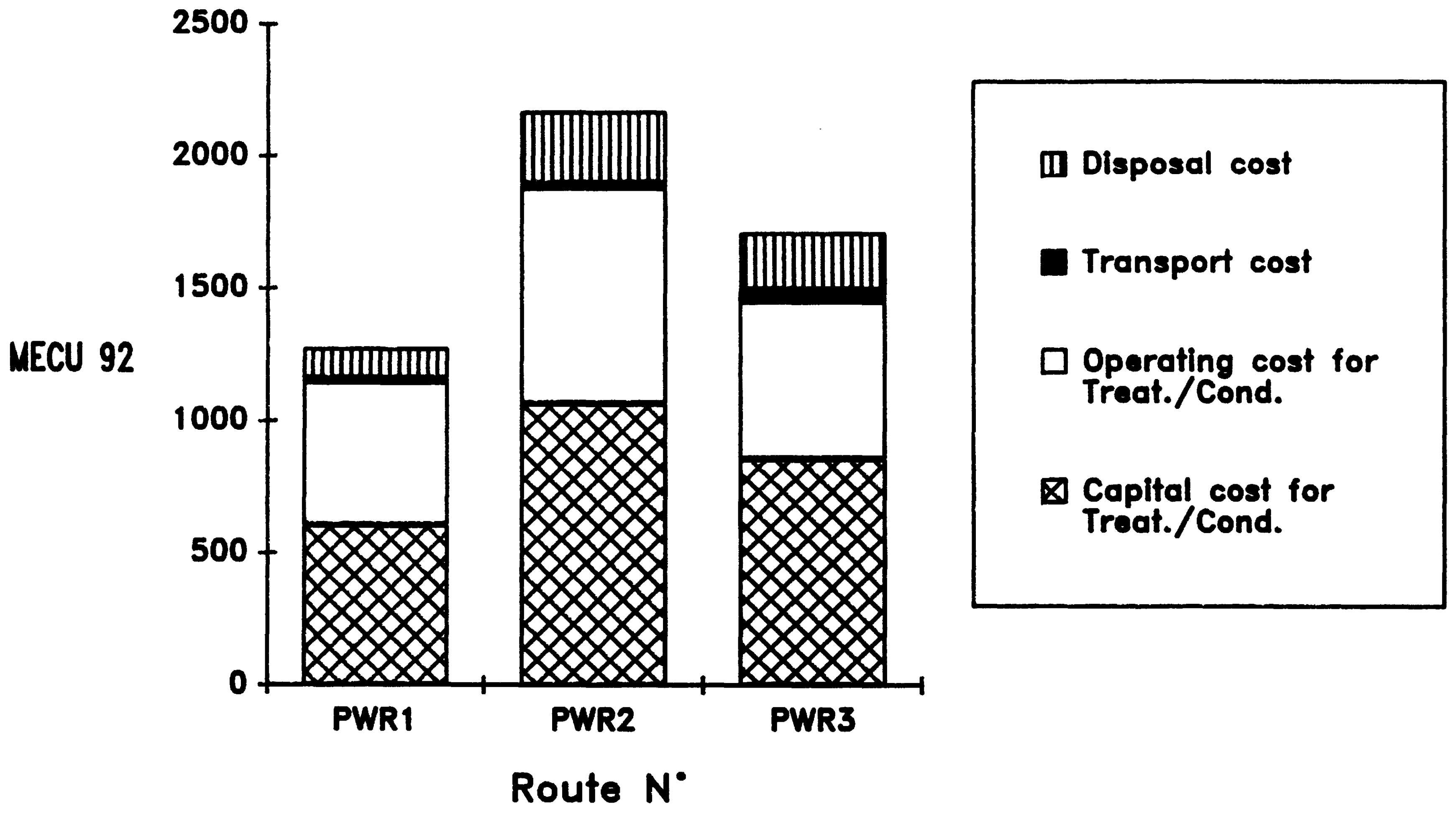


Fig 6.1 : TOTAL MANAGEMENT COST FOR 30 YEARS OPERATION

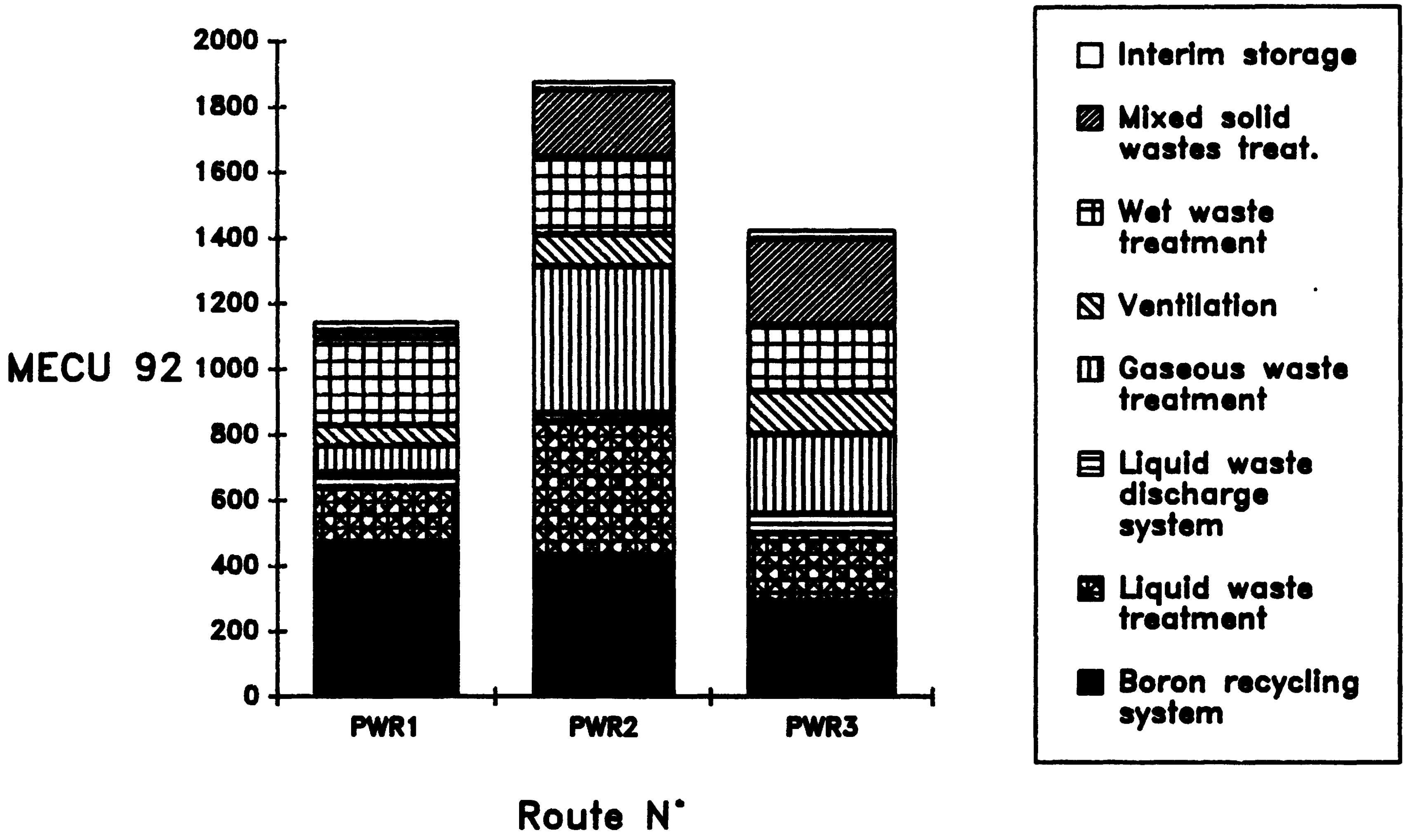


Fig 6.2 : SITE MANAGEMENT COST FOR 30 YEARS OPERATION

7. *RADIOLOGICAL IMPACT*

7.1. *INTRODUCTION*

The radiological impact on the public associated to each principle management route for PWR waste was mainly assessed on the basis of the radionuclide inventories annually released into the environment as liquid and airborne effluents. Moreover, for sake of completeness, the long-term radiological impact which might result from the disposal of radioactive waste products in near surface sites was also assessed.

As most of the available data for determining the occupational exposure only concerned routine operations and due to the fact that the estimated individual doses are proportional to a large extent to manpower, the evaluation of the radiological impact to workers involved in the implementation of each route was volontarily discarded from this study.

Basically, the evaluation of the radiological impact to the public resulting from effluent releases into the environment consisted in applying the methodology developed by BELGATOM to the three PWR-routes. This methodology(Volume n° 5) enables an estimate of annual individual maximum doses as well as collective doses for different groups of population living in the neighbourhood of the TIHANGE-2 PWR reactor in Belgium.

As far as long-term radiological impact to the public deriving from disposal of radioactive waste products in near surface sites is concerned, two distinct methodologies were applied. The first one set-up by CEN/Fontenay-aux-Roses (Volume n° 7) refers to disposal of radioactive waste in the "Centre de Stockage de l'Aube" while the second one, considered by INITEC (Volume n° 8) is linked to a Spanish disposal concept named "Below-Ground-Vaults".

7.2. *RADIOLOGICAL IMPACT RESULTING FROM RADIOACTIVE DISCHARGES*

7.2.1. Definition of Discharges Inventories

In order to perform a consistent comparison between the different management routes, it was deemed worthwhile to define first common primary waste inventories for liquid and gas including typical radionuclide compositions (see table VII.1 to VII.5 of Annex 2). These common primary waste inventories mainly differ from the reference national cases in that they all rely on the same reactor type (900 MWe) and consider the same waste arising for the off-gas treatment system (10,000 m^3/a).

On the basis of the different national liquid and gas treatment concepts and performances summarized in table VII.6 of Annex 2 for the three routes and taking into account the storage periods in decay tanks for the gaseous effluents containing short lived radionuclides (see table VII.7 of Annex 2), the annual activities released as liquid and airborne effluents were subsequently calculated.

It is important to note that although each route involves the use of discharge tanks as a mean to enable a further decay of short-lived radionuclides prior to release liquid effluents into a river, these were not accounted in the inventory of radioactive discharges. Accordingly, the annual releases of activity thus calculated are very conservative.

7.2.2. *Activity Released as Gaseous Effluents*

For the treatment of gaseous effluents and especially for the fraction released from the primary circuit, the three PWR routes differ with respect to :

- Removal of iodine (the "German" route appears much more efficient - by the two orders of magnitude - than the two other routes) ;
- Removal of aerosols (actually a mixture of Cs-137 and Co-60) for which the "French" route is expected to give rise to the least releases (DF = 3000 instead of 100 for the two other routes) ;
- Decay time for noble gases which appears to be the longest for route PWR2 (60 and 2.5 days for Xe and Kr respectively) instead of 54 days for route PWR3 and only 22 days for route PWR1.

With regard to the gaseous effluents released from the ventilation system, the "French" and Belgian" routes involve no treatment at all except for aerosols (DFs = 3000 and 100 respectively) while the "German" route considers the achievement of the DFs equal to 1000 and 100 for iodine and aerosols respectively.

Relying on the assumptions and the methodology mentioned in section 7.2.1., the annual activities released from 1 x 900 MWe PWR as airborne effluents are quoted in table VII.8 of annex 2.

The analysis of the results shows that for the three PWR routes, the activity released from ventilation is nearly the same (about 30 TBq/a per reactor). This is due to the fact that implementation of a more efficient treatment process for the removal of iodine, caesium and cobalt radioisotopes (specific case of the PWR1 route) has practically no impact on account of the rather low contribution of these radioisotopes in the total activity (about 0.03%).

However, for hydrogenated gaseous waste, it must be pointed out that the adoption of a longer decay time, especially for Xe-133, has an important effect on the total activity released which varies from 41 TBq/a for the PWR1 route (approximatively 22 days decay time) down to 814 GBq/a for the PWR2 route (60 days decay time).

For I-131 which is the most troublesome radioisotope on the viewpoint of radiological impact , the highest releases have been recorded for the "French" PWR route (approximately 3.7 GBq/a) which is penalized both by a low DF (10 instead of 1000 for the "German" PWR route) and a low decay time (22 days to be compared with 54 days for the PWR3 route).

7.2.3. *Activity Released as Liquid Effluents*

Although all three basic management routes involve the implementation of the same kind of treatment processes (evaporation, ion-exchange and in some cases chemical precipitation), they differ on the range of application of each of these processes and on their decontamination efficiency. For example, for the specific case of iodine contained in primary liquid waste, the highest decontamination efficiency is recorded in case of route PWR1 (10^5) while DFs equal to 5×10^4 and 10^3 have been quoted for routes PWR2 and PWR3 respectively despite the fact that all three routes consider iodine removal through combination of evaporation with ion-exchange.

It must be stressed that some specific streams (e.g. building or floor waste are processed in certain cases (e.g. routes PWR2 and PWR3) while they are not in other cases (route PWR1).

As a result, the releases of radioactive liquid effluents significantly differ from one route to another.

Finally, for route PWR2, the radionuclides inventory estimated for releases only relies on the assumption that all the liquid waste streams (except primary liquid waste) are mixed altogether and continuously processed until their final activity is below 37 GBq/a (tritium excluded).

Therefore, in contrast with the other routes for which accurate calculations have been made taking into account the transit time into the reservoirs (for short-lived radionuclides like I-131, I-133 and Mo-99), the determination of the radionuclide inventory in liquid effluents was simply made by dividing by 30 the activity.

The results of the annual activities released for the three cases looked into are quoted in table VII.9 of annex 2.

These show that :

- The most important releases occur in case of route PWR1 mainly because floor wastes are not processed ;
- The route PWR3 is the least penalizing route in terms of global activity released as a result of the extensive treatment processes applied on waste streams (except laundry waste).
- For the specific case of iodine releases, however, route PWR3 gives the worst results because of the relatively low DF recorded in the treatment line (10^3 against 5 x 10^4 or even 10^5 for the two other routes).

It must be pointed out that the determination of annual releases is irrespective of the possible effluent recycling within the treatment plant (case of route PWR1). Accordingly, especially for the short-lived radionuclides, the figures quoted can be considered as representing an extreme case.

7.2.4. *Calculation of Individual Doses Resulting from Airborne Releases*

The determination of the maximum individual doses to the members of a critical group of the public was carried out through estimates of the external irradiation mainly resulting from noble gases and the internal irradiation deriving from inhalation and ingestion of food products contaminated by the deposits and incorporation of C-14, H-3, iodine and aerosols.

All the details concerning the methodology followed are quoted in the BELGATOM report already mentioned (volume n° 5).

It is important noting that maximum individual doses have been calculated for the critical group of the population living around a nuclear site with four 900 MWe PWR units.

For the sake of easiness, only the maximum annual individual doses to the skin, the whole body and the most exposed organ (thyroid) have been calculated in case of an in-land location of the nuclear power plant of concern. The results are reported in tables VII.10 to VII.12 of annex 2 for routes PWR1 to PWR3 respectively.

As expected, the most important doses are related to the action of I-131 on thyroid. Regarding this, maximum individual dose of about 54 µSv/a can be reached in case of the PWR1 route. For the PWR2 route, which involves high recovery yields for iodine, this dose is lowered to 6µSv/a, hence 9 times less.

7.2.5. *Calculation of Collective Doses Resulting from Airborne Discharge*

Collective doses were estimated for an extended group of population distributed around the nuclear site up to 80 km (i.e. about 5.6 millions inhabitants). As quoted in table VII.13 of annex 2, thyroid doses are the most important contributors to collective doses whatever the route considered. These results are consistent with the foregoing ones related to individual doses. Collective whole body doses are nearly all the same for the three routes mainly because directly related to the ingestion of C-14 and H-3 for which the releases estimated are equal in all cases.

7.2.6. *Calculation of Individual Doses Resulting from Liquid Discharges*

The doses are calculated for the adult critical individual taking into account ingestion, inhalation and external exposure pathways. In addition, discharges have been assumed to take place into the Meuse river (see volume Nr. 5).

As for gaseous discharges, the calculation of maximum individual doses was carried out for the critical group of the population living around a nuclear site with four 900 MWe PWR units.

Only the doses to the most exposed organs (liver and thyroid) as well as to the whole body, have been calculated.

The results which are quoted in tables VII.14 to 16 of annex 2 show that the doses to thyroid are similar and extremely low for the three routes (from 3 to 7 µSv/a). However, significant differences appear for doses to liver which rise by one order of magnitude from route PWR1 to route PWR3 (5 to 50 µSv/a) as a consequence of the discharges of Cs-134 and Cs-137 (about 150 GBq/a) which are themselves a result of the non-processing of floor waste in case of the PWR1 route. For the same reason, the highest doses to the whole body are recorded for route PWR1 (40µSv/a instead of 14 and 4 for routes PWR2 and PWR3 respectively).

7.2.7. *Calculation of Collective Dose Resulting from Liquid Discharges*

The methodology applied for calculating doses resulting from liquid discharges deals with three main exposure pathways : first drinking water especially for the groups of populations living in Antwerpen and Rotterdam (more than 3 millions in total), second fish ingestion and third ingestion of agricultural product irrigated with Meuse water and by the ingestion of animals product watered with Meuse water (approximatively 1.5 millions of inhabitants).

Only collective doses for whole body and thyroid have been determined. The results of the assessment indicated in table VII.17 to VII.19 of annex 2 clearly show that in contrast with gaseous releases, collective doses due to liquid discharges are higher for the whole body than for thyroid alone. Likewise, approximatively half of the collective doses are resulting from the ingestion of drinking water.

As for the individual doses, the collective whole body doses are higher for the PWR1 route (French practices) than for the two other routes because of the releases of slightly higher amounts of Cs-134 and Cs-137. Regarding collective thyroid doses, the three PWR routes are comparable since the dominant radionuclide is tritium the discharges of which have been kept constant for all the routes.

The summary of the radiological impact to the public resulting from the gaseous and liquid discharges which might occur from a 20 GWe nuclear park operating for 30 years is displayed in Figures 7.1 and 7.2.

7.3. *RADIOLOGICAL IMPACT RESULTING FROM WASTE DISPOSAL*

7.3.1. *Introduction*

In order to assess the long term radiological impact to the public resulting from waste disposal in near surface site, two disinct cases have been considered : the "Centre de Stockage de l'Aube" in France on the hand and a Spanish concept similar to the future "El Cabril" disposal centre on the other hand (see table VII.20 of annex 2).

This evaluation was carried out on the basis of a number of assumptions, i.e. : disposal site characteristics, radionuclide inventories, leaching rates, fraction of waste packages degraded over 300 years, site hydrogeology and water consumption scenarios which have been been extensively described in specific reports (Volume N° 4 and 5).

Despite the fact that the radionuclide inventory for reactor waste including long-lived radionuclides was drawn from the NUREG/CR-1759 report for both disposal sites, some important differences were recorded as quoted in table VII.21. of annex 2. These might be attributed to variations in the composition of the 20 GWe nuclear park contemplated in each scenario.

Although both evaluations refer to waste packages generated in case of PWR1 route, it is thought that, as a first approach, the resulting long-term radiological impact is not significantly altered by the selection of other package types.

7.3.2. *Calculation of Maximum Annual Individual Doses*

While the exposure models used for the evaluation of the radiological impact associated with the Spanish disposal concept involves three categories of critical groups (adults, children and infants), the one developed by the French only considers one category of people with three diet variants. In both cases, it was found out that the most important exposure pathways were primarily terrestrial food ingestion and then drinking water. in terms of individual doses, the figures quoted in table VII.1 appear quite comparable and extremely low (max. : 10^{-6} SV/y).

7.3.3. *Calculation of Collective Doses*

The determination of collective doses deriving from disposal of reactor wastes in near surface sites was performed in considering the same river case scenario for the French and the Spanish concepts as well i.e. : use of slightly contamined water for irrigation of the same agricultural area crossed by rivers. The results, indicated in table VII.2, are very similar for both disposal concepts showing no significant radiological impact to the public even for the far future.

TABLE VII.1 MAXIMUM ANNUAL INDIVIDUAL DOSES (Sv/y) FOR THE CRITICAL GROUP OF POPULATION LIVING AROUND NEAR SURFACE DISPOSAL SITES FOR REACTOR WASTE

EXPOSURE PATHWAY	SPANISH DISPOSAL CONCEPT	FRENCH DISPOSAL CONCEPT
DRINKING WATER	2×10^{-8} (A) at 2600 y 1.8×10^{-8} (C) at 2600 y 1.9×10^{-8} (I) at 2600 y	5.9×10^{-7} at 400 y 4.2×10^{-7} at 4000 y
TERRESTRIAL FOOD INGESTION	8.4×10^{-7} (A) at 2600 y 9.2×10^{-7} (C) at 380 y 6.8×10^{-7} (I) at 380 y	
AQUATIC FOOD INGESTION	4.1×10^{-8} (A) at 1500 y 2.2×10^{-8} (C) at 1500 y -- (I) --	

NOTE : (A) = adult, (C) = children, (I) = infant

TABLE VII.2 COLLECTIVE DOSES (Man-Sv) DERIVING FROM DISPOSAL OF REACTOR WASTES IN NEAR SURFACE SITES

DISPOSAL TYPE	SPANISH DISPOSAL CONCEPT	FRENCH DISPOSAL CONCEPT
COLLECTIVE DOSES	55.47 (integrated in 10^{7} y)	11.37 (integrated in 10^{6} y)

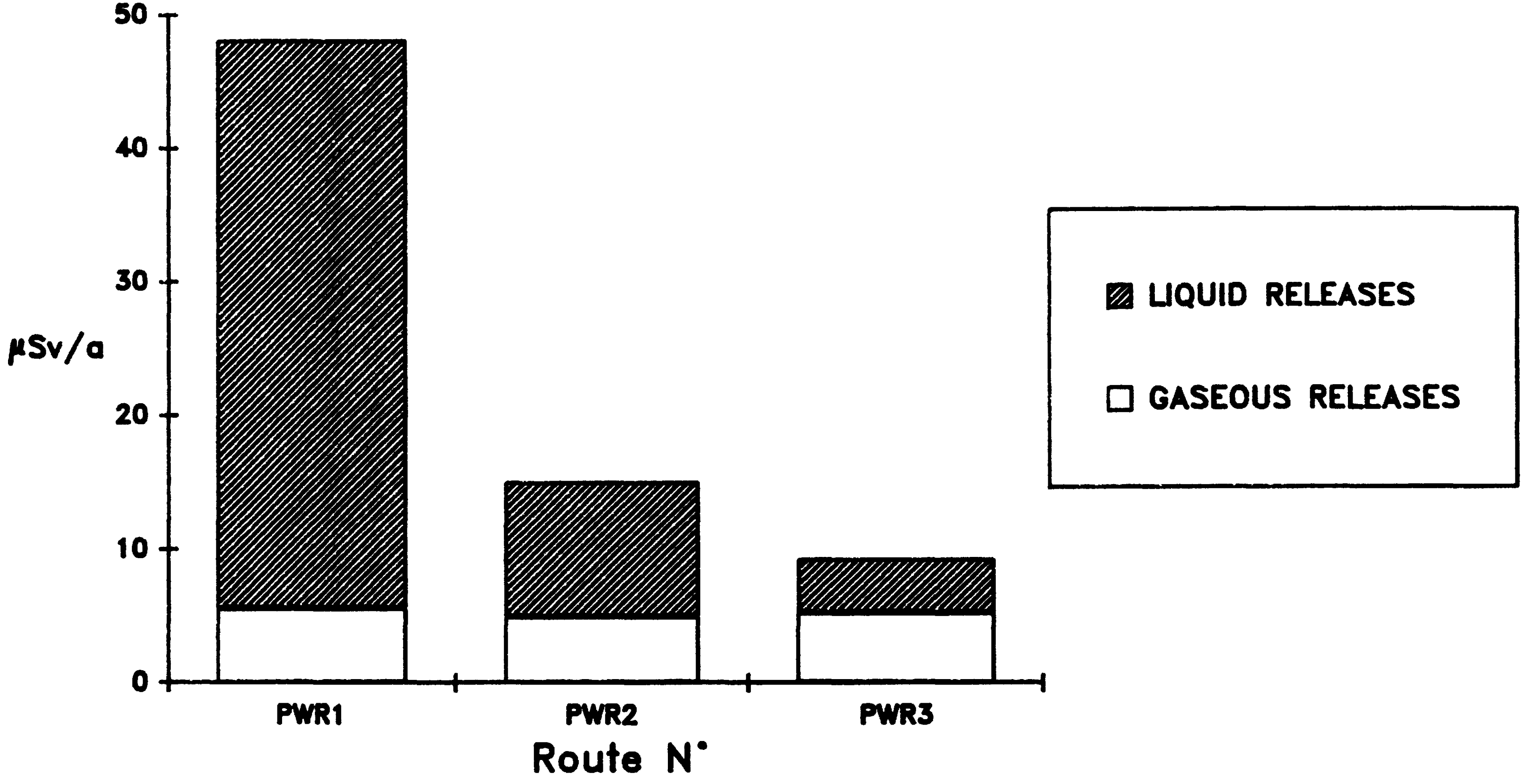


Fig 7.1 : INDIVIDUAL DOSES TO CRITICAL ADULT LIVING AROUND A NUCLEAR SITE WITH 4x900 MWe PWR units (Doses to whole body)

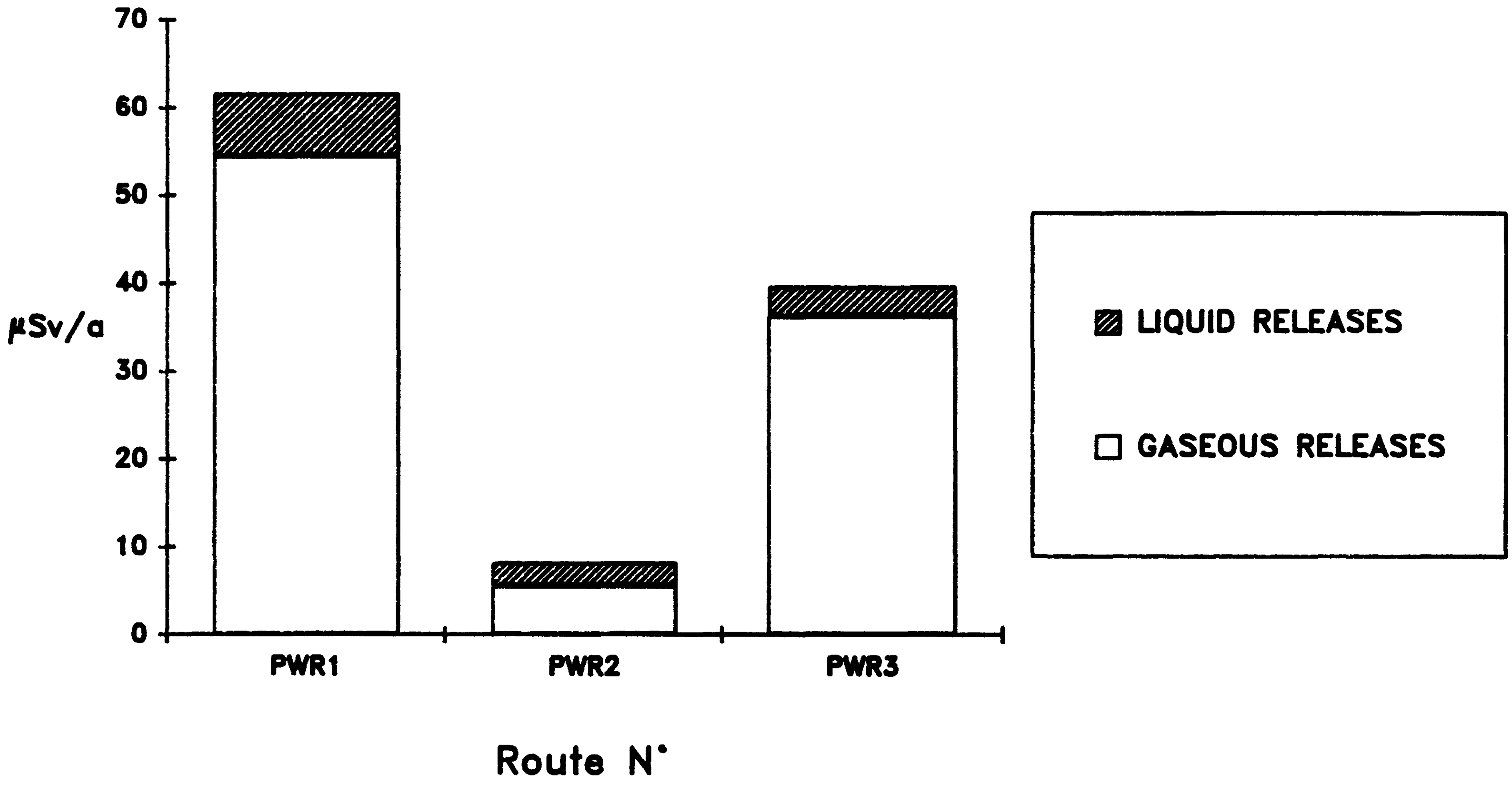


Fig 7.2 : INDIVIDUAL DOSES TO CRITICAL ADULT LIVING AROUND A NUCLEAR SITE WITH 4x900 MWe PWR units (Doses to thyroid)

8. *SENSITIVITY STUDIES*

Sensitivity studies were performed on the main parameters affecting waste volumes and/or costs. These sensitivity studies concerned the solid wastes treatments and the management of the conditioned packages. They were restricted to the variation of parameters or options for a defined PWR radwaste management route.

The following case studies have been analyzed :

- Dry and wet solid wastes treatment alternatives in route PWR2.
- Variation of interim storage period in route PWR3.
- Effect of using mobile treatment facilities in place of fixed ones in routes PWR 1 and 3.

So far as the BWR radwaste management route is concerned, some partial cost evaluations have been performed for unit operations of the two routes. These economical evaluations have allowed some comparison between the radwaste management of PWR and BWR within a national practice (German practice) and operation units of the same BWR type.

8.1. *SOLID WASTE TREATMENT ALTERNATIVES IN ROUTE PWR2*

The effect of selecting various treatment techniques for dry and wet solid radwastes has been analyzed in the frame of route PWR2, using basic assumptions technical and economical, prevailing on the German market.

8.1.1. Dry Solid Waste Treatments

As it concerns the dry solid wastes, two treatment techniques can be applied namely compaction and incineration. These techniques are generally combined and the treatment modes are as follows :

Mode 1 : Precompaction, no incineration
(precompaction force : 16 to 30 tons).

Mode 2 : Precompaction and incineration with cementation of ashes

Mode 3 : Supercompaction, no incineration
(Supercompaction : > 1000 tons).

Mode 4 : Supercompaction and incineration with supercompaction of ashes.

All the power plants use compaction. Incineration technique is applied in Germany an Belgium.

The comparative analysis has been performed between the two main options :

- Option 1 : compaction without incineration
- Option 2 : compaction combined with incineration

It has been assumed that about 40 - 50% of the total dry solid waste is combustible, the other part is compactable. In addition, the compactable dry solid waste is assumed to be distributed among equal part between combustible and uncombustible. The total dry solid waste is thus considered to be compactable which is close to the reality (compactable +/- 90%).

With these assumptions, the two reference options have been compared .

8.1.1.1. *Effect on Volume Reduction*

The figure 8.1 gives the volume reduction ratios for different treatement modes of dry solid waste.

It is observed that the compaction technique alone (pre- and super) provides reduction factors of respectively 3 (precompaction) and 9 (Supercompaction).

The combination of compaction and incineration with additional compaction of the incinerated residues or cementation of ashes gives respectively volume reduction factors of 18 and 5.1.

It results that a simple compaction (16 to 30 tons compaction force) is a very efficient first step to reduce drum handling operations by decreasing the waste volume by a factor 3.

This operation is generally performed on the site of the power station. The high force compaction (> 1000 tons) provides an appreciable high reduction factor (9). This factor of 9 can only be overpass by combining techniques of incineration and ash compaction.

8.1.1.2. *Effect on Cost*

The following cost elements are affected by the choice of a reference system for the treatment of dry solid wastes :

- Manpower corresponding to the waste ;
- Collection, sorting and treatment ;
- Equipment ;
- Package, transport ;
- Interim and final storages.

- *MANPOWER*

  Figure 8.2 shows the required manpower expressed in man-hours corresponding to the amount of dry solid wastes generated by a 1300 MWe PWR (+/- 400 m3).

  Compaction without incineration requires the lowest value in the case of precompaction . Requirements are respectively 10 and 14.8 $X10^3$ man hours/year for pre and supercompaction.

  The need of manpower for the system compaction + incineration is equal or higher : 14.6 and 18.6 x 10^3 man hours/year

  Incineration of waste needs a good sorting of combustible and uncombustible prior to this process.

- *EQUIPMENT*

  Investment costs for precompactor and supercompactor amount respectively to 50,000 ECU and 1 MECU.
  The cost of service incinerator is 18 ECU/kg (1 m3=500 kg).
  In Germany, the option compaction includes a step of drying of wet compacts (50% of compacts are wet).

  Remark : In Belgium, the compacts are embedded in concrete.

- *INTERIM AND FINAL STORAGE*

  In the case of the German situation, the costs of storage are the following :

  - Interim storage : 600 ECU/m^3 year
  - Final storage : 2,500 ECU/m^3.

- *TRANSPORT AND PACKAGES*

  The cost are directly related to the volume reduction reached by the applied processes and takes into account the cost of mobile compactor transport.

Table VIII.1 gives the comparison of two treatment modes of dry solid wastes generated by a German 1300 MWe - PWR.

The incineration combined with supercompaction provides a volume reduction factor including package 4 times greater than the supercompaction without incineration. The investment and operating cost of the treatment combining the two technologies is 60% more expensive that the treatment compaction without incineration. This difference is reduced to 20% if the costs of interim (1 year) and final storages are taken into account. This global economical advantage of compaction without incineration is depending on the technical specifications for the dry solid waste management in Germany. These specifications are related to the legal and licensing conditions prevailing in Germany.

TABLE VIII.1 COMPARISON OF TREATMENT MODES OF DRY SOLID WASTES (200,000 kg) generated by a German 1300 MWe PWR (Route Nr. 2)

Treatment mode	Supercompaction (100%)	Supercompaction (50%) + Incineration (50%)
Volume Reduction factor (including package)	$\frac{2}{1.4} = 1.42$	$\frac{2}{1.4} \times 0.5 + \frac{2}{0.2} \times 0.5 = 5.714$
Investment and operating cost including transport	17.6 MECU	28.1 MECU
Interim (1 year) and final storage costs	8.7 MECU	4.97 MECU
Total Cost	26.3 MECU	33.07 MECU

8.1.2. *Wet Solid Waste Treatments*

The main treatment alternatives are considered for the processing of wet solid wastes namely solidification of wet solid wastes into a matrix material (cement, or plastic) or drying of wet wastes to obtain the formation of a solid block inside a special container. Wet solid wastes are mainly distributed into evaporator concentrates and spent resins.

8.1.2.1. *Effect on Volume Reduction*

- **Liquid concentrates**

  The figure 8.3 gives the resulting volume of treated liquid concentrates for different treatment modes corresponding to 1 m^3 of raw wastes.

  One m^3 of liquid concentrates (0.6 Ci/m^3) generates 15 m^3 including packages of cemented waste product if there is direct cementation without pretreatment. Pretreatment by dehydratation and subsequent cementation leads to an increase of this volume of respectively 7 or 3 for Boron - containing and no - Boron containing liquid solutions. In drum drying process gives a volume reduction of about 25% of the initial volume.

- **Spent resins**

  The figure 8.4 gives the resulting volumes of treated spent resins for different treatment modes corresponding to $1m^3$ of spent resins.

  One m3 of high active spent resins generates about $15m^3$ including packages of a polymer waste product. The use of a cement matrix increases the volume of treated low active spent resins to $8m^3$.

  Draining or/and vacuum drying of $1m^3$ of high and low active resins provides disposal volumes respectively of 4 and 3 m^3

8.1.2.2. *Effect on Cost*

The cost of the two main treatment modes mainly differ by the following cost elements :

- packages and transport ;
- interim and final storages.

Table VIII-2 gives a comparison of treatment modes of wet solid wastes based on 1m3 of raw wastes. The values which are mentioned in this table correspond to the German economic, technical and safety situation.

As it concerns the concentrates, the cost of the drying into shielded cask technique is 4.6 times lower than the solidification technique.

As it concerns the spent resins, depending on the high or low active types, the cost differences are relatively reduced from + 8% to - 27% (= low active).

If the period of interim storage is increasing (more than 1 year) the economical advantage of the drying technology will become more and more important.

TABLE VIII.2. : COMPARISON OF TREATMENT MODES OF WET SOLID WASTES BASED ON $1 m^3$ OF RAW WASTES (Route Nr. 2)

Treatment mode	Solidification			Drying into shielded cask		
Type of wastes	(*) Concentrates	Spent resins (**) High active	Spent resins (*) Low active	Concentrates	Spent resins High active	Spent resins Low active
Volume modification factor including package	15	15	8	0.75	4	3
Packages and transport costs corresponding to $1 m^3$ of raw wastes	12.3×10^3 ECU	12.3×10^3 ECU	8×10^3 ECU	10.5×10^3 ECU	42×10^3 ECU	32.3×10^3 ECU
Interim (1 year) and final storage costs corresponding to $1 m^3$ of raw wastes	46.5×10^3 ECU	46.5×10^3 ECU	24.8×10^3 ECU	2.35×10^3 ECU	12.4×10^3 ECU	9.3×10^3
Sub Total Cost	58.8×10^3 ECU	58.8×10^3 ECU	32.8×10^3 ECU	12.85×10^3 ECU	54.4×10^3 ECU	41.6×10^3 ECU

* Solidification is performed with cement
** Solidification is performed with polymers

8.2. *INTERIM STORAGE PERIOD (ROUTE PWR3)*

Interim storage periods longer than one year are considered by various countries. It is, therefore, of interest to examine the effect of the duration of the interim storage period on the total cost of the interim storage and disposal system. In this parametric study the reference system consisted of a centralized interim storage followed by surface disposal such as defined in route PWR-3.

The cost assessment and economic assumptions defined in Chapter 3 were followed for this evaluation.

The results are shown in Figure 8.5. The total cost of interim storage and disposal passes through a minimum for an interim storage of 18 years.

This optimum value is affected by financial factors, such as interest rate and inflation. This is illustrated in Figure 8.6 where the total cost of interim storage and disposal is given in function of the interim storage capacity expressed in years for various net discount rates. It is clear that the optimum interim storage period strongly depends on prevailing financial conditions. This period decreases with increasing Net Discount Rate.

8.3. *MOBILE TREATMENT FACILITIES VERSUS FIXED ONES*

In the assumption of an installed park of 20 GWe distributed among 5 sites, two types of wet solid waste treatment facilities were compared on the technical and economical points of view : mobile facilities and fixed ones.

This comparison was performed in the frame of the routes No. 1 and 3 : the respective wet solid waste treatment of each route was considered as reference system.

8.3.1. Route PWR1 Case

The reference system of route PWR-1 for the treatment of wet solid waste includes the following facilities :

- A mobile facility for the embedding of I.E.R.'s into a polymer matrix ;
- Fixed station for the concreting of concentrates/sludges and filters.

The system which has to be compared, only contains mobile concreting units. Those operate with the following main assumptions :

- ▸ 250 days/year with a load factor of 0.66 corresponding to a production period of 165 days/year.
- ▸ One day shift and 6.5 effective working hours per shift dedicated to active waste concreting.

The optimized number of mobile facilities has been evaluated to 5 serving the different wet solid waste as described in Table VIII.3

TABLE VIII.3. : Optimized Number of Mobile Facilities Required

	TYPE OF CONTAINER	NUMBER OF CONTAINERS OR DRUMS/ YEAR/UNIT	OPERATING PERIOD OF THE FACILITIES (IN DAYS)	NUMBER OF MOBILE FACILITIES
Concentrates and sludges	C 1	9	100	1
IER's	C 4	88	433	3*
Filters	C 4	39	222	1**

* Conditioning of IERs : 2 facilities
** Conditioning of filters : 1 facility
* Conditioning of IERS and filters : 1 facility.

One of the concreting facilities is used for the conditioning of both IER's and filters.

With respect to the reference system of route PWR-1, the use of mobile concreting facilities for all the wet solid wastes reduces both capital and operating costs :

- Capital cost reduction is estimated to 10.9 MFF_{88} or 1.4 $MECU_{88}$
- Operating cost reduction is estimated to 6.32 MFF_{88} or 0.9 $MECU_{88}$

Capital cost reduction is due to the deletion of fixed equipment items and a part of the building of the reference system.
On the other hand, the use of mobile concreting facilities reduces the operating cost of the IER'S and filters treatment and conditioning (container cost reduction).

8.3.2. *Route PWR3 Case*

The system using mobile units will include a fixed station devoted to the embedding of solid wastes (filters, technological wastes,...). Both systems- the reference one and this considered for the sensitive study-use cement matrix.

Besides the operating conditions similar to those defined for the route PWR1 case, the MOWA-mobile waste conditioning plant has been retained as mobile unit.

The main characteristics of this mobile unit are the following :

- standard drum : 400 l useful volume ;
- concreting capacities (maximum)
  - 2m^3 IERS/shift (8 hrs)
  - 10 m^3 concentrates/sludges/shift.

The optimized configuration for a system using mobile plants will include two MOWA facilities : one dedicated to the treatment of concentrates/sludges, the other to the IER's.
The economic assessment of this system has shown a slight reduction of the capital cost of 2.55 MECU$_{88}$ corresponding to a reduction factor of 5%. No significant cost reduction regarding the operating cost has been estimated.

8.3.3. *Conclusions*

In the two considered cases, the use of mobile facilities in place of fixed ones for the wet solid waste treatment provides some economical advantages : capital (routes PWR1 and 3) and operating (route PWR1) cost reduction.

Regarding the technical aspects, a lot of qualitative advantages are claimed such as the possibility for the power station operator to get the best state of the art conditioning equipment available and a rapid adaptation of a process in compliance with any requirements issued by the Safety Authorities.

8.4. *BWR RADWASTE MANAGEMENT ROUTE*

8.4.1. *Economical Comparison of the Radwaste Management of PWR and BWR Routes*

The total plant cost for 30 years of operation which reflect the combination of the total capital and operating costs have been evaluated for all the cost elements except the reactor water clean-up system of the radwaste ùmanagement route of BWR1 (see tables 8.1 to 8.3 of annex 1). These cost elements have been compared in table 8.4 with the corresponding elements of the route PWR 2 (German practice).
This table mentions the difference expressed in percentage between the cost elements of both routes.

It can be observed the following main differences :

- Cost of wet waste conditioning of BWR1 route is practically twice the cost of corresponding PWR systems. The reason for this difference lies in the difference of wet waste generation (3,115 m^3 against 580 m^3) and the kind of wet wastes : more spent resins for the BWR than the PWR.

- Cost of liquid waste treatment of BWR1 is 68% more expensive than the corresponding one of PWR. Capacity of the liquid waste treatment of BWR1 route is more than twice this of the PWR-2 route (flow-rate of 25,000 m^3/a against 11,010 m^3/a).

- Cost of off-gas system is 45% more expensive than the corresponding one of PWR. In the same way than the previous cases, the difference of capacities explains the difference of cost (200,000 Nm^3/a against 90,000 Nm^3/a).

TABLE VIII.4. COMPARISON OF COST ELEMENTS (total cost) of routes PWR2 and BWR1 (German practice)

Cost element	Total cost for 30 years operation ($MECU_{92}$)		Difference BWR1/PWR2
	PWR2	BWR1	%
- Site Improvement	35.88	38.15	6.3
- Civil Works	144.52	180.8	25.2
Unit Operations			
- Primary coolant treatment/ Reactor Water clean-up system	287.17	not available	
- Liquid Waste treatment	286.06	484.6	68.7
- Off-gas + (leak-off systems)	305.11	442.16	45
- Ventilation	69.07	95.43	38.1
- Wet Waste Conditioning	191.05	347.32	81.8
- Dry Waste treatment	170.62	170.02	-
- Interim storage	18.25	23.74	30
- Quality Assurance	102.25	108.71	6.3
- Indirect construction	45.39	48.25	6.3
- Laboratory	20.83	21.2	1.7
- Safety and health physics	55.02	56.13	2
- Labour associated with plant operation	37.31	37.31	-
- Overheads	44.78	44.78	-

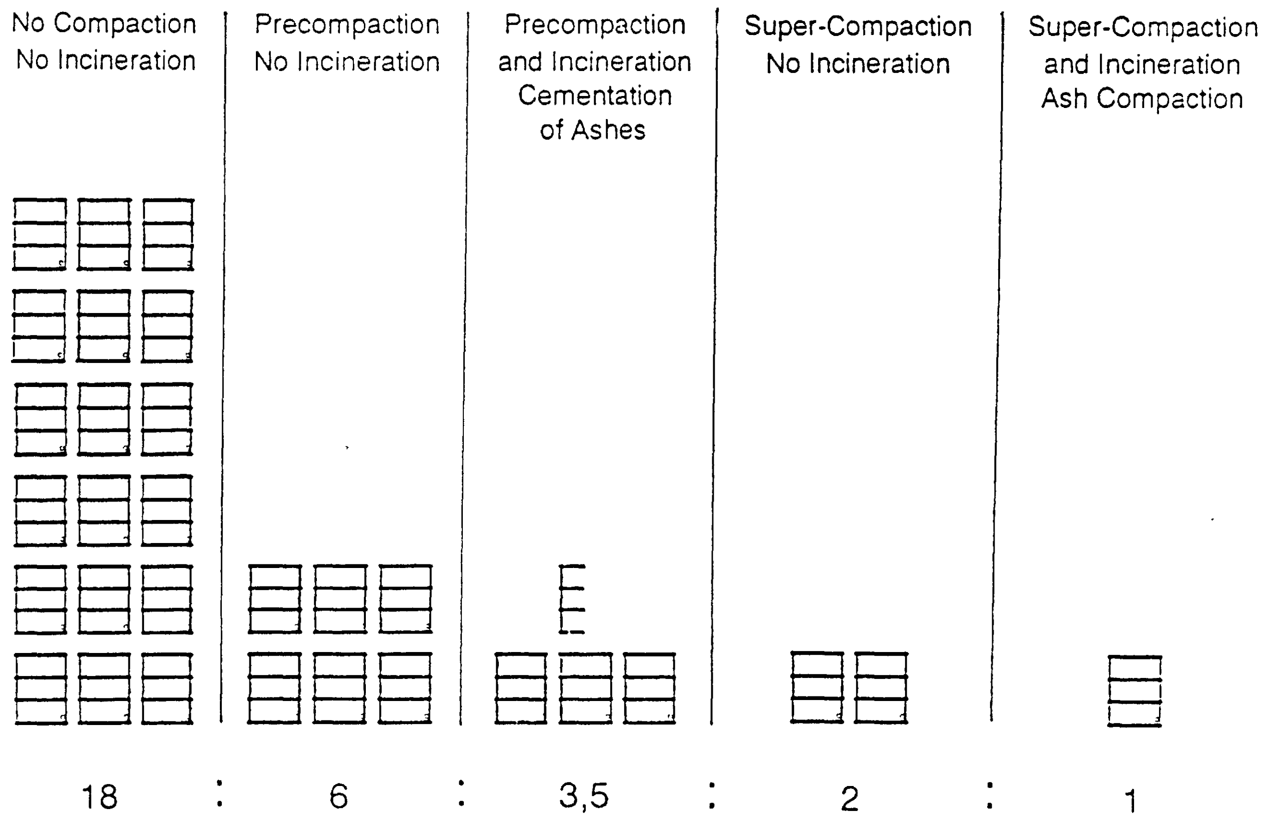
8.4.2. *Economical Comparison of Elements of BWR Routes*

The total cost for 30 years of operation have been evaluated for some unit operations (see tables VIII.4 to VIII.5 of annex 1). These cost elements have been compared in table VIII.5.

The cost of off-gas treatment of BWR1 route is more expensive than the BWR2 one. Gaseous wastes treatment system of BWR1 route is designed to handle not only the gas extracted from the main condenser but also gas leakages originating from gland of valves.

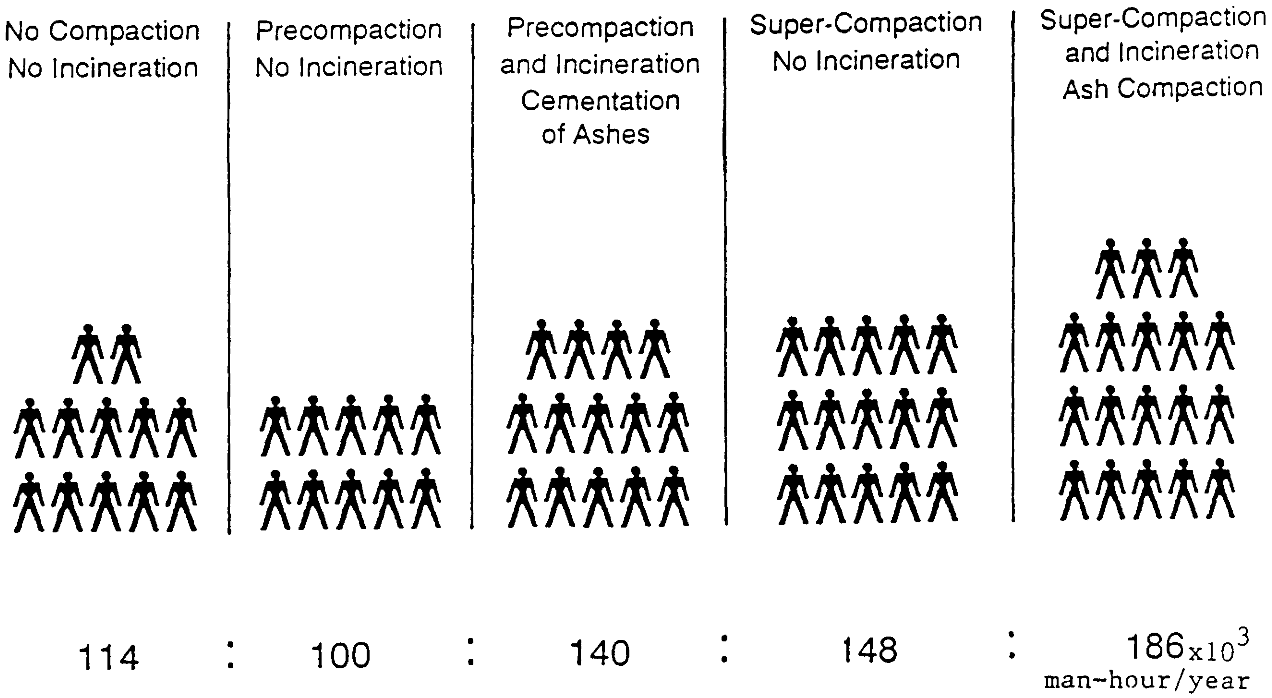
TABLE VIII.5 COMPARISON OF SOME COST ELEMENTS (total cost) OF RADWASTE MANAGEMENT BWR1 and 2 ROUTES (German and Spanish practice).

Cost Element	Total Cost for 30 years Operation ($MECU_{92}$)		Difference BWR1/BWR2
	BWR1	BWR2	%
- Liquid Waste treatment	484.6	495.59	- 2.2
- Off-gas treatment	442.16	380.83	+ 16.1
- Interim storage	23.74	29.25	- 18.8



Precompaction force: 20 tons; Super-Compaction: 1500 tons

Fig. 8.1 : Volume Reduction Ratios for Different Treatment Modes of Solid Radioactive Waste



Precompaction force: 20 tons; Super-Compaction: 1500 tons

Fig. 8.2 : Waste Handling Effort for the Different Treatment Modes of Mixed Solid Waste.

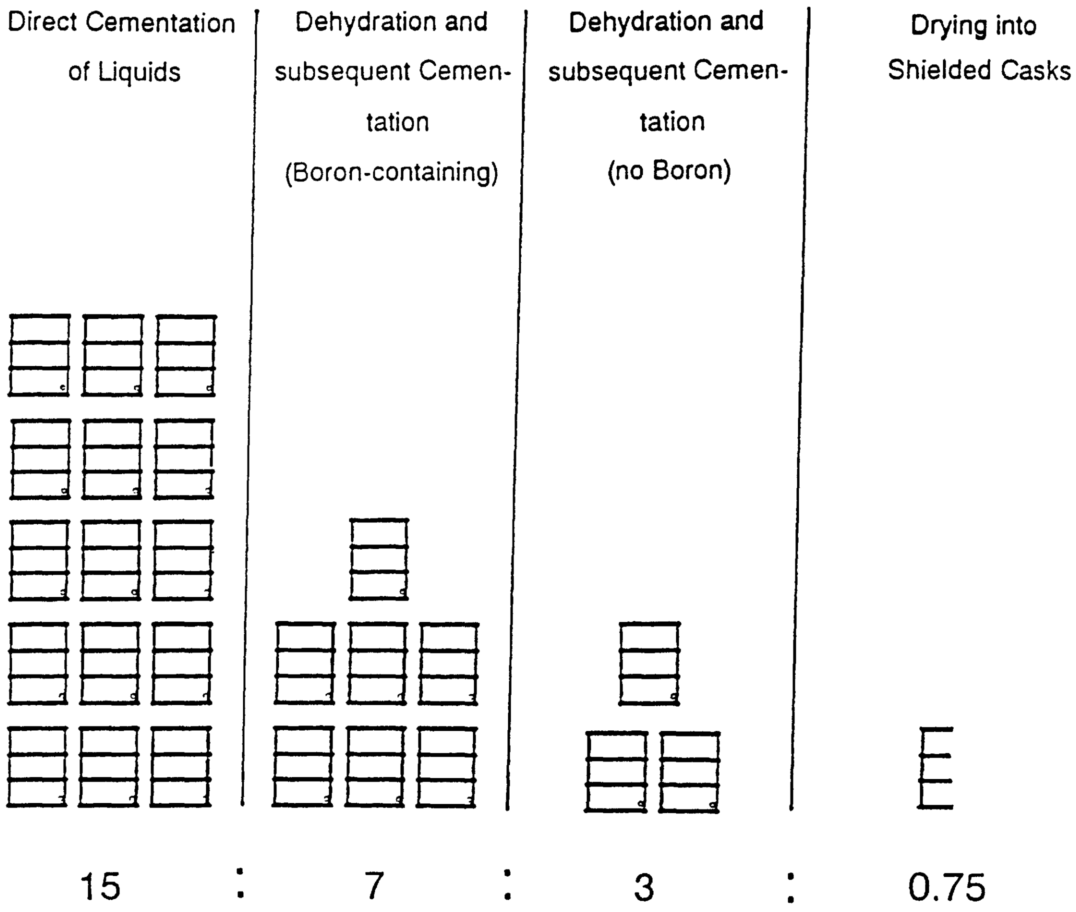


Fig. 8.3 : Disposal volumes for Different Treatment Modes of Liquid Concentrates (Volumes incl. shielded packages corresponding to 1 m^3 of raw waste)

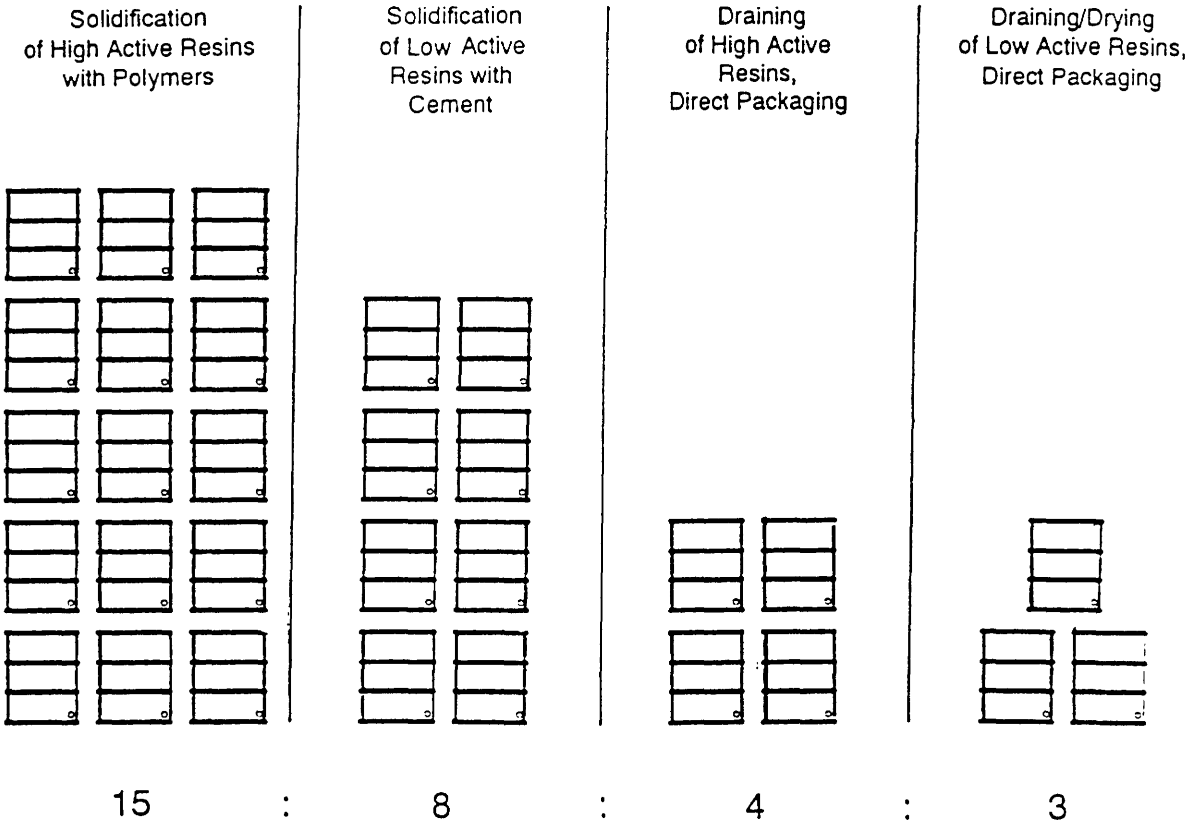


Fig. 8.4 : Disposal Volumes for Different Treatment Modes of Spent Resins (Volumes incl. shielded packages and correspond to 1 m^3 untreated resin)

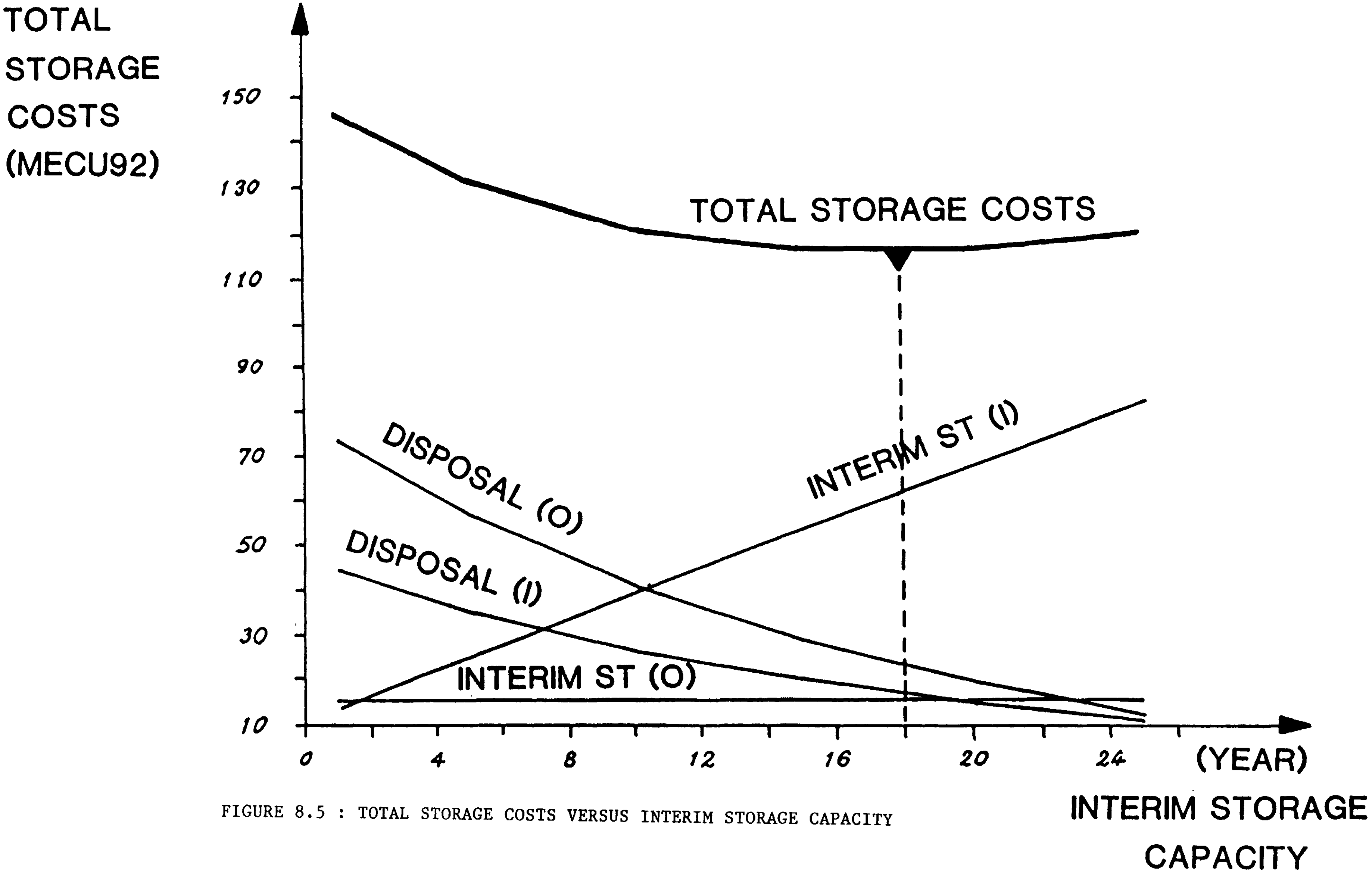


FIGURE 8.5 : TOTAL STORAGE COSTS VERSUS INTERIM STORAGE CAPACITY

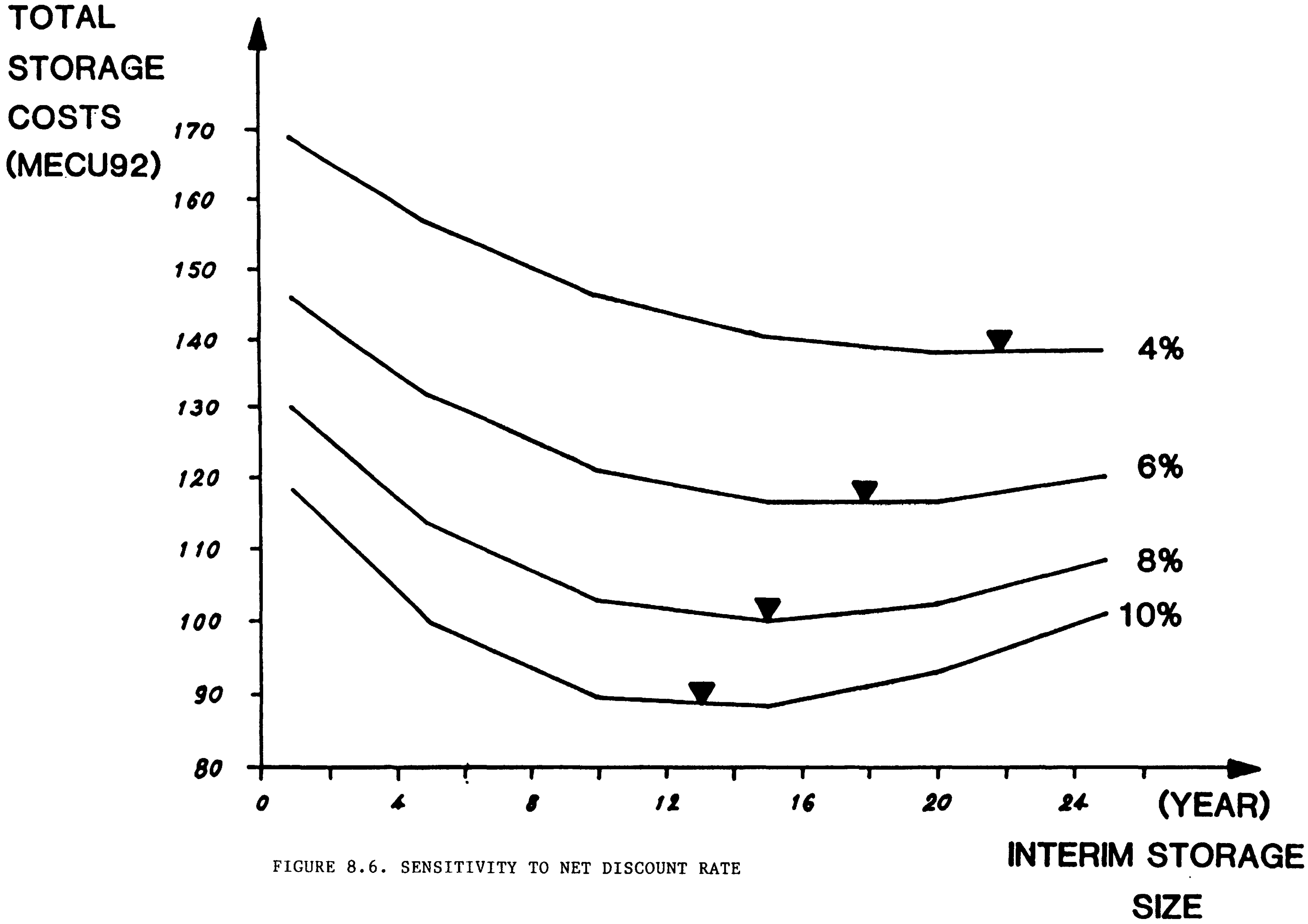


FIGURE 8.6. SENSITIVITY TO NET DISCOUNT RATE

9. *SUMMARY AND CONCLUSIONS*

9.1. *SCOPE OF THE STUDY*

The main objective of this theoretical study was to assess the different practices used to manage liquid, gaseous and solid radwastes arising from operation of light water reactors.

Different practices means processes or technologies used in the late eighties by European countries for the power units and recent developments in radwaste disposal systems. Technical, economic and radiological aspects were considered in this evaluation.

Sensitivity studies examined the effects of selecting different technologies for solid waste treatment on radwaste packages and cost and of varying the interim storage period on overall cost.

The study was focused mainly on PWR radwastes. Some technical and economic evaluations were performed for the BWR within the framework of sensitivity studies.

9.2. *BASIC ASSUMPTIONS*

- The routes are defined for the overall management of radwastes from their production and treatment inside the power station to their release, for gaseous and liquid effluents and their disposal for the radwaste packages, and also include transport.
- In order to analyse and compare the various routes a 20 GWe nuclear park of light water reactors situated on 5 sites was selected as reference scenario.
- Wastes inventories corresponding to each route were derived from operating figures originating from the reference reactor selected for each route. However, a typical European waste inventory was established, for the sake of harmonization, for the evaluation of the environmental impact associated with each route.
- The radwaste packages were assumed to be placed in interim storage facilities during a 1 year period, followed by disposal in near-surface or geological storage systems.

9.3. *METHODOLOGY*

Waste inventories related to each route (3PWR + 2BWR routes) were established for liquid, gaseous and solid wastes with the emphasis on the solid category. The latter was decomposed into wet and dry wastes and their volumes before and after conditioning were quoted.

All the intermediate management stages entering into each of the routes were defined. The main stages corresponding to the operations inside each reference reactor were analysed. Detailed operations of treatment and conditioning of the effluents were grouped into unit operations serving the same purpose. These unit operations were identified on the corresponding flow-sheets and engineering flow diagrams.

Standardisation of costing for the PWR routes was performed on the basis of engineered flow-sheets and flow-diagrams where available. The cost of unit operations was calculated from price values for major equipment or "base values" found in the chemical industry on the German market. Otherwise, the cost of unit operations was either directly provided by plant operators or estimated.

The cost of major equipment having been defined, a cost evaluation method was applied for the overall plant cost of the 5 routes. The cost of the elements considered for the evaluation was calculated in ECU_{88}. A cost projection for all the facilities was performed using the present worth method. The date of actualisation of the cost corresponds to an assumed start-up of the radwaste facilities in 1992.

The radiological impact on the public resulting from discharges of gaseous and liquid effluents into the environment was evaluated for the three PWR-routes. The methodology developed by BELGATOM for the TIHANGE 2 PWR reactor in Belgium was applied for the estimation of annual individual maximum doses as well as of collective doses to different groups of population. The long-term radiological impact linked to waste disposal was also assessed for near surface sites. Two distinct methodologies were applied : the first, which was developed by CEN/Fontenay-aux-Roses refers to the "Centre de stockage de l'Aube" while the second pertains to the Spanish disposal concept named "Below-Ground Vaults".

9.4. *RESULTS*

This study on the management of waste arising from a 20 GWe LWR park operated for 30 years has demonstrated the following results.

9.4.1. Technical Level

Regarding PWR'S , it has been shown that the three routes studied diverge considerably in the management of their gaseous and solid wastes.

- *Gaseous Wastes*

  In Germany (route PWR2), the gaseous treatment system is designed not only to control the H_2 explosion risk during normal operation via a recombiner but also to take care of possible accident conditions (recombination of hydrogen released in the reactor confinement under abnormal conditions) which involves an overcapacity of the recombiner unit. Moreover, delaying of noble gases is ensured by the active charcoal bed technology.
  The decay tanks technology is applied in France and Belgium. In addition, Belgian gaseous waste systems permits the removal of hydrogen from the gaseous effluents circuits during normal operation (processing capacity of the recombiner is about 10 times lower than that used in the German practice).

- *Solid Wastes*

  The management strategies applied to the solid wastes explains the differences observed in the generation of conditioned wastes, i.e. :

- *Wet Wastes*

  - Drying in a shielded cask of concentrates and spent resins as practiced in Germany (route PWR2) gives volume modification factors as compared to the embedding technique that vary from 20 to 2.7. This treatment alternative gives rise to the lowest generation of conditioned wet radwastes.

  - The use of concrete containers as is the case in France (route PWR-1) instead of the 400 l metallic drums in Belgium leads to double the volume of conditioned wet wastes.

- *Dry Wastes*
  - ▸ The maximum volume reduction factor (5x) is obtained by the French route (PWR1), despite the use of only one reduction technique (compaction).
  - ▸ The techniques of compaction and incineration applied in the German (PWR2) and Belgian (PWR3) routes decrease the volume by 9 and 40x respectively. These large intrinsic reduction factors are counterbalanced by use of additional storage containers (German practice) and by concreting the ashes resulting from incineration (Belgian practice).

  Liquid waste management is similar for all three routes. However, differences of wet solid wastes in the generation are noted due to the greater use of the demineralization technique (Ion-exchange resin) rather than the evaporation technique for the purification of liquid waste effluents in France.

As regards BWR radwaste management, an analysis restricted to 2 routes has led to the same conclusions : differences exist essentially in the management of gaseous and solid wastes.

- The processing capacity of the gaseous waste treatment system of the German reference reactor (route BWR1) is about 8 times higher than the Spanish one (route BWR2) : gaseous effluents with very low level activity are treated in the off-gas treatment system of the German reactor.
- Conditioned wet and dry wastes volumes differ as a function of the applied technology applied :
- Wet wastes : direct drying in a shielded cask for route BWR1 (Germany) ; cement embedding for route BWR2 (Spain).
- Dry waste : compaction and incineration plus overpacking for route BWR1 (Germany) ; compaction for route BWR2 (Spain).

Concerning a comparison of radwaste management for BWR and PWR routes, the high generation level of spent resins produced by the BWR route must be pointed out : 5 times more than for the PWR route.

9.4.2. *Economic Level*

Appreciable cost differences were observed between the three PWR routes. The difference of the total cost (operating for 30 years + capital costs) of the complete sequence of radwaste management from generation to disposal reaches 40% between the maximum (German practice) and the minimum (French practice). This cost difference is mainly due to the following unit operations : boron recycling, liquid waste, gaseous and dry solid waste treatment. The cost divergences result from the applied design criteria used for the radwaste facilities of the three reference reactors. These design criteria (level of redundancy, requirements for evacuation of packages, additional safety requirements) are enforced by National Safety Authorities.

Moreover, a cost analysis of the three routes leads to the following obervations :

- The cost for disposal of conditioned waste is relatively low (about 10%) by comparison with the overall costs.
- Deep underground disposal costs have a greater impact than those associated with near surface disposal.
- Transport costs remain below 3%.

Some sensitivity studies were performed on the conditioning techniques for solid wastes.

The first study carried out in the framework of route PWR2 (German practice) concerned a comparison of the treatment of dry solid waste by compaction or by a combination of compaction plus incineration.

Incineration combined with supercompaction provides a volume reduction factor (including the package) that is 4 times greater than is obtained by supercompaction. The investment and cost of operating the treatment combining the two technologies is 60% higher than for supercompaction alone.

In the second study, also performed within the framework of route PWR2 (German practice), the techniques of embedding into cement or direct drying in a shielded cask were compared for concentrates and spent resins.

The cost of direct drying of concentrates in a shielded cask is 4.6 times cheaper than the embedding technique, taking into account packaging, transport, interim storage and disposal costs. This technique is only 8% cheaper for highly active spent resins and 27% more expensive for low active ones.

The use of mobile facilities in place of fixed ones for the wet solid waste treatment studied within the framework of routes PWR1 and 3 (French and Belgian practices respectively) shows a slight economic advantage. The main interest of such a mobile facility is the possible rapid adaptation of a process to requirements issued by the Safety Authorities.

Finally, the effect of the duration of the interim storage period on the total cost of the interim storage and disposal system was analysed within the framework of route PWR3 (Belgian practice). The total cost passes through a minimum for an interim storage period of 18 years. This optimum period is affected by financial factors, such as interest rate and inflation.

9.4.3. *Radiological Impact*

The radiological impact on the public from discharges of radioactivity into the environment assessed for the three PWR-routes reflects the decontamination efficiencies of the gaseous and liquid effluents.

The maximum annual individual doses due to airborne releases were calculated for various organs and for the whole body.

The most important doses are related to the action of I-131 on the thyroid. Even in the case of the PWR1 route, the maximum individual dose is always well below the maximum admissible dose limit.

In the same way, maximum annual individual doses due to radioactive liquid releases were calculated for the most exposed organs and for the whole body.

Doses to the thyroid are similar and extremely low for all the three routes. Significant differences appears for doses to the liver and to the whole body as a consequence of the discharges of Cs-134 and Cs-137, which are themselves a result of the non-processing of floor waste in the case of the PWR-1 route.

Route PWR2 (German practice) which appears to be the most expensive one also proved to be the least detrimental in terms of discharges

However maximum annual individual doses due to airborne and liquid releases are much lower than the safety requirement level.
The determination of collective doses due to disposal of reactor wastes in near surface sites provided very similar results for both disposal concepts, showing no significant radiological impact to the public even in the distant future.

9.5. *GENERAL CONCLUSIONS*

In a general way, the study to assess waste management practices in four European Countries has revealed the major influence of the state of development of the disposal option for conditioned wastes on the strategy of management of LWR wastes.

In Germany and Belgium, where the final choice of a disposal system has not yet been made (open waste management alternative), volume reduction is a major objective. This involves the use of techniques of direct in-cask drying of wet wastes and incineration of dry wastes.

In France, where near-surface disposal is available and operates at relatively low cost, the volume reduction is achieved by compaction. The incineration technique appears to be economically unfavourable in the different management routes analysed : increase of volume reduction (interim and final storage profits) does not counterbalance the investment and operation costs of this technique.

Finally, this comparative analysis of the radwaste management routes practiced in the four European countries has highlighted differences of efficiency which are paid for by differences in cost. But all three radwaste management chains studied lead to activities of airborne and liquid releases that are much lower than the safety requirement limits enforced by the national Safety Authorities.

ANNEX 1

ASSESSMENT OF THE BWR PLANT COSTS

1. *ASSESSMENT OF THE BWR PLANT COSTS*

The cost estimates of the BWR waste management routes refer to the treatment of the radioactive effluents arising from a 20 GWe nuclear park of standard BWR's. The treatment and conditioning plants are located on each reactor site (single or twin), whereas the interim storage stores the conditioned waste products from the whole nuclear park (20 GWe).

The following input data were established to perform the cost actualisation of both BWR waste management routes :

- Construction period of the plant : 4a
- Start of construction : 01.01.88
- Date of actualisation : 01.01.92
- Duration of plant operation : 30 a

Thus, the bar chart shown in Fig. 3.3. of volume Nr.1 is valid for both routes.

1.1. *ROUTE BWR1*

The assessment of the German route is based on the cost data provided by GNS-FRAMATOME . However since no costs nor a complete technical description (ventilation and reactor water clean-up system) were provided, BELGATOM has inserted some estimates for the lacking data. These estimates are correlated with those carried out for the PWR2 route.

The following specific data were used for the German route as basis for the calculations :

- Basic data provided for a 1.3 GWe unit
- Adjustment factor to 20 GWe : 15.385.
- Building volumes for 20 GWe capacity
- Process building : 1,030,769 m^3.
- Interim storage : 23,750 m^3 (1a capacity)
- Total volume : 1,054,519 m^3
- Average cost for civil Works : 135 ECU m^3.
- Architectural and Engineering Services : 4.4 % of the direct capital cost.

The acquisition of all the mobile conditioning units and incinerator by the plant owner has been considered

The material costs of the Major Equipment of the various unit operations and the Base value are shown in table VIII.1.

Additional details on the unit operations are given in table VIII.2. Finally, the actualised capital and annual operating costs for route BWR-1 are reported in Table VIII.3.

Table VIII.1. : ***Indicative Material Cost of the Major Equipment for the Different Unit Operations and Base Value of Route BWR1 (20 GWe).***

All the figures are quoted for 1988.

UNIT OPERATION	TOTAL COST ($MECU_{88}$)
Liquid Waste treatment	103.77
Off gas treatment) +) Leak off system)	94.338
Ventilation	15.492 *
Wet Waste conditioning	2.55
Dry Waste treatment	
. Precompaction	0.277
. Supercompaction + incineration	3.73
Interim storage (1a capacity)	1.890
Base Value	222.05

* BA estimates : . (hourly flow rate 2 x 10^5.Nm^3/h
against 1.5 x 10.^{5} Nm^3/h (PWR)
. Base value PWR2 : 11.62 $MECU_{88}$

Table VIII.2. : Analysis of the Various Unit Operations of Route BWR1 (20 GWe).

All figures are given in MECU$_{88}$ for the capital cost and in MECU$_{88}$ a^{-1} for the operating cost

UNIT OPERATION : Liquid Waste treatment			
Major Equipment :	103.77	Process Mat.	: 0.54
		Utilities	: 0.96
Bulk Materials	67.45	Maintenance Mat.	: 8.561
Install. labour	98.58	Direct labour	: 0.488
Capital cost	269.80	Operating cost	10.55
UNIT OPERATION : Off-gas + leak-off systems			
Major Equipment	94.338	Process mat.	: 0.55
Bulk Materials	61.32	Utilies	: 0.88
		Mainten. Mat.	: 7.78
Inst. labour	89.62	Direct Labour	:0.488
Capital Cost	245.28	Operating Cost	: 9.7
UNIT OPERATION : Ventilation			
Major Equipment	15.492	Process Mat	: 1.06
Bulk Materials	1.66	Utilities	: 0.28
		Maint. Mat	: -
Inst. Labour	2.43	Direct labour	: 0.488
Capital	40.28	Operating Cost	: 3.11
UNIT OPERATION : Wet Waste Conditioning			
Major eq.	2.55	Process Mat.	19.95
Bulk Materials		Utilities	2.05
		Maint. Mat	
Inst. labour		Direct labour	0.523
Capital cost	6.64	Operating Cost	22.52

UNIT OPERATION : Dry Waste treatment (Supercompaction + incineration)			
Major Equipment	3.73	Process Mat	2.763
Bulk Materials	2.42	Utilities	0.6
		Maint. Mat.	0.03
Inst. labour	3.55		
		Direct labour	3.24
Capital cost	9.70	Operating cost	6.63

UNIT OPERATION : Dry Waste treatment (Technological Waste Pre-compaction)			
Major éq.	0.277	Proc. Mat	0.45
Bulk Mat.	0.180	Utilities	0.28
		Maint. Mat.	0.23
Inst. labour	0.263	Direct labour	2.11
Capital cost	0.869	Operating Cost	

UNIT OPERATION : Interim storage (1a capacity)			
Major equipmt.	1.890	Process Mat	-
Bulk materials	1.228	Utilities	0.101
		Maint. Mat.	0.156
Inst. labour	1.795	Direct Labour	0.915
Capital cost	4.914	Operating Cost	1.181

Table VIII.3. : Actualised Capital and Annual Operating Costs for Route BWR1 (20 GWe).

The capital cost is defined as the combined costs for material and labour of each cost element

Cost element	Capital cost (MECU$_{92}$)	Operating Cost (MECU$_{92}$.a^{-1})
Site Improvement	38.15	-
Civil works	180.797	-
Unit Operations		
- Reactor Water clean-up	not	available
- Liquid Waste treatment	325.65	11.51
- Off-gas + leak-off systems	296.05	10.58
- Ventilation	48.62	3.39
- Wet Waste Conditioning	8.01	24.57
- Dry Waste treatment		
. Pre-compaction	0.869	3.27
. Supercomp. + incineration	11.723	8.13
- Interim storage	5.93	1.29
Quality Assurance	108.71	-
Indirect construction	48.25	-
Laboratory	6.27	1.081*
Safety and Health physics	18.82	2.702*
Architectural and Eng. services	48.39	
Labour associated with plant operation	-	2.702*
Overheads		3.243*
Sub total	1,146.050	72.468

* Values similar to those of PWR2 (German route)

1.2. *ROUTE BWR2*

The assessment of the Spanish route is based on the cost data provided by INYPSA-SGN. However since no costs have been given for the solid waste treatment, the ventilation and the Reactor water clean up system, a complete assessment of the route BWR2 has not been performed.
The following specific data were used for the Spanish route as basis for the calculations.

- Basic data provided for a 0.975 GWe unit.
- Adjustement factor to 20 GWe : 20.513
- Building volumes for 20 GWe capacity :
- Process building 798086 m^3
- Interim storage 51,914 m^3 (1a capacity)
- Total volume : 850,000 m^3.
- Average cost for Civil Works : 135 ECU/m^3.

The material costs of the Major Equipment, the base value of some various units operation and the corresponding actualised capital and operating costs are shown in tables VIII.4 and VIII.5.

Table VIII.4. : Indicative Material Cost of the Major Equipment for the Different Unit Operations and Base Value of Route BWR2 (20 GWe).

All the figures are quoted for 1988.

UNIT OPERATION	TOTAL COST ($MECU_{88}$)
1. Liquid Waste treatment	77.57
1.1. Low conductivity	15.51
1.2. High conductivity	31.03
1.3. Detergent system	31.03
2. Off-Gas treatment	77.57
3. Interim storage (1 a capacity)	3.00
Base Value	158.14

Table VIII.5. : Analysis of Various Unit Operations of Route BWR2 (20 GWe).

All figures are given in $MECU_{88}$ for the capital cost and in $MECU_{88}$ a^{-1} for the operating cost.

UNIT OPERATION : Liquid Waste Treatment			
Major Equipment	77.57	Process Mat.	0.465
		Utilities	1.523
Bulk Materials	50.42	Maint. Mat.	6.40
		Direct Labour	8.369
Install. Labour	73.69		
Capital Cost	201.68	Operating Cost	16.757

UNIT OPERATION : Off Gas Treatment			
Major Equipment	77.57	Process Mat.	0.155
		Utilities	0.83
Bulk Materials	50.42	Mainten. Mat	6.40
		Direct Labour	1.744
Install. Labour	73.69		
Capital cost	201.68	Operating Cost	9.129

UNIT OPERATION : Interim Storage			
Major Equipment	3.00	Process Mat	-
		Utilities	0.120
Bulk Materials	1.95	Maintain. Mat.	0.248
		Direct Labour	0.950
Install. Labour	2.85		
Capital cost	7.80	Operating cost	1.318

ANNEX 2

ELEMENTS OF CALCULATION OF THE RADIOLOGICAL IMPACT

TABLE 7.1. PRIMARY WASTE INVENTORIES FOR LIQUIDS (PWR's)

WASTE ORIGIN	SPECIFIC ACTIVITY (ANNUAL ARISING)
Primary circuit effluents	3.7 GBq/m^3 (without gas) (10 000 m^3/a)
Secondary drain waste	370 MBq/m^3 (2 500 m^3/a)
Laundry waste	370 KBq/m^3 (on average) (4 000 m^3/a)
Decontamination operations	370 MBq/m^3 (10 m^3/a)
Chemicals	37 MBq/m^3 (1 500 m^3/a)
Building or floor waste	37 MBq/m^3 (3 000 m^3/a)

TABLE 7.2. RADIONUCLIDE COMPOSITION FOR THE PRIMARY CIRCUIT EFFLUENTS

Radionuclide		Mn-54	Co-58	Co-60	Sr-90	Nb-95	Mo-99	Ag-110m
%		0.44	3.0	0.6	0.018	0.001	0.44	0.44
Radionuclide	Sb-124	I-131	I-132	I-133	I-134	I-135	Cs-134	Cs-137
%	0.44	10.4	18.2	31.2	10.2	20.8	1.79	1.79

H - 3 : 22.2 GBq/m^3

TABLE 7.3. RADIONUCLIDE COMPOSITION FOR ALL THE OTHER AUXILIARY LIQUID EFFLUENTS

Radionuclide	H-3	Mn-54	Co-58	Co-60	Sr-90	Nb-95	Mo-99	Ag-110m
%	1	4.75	31.66	6.33	0.19	0.013	4.75	4.75
Radionuclide	Sb-124	I-131	I-132	I-133	I-134	I-135	Cs-134	Cs-137
%	4.75	0.46	0.79	1.38	0.46	0.92	19.00	19.00

TABLE 7.4. GASEOUS WASTE INVENTORIES (PWR's)

WASTE ORIGIN	ARISINGS SPECIFIC ACTIVITY
Chem. & volume control system + primary circuit degasing	10 000 Nm^3/a 111 GBq/Nm^3
Ventilation	150 000 Nm^3/h 18.5 KBq/Nm^3

TABLE 7.5. RADIONUCLIDE COMPOSITION FOR GAS (PWR's)

Radionuclide		Kr-85	Kr-58m	Kr-87	Kr-88	Xe-133	Xe-133m
%		0.03	1.83	1.25	3.32	80.41	1.75
Radionuclide	Xe-135	I-131	I-132	I-133	I-134	I-135	Aerosols
%	11.31	0.01	0.02	0.03	0.01	0.02	0.00001

C - 14 = 200 GBq/a (upstream any recovery system)
H-3 = 5.55 TBq/a

TABLE 7.6. DFs ACHIEVED DURING TREATMENT OF THE PRIMARY LIQUID AND GASEOUS WASTES GENERATED IN THE 3 BASIC ROUTES

WASTE TYPE	RADIONUCLIDE	ROUTE N° 1 (French case)	ROUTE N° 2 (German case)	ROUTE N° 3 (Belgian case)
Gaseous	I C-14 Aerosols Noble Gases	10 1 3000 1	1000 1 100 1	10 1 100 1
Gaseous (ventilation)	I C-14 Aerosols Noble gases	1 1 3000 1	1000 1 100 1	1 1 100 1
Primary liquid waste	I	10^2 (dem) x 10^3 (evap)	5 (dem) x 10^4 (evap) = 5 x 10^4	10^1 (dem) x 10^2 (evap) = 10^3
	Others	= 10^3		10^2 (dem) x 10^3 (evap) = 10^5
Secondary liquid waste	I	10^2 (dem)	Overall DF = 30 to comply with discharge limits in the FRG 37 GBq/a	10^3 (evap)
	Others			10^4 (evap)
Laundry waste	All	1		1
Chemical and decontamination waste	All	10^3 (evap)		10 (floc)
Building waste	All	1		10 (floc) x 10^2 (evap) = 10^3

TABLE 7.7. ESTIMATION OF THE STORAGE PERIOD IN DECAY TANKS OF THE HYDROGENATED GASEOUS WASTES GENERATED IN THE THREE BASIC ROUTES

ROUTE N°	DECAY TIME (d)
PWR1	22 for all radionuclides
PWR2	60 for Xe 2.5 for Kr
PWR3	54 for all radionuclides

TABLE 7.8. ANNUAL ACTIVITIES (GBq/a) RELEASED FROM 1 X 900 MWe PWR AS AIRBORNE EFFLUENTS (MIXTURE OF ALL) FOR THE THREE MANAGEMENT ROUTES

RADIONUCLIDE	RELEASE FROM ROUTE N°		
	PWR1	PWR2	PWR3
I-131	3.85	114.70×10^{-3}	2.41
I-133	7.40	340.40×10^{-3}	7.40
Cs-137	18.50×10^{-6}	555.00×10^{-6}	573.50×10^{-6}
Co-60	18.50×10^{-6}	555.00×10^{-6}	573.50×10^{-6}
C-14	199.80	199.80	199.80
Kr-85	333.00	333.00	333.00
Kr-85m	444.00	445.85	444.00
Kr-87	303.40	303.40	303.40
Kr-88	814.00	814.00	814.00
Xe-133	60.37×10^{3}	19.87×10^{3}	20.35×10^{3}
Xe-133m	451.40	444.00	444.00
Xe-135	2.74×10^{3}	2.74×10^{3}	2.74×10^{3}
H-3	5.55×10^{3}	5.55×10^{3}	5.55×10^{3}
TOTAL	71.22×10^{3}	30.70×10^{3}	31.19×10^{3}

TABLE 7.9. ANNUAL ACTIVITIES (GBq/a) RELEASED FROM 1 X 900 MWe PWR AS LIQUID EFFLUENTS (MIXTURE OF ALL) FOR THE THREE MANAGEMENT ROUTES.

RADIONUCLIDE	RELEASE FROM ROUTE N°		
	PWR1	PWR2	PWR3
I-131	536.50 x 10^{-3}	222.00 x 10^{-3}	3.33
I-133	832.50 x 10^{-3}	555.00 x 10^{-3}	3.51
Cs-134	23.13	7.03	1.50
Cs-137	23.13	7.03	1.50
Co-58	38.67	11.47	2.41
Co-60	7.77	2.33	518.00 x 10^{-3}
Mn-54	5.74	1.74	370.00 x 10^{-3}
Sr-90	222 x 10^{-3}	70.30 x 10^{-3}	14.99 x 10^{-3}
Nb-95	15.91 x 10^{-3}	4.81 x 10^{-3}	999.00 x 10^{-6}
Mo-99	4.44	1.74	407.00 x 10^{-3}
Ag-110m	5.92	1.74	370 x 10^{-3}
Sb-124	5.92	1.74	370 x 10^{-3}
H-3	22.20 x 10^{3}	22.20 x 10^{3}	22.20 x 10^{3}
TOTAL	22.32 x 10^{3}	22.24 x 10^{3}	22.21 x 10^{3}

TABLE 7.10. **MAXIMUM DOSES TO ADULT CRITICAL INDIVIDUAL LIVING AROUND A NUCLEAR SITE WITH FOUR 900 MWe PWR UNITS (mSv/a) DUE TO GASEOUS EFFLUENT RELEASES. CASE OF PWR1 ROUTE**

RADIONUCLIDE	DOSE TO		
	THYROID	SKIN	WHOLE BODY
I-131	4.92×10^{-2}	1.40×10^{-5}	1.60×10^{-4}
I-133	6.40×10^{-4}	1.20×10^{-6}	2.20×10^{-4}
Cs-137	2.40×10^{-10}	2.90×10^{-10}	5.70×10^{-10}
Co-60	5.30×10^{-10}	6.00×10^{-10}	5.3×10^{-10}
C-14	4.4×10^{-3}	----	4.4×10^{-3}
Kr-85	----	3.20×10^{-5}	----
Kr-85m	----	----	----
Kr-87	----	5.60×10^{-5}	----
Kr-88	----	2.00×10^{-4}	----
Xe-133	----	1.5×10^{-3}	7.4×10^{-4}
Xe-133m	----	----	----
Xe-135	----	1.2×10^{-4}	6.4×10^{-5}
H-3	2.6×10^{-4}	----	2.6×10^{-4}
TOTAL	5.45×10^{-2}	0.19×10^{-2}	0.56×10^{-2}

TABLE 7.11. MAXIMUM DOSES TO ADULT CRITICAL INDIVIDUAL LIVING AROUND A NUCLEAR SITE WITH FOUR 900 MWe PWR UNITS (mSv/a) DUE TO GASEOUS EFFLUENT RELEASES. CASE OF PWR2 ROUTE

RADIONUCLIDE	DOSE TO		
	THYROID	SKIN	WHOLE BODY
I-131	1.40 x 10^{-3}	4.00 x 10^{-7}	4.80 x 10^{-6}
I-133	3.00 x 10^{-5}	5.20 x 10^{-8}	1.00 x 10^{-7}
Cs-137	3.40 x 10^{-9}	4.00 x 10^{-9}	7.60 x 10^{-8}
Co-60	7.20 x 10^{-9}	8.40 x 10^{-9}	7.20 x 10^{-9}
C-14	4.40 x 10^{-3}	----	4.40 x 10^{-3}
Kr-85	----	3.20 x 10^{-5}	----
Kr-85m	----	----	----
Kr-87	----	5.60 x 10^{-5}	----
Kr-88	----	2.00 x 10^{-4}	1.70 x 10^{-4}
Xe-133	----	4.80 x 10^{-4}	2.40 x 10^{-4}
Xe-133	----	----	----
Xe-135	----	1.20 x 10^{-4}	6.40 x 10^{-5}
H-3	2.60 x 10^{-4}	----	2.60 x 10^{-4}
TOTAL	0.6 x 10^{-2}	0.09 x 10^{-2}	0.52 x 10^{-2}

TABLE 7.12. MAXIMUM DOSES TO ADULT CRITICAL INDIVIDUAL LIVING AROUND A NUCLEAR SITE WITH FOUR 900 MWe PWR UNITS (mSv/a) DUE TO GASEOUS EFFLUENT RELEASES. CASE OF PWR3 ROUTE

RADIONUCLIDE	DOSE TO		
	THYROID	SKIN	WHOLE BODY
I-131	3.10×10^{-2}	8.50×10^{-6}	1.00×10^{-4}
I-133	6.40×10^{-4}	1.20×10^{-6}	2.20×10^{-6}
Cs-137	1.00×10^{-8}	1.20×10^{-8}	2.40×10^{-8}
Co-60	2.30×10^{-8}	2.60×10^{-8}	2.30×10^{-8}
C-14	4.40×10^{-3}	----	4.40×10^{-3}
Kr-85	----	3.20×10^{-5}	----
Kr-85m	----	----	----
Kr-87	----	5.60×10^{-5}	----
Kr-88	----	2.00×10^{-4}	1.70×10^{-4}
Xe-133	----	5.10×10^{-4}	2.50×10^{-4}
Xe-133m	----	----	----
Xe-135	----	1.20×10^{-4}	6.40×10^{-5}
H-3	2.60×10^{-4}	----	2.60×10^{-4}
TOTAL	3.63×10^{-2}	0.09×10^{-2}	0.53×10^{-2}

TABLE 7.13. COLLECTIVE DOSES MAN-Sv DUE TO GASEOUS RELEASES TO BE EXPECTED FROM THE THREE PWR ROUTES OVER 30 YEARS OPERATION (20 GWe)

ROUTE N°	COLLECTIVE WHOLE BODY DOSES	COLLECTIVE THYROID DOSES
PWR1	9.2	465.0
PWR2	6.3	13.4
PWR3	6.9	291.0

TABLE 7.14. MAXIMUM DOSES TO ADULT CRITICAL INDIVIDUAL LIVING AROUND A NUCLEAR SITE WITH FOUR 900 MWe PWR UNITS (mSv/a) FOR ROUTE N° 1 DUE TO LIQUID EFFLUENT RELEASES

RADIONUCLIDE	DOSE TO LIVER	DOSE TO THYROID	DOSE TO WHOLE BODY
I-131	8.0 x 10^{-7}	2.0 x 10^{-4}	2.8 x 10^{-7}
I-133	5.1 x 10^{-7}	4.9 x 10^{-5}	2.8 x 10^{-7}
Cs-137	2.74 x 10^{-2}	1.4 x 10^{-3}	2.20 x 10^{-2}
Cs-134	2.20 x 10^{-2}	2.1 x 10^{-3}	1.55 x 10^{-2}
Co-58	2.2 x 10^{-4}	1.5 x 10^{-4}	3.1 x 10^{-4}
Co-60	1.6 x 10^{-3}	1.5 x 10^{-3}	1.6 x 10^{-3}
Mn-54	1.4 x 10^{-4}	7.3 x 10^{-5}	1.1 x 10^{-4}
Sr-90	1.1 x 10^{-8}	1.1 x 10^{-8}	1.1 x 10^{-3}
Nb-95	3.5 x 10^{-8}	2.3 x 10^{-8}	3.0 x 10^{-8}
Mo-99	3.7 x 10^{-6}	5.7 x 10^{-7}	1.1 x 10^{-6}
Ag-110m	1.9 x 10^{-4}	1.9 x 10^{-4}	1.9 x 10^{-4}
Sb-124	1.4 x 10^{-4}	1.6 x 10^{-7}	2.7 x 10^{-4}
H-3	1.4 x 10^{-3}	1.4 x 10^{-3}	1.4 x 10^{-3}
TOTAL	5.31 x 10^{-2}	0.71 x 10^{-2}	4.25 x 10^{-2}

TABLE 7.15. MAXIMUM DOSES TO ADULT CRITICAL INDIVIDUAL LIVING AROUND A NUCLEAR SITE WITH FOUR 900 MWe PWR UNITS (mSv/a) FOR ROUTE N° 2 DUE TO LIQUID EFFLUENT RELEASES

RADIONUCLIDE	DOSE TO LIVER	DOSE TO THYROID	DOSE TO WHOLE BODY
I-131	3.3×10^{-7}	8.4×10^{-5}	2.1×10^{-7}
I-133	3.4×10^{-7}	3.3×10^{-5}	1.9×10^{-7}
Cs-134	8.3×10^{-3}	4.3×10^{-4}	6.7×10^{-3}
Cs-137	6.7×10^{-3}	6.5×10^{-4}	4.7×10^{-3}
Co-58	6.4×10^{-5}	4.4×10^{-5}	9.0×10^{-5}
Co-60	4.8×10^{-4}	4.5×10^{-4}	4.8×10^{-4}
Mn-54	4.3×10^{-5}	2.2×10^{-5}	3.5×10^{-5}
Sr-90	3.6×10^{-9}	3.6×10^{-9}	3.4×10^{-4}
Nb-95	1.1×10^{-8}	7.2×10^{-9}	9.3×10^{-9}
Mo-99	1.4×10^{-6}	2.2×10^{-7}	4.5×10^{-7}
Ag-110m	5.7×10^{-5}	5.7×10^{-5}	5.7×10^{-5}
Sb-124	3.8×10^{-5}	4.8×10^{-8}	7.9×10^{-5}
H-3	1.4×10^{-3}	1.4×10^{-3}	1.4×10^{-3}
TOTAL	1.71×10^{-2}	0.32×10^{-2}	1.39×10^{-2}

TABLE 7.16. MAXIMUM DOSES TO ADULT CRITICAL INDIVIDUAL LIVING AROUND A NUCLEAR SITE WITH FOUR 900 MWe PWR UNITS (mSv/a) FOR ROUTE N° 3 DUE TO LIQUID EFFLUENT RELEASES

RADIONUCLIDE	DOSE TO LIVER	DOSE TO THYROID	DOSE TO WHOLE BODY
I-131	5.0×10^{-6}	1.3×10^{-3}	3.2×10^{-6}
I-133	2.1×10^{-6}	2.1×10^{-4}	1.2×10^{-6}
Cs-134	1.8×10^{-3}	9.1×10^{-5}	1.4×10^{-3}
Cs-137	1.4×10^{-3}	1.4×10^{-4}	9.9×10^{-4}
Co-58	1.3×10^{-5}	9.3×10^{-6}	1.9×10^{-5}
Co-60	1.1×10^{-4}	1.0×10^{-4}	1.1×10^{-4}
Mn-54	9.1×10^{-6}	4.7×10^{-6}	7.3×10^{-6}
Sr-90	7.6×10^{-10}	7.6×10^{-10}	7.2×10^{-5}
Nb-95	2.3×10^{-9}	1.5×10^{-9}	2.0×10^{-9}
Mo-99	3.4×10^{-7}	5.2×10^{-8}	1.0×10^{-7}
Ag-110m	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}
Sb-124	8.0×10^{-6}	1.0×10^{-8}	1.7×10^{-5}
H-3	1.4×10^{-3}	1.4×10^{-3}	1.4×10^{-3}
TOTAL	0.48×10^{-2}	0.33×10^{-2}	0.40×10^{-2}

TABLE 7.19 COLLECTIVE DOSES DUE TO LIQUID RELEASES TO BE EXPECTED FROM PWR ROUTE N° 3 OVER 30 YEARS OPERATION (20 GWe)

EXPOSURE PATHWAY	COLLECTIVE WHOLE BODY DOSE (Man-Sv)		MAIN ISOTOPES CONTRIBUTION (%)	COLLLECTIVE THYROID DOSE (Man-Sv)		MAIN ISOTOPES CONTRIBUTION (%)
DRINKING WATER	115.8		H-3 (38), Cs-134 (5), Cs-137	105.1		H-3 (99)
FISH	10.4		Cs-134 (62), Cs-137 (37)	1.4		I-131 (96)
WATERING AND IRRIGATION PRODUCTS						
-milk	- 21.90	75.7	- H-3 (86), Cs-134 (9), Cs-137 (5)	- 30.2	78.7	- H-3 (62) I-131 (38)
-meat	- 11.90		- H-3 (94)	- 11.8		- H-3 (95), I-131 (5)
-vegetables + fruits + grains	- 41.90		- H3 (86)	- 36.7		- H-3 (98)
TOTAL Man-Sv	201.9			185.2		

TABLE 7.17 COLLECTIVE DOSES DUE TO LIQUID RELEASES TO BE EXPECTED FROM PWR ROUTE N° 1 OVER 30 YEARS OPERATION (20 GWe)

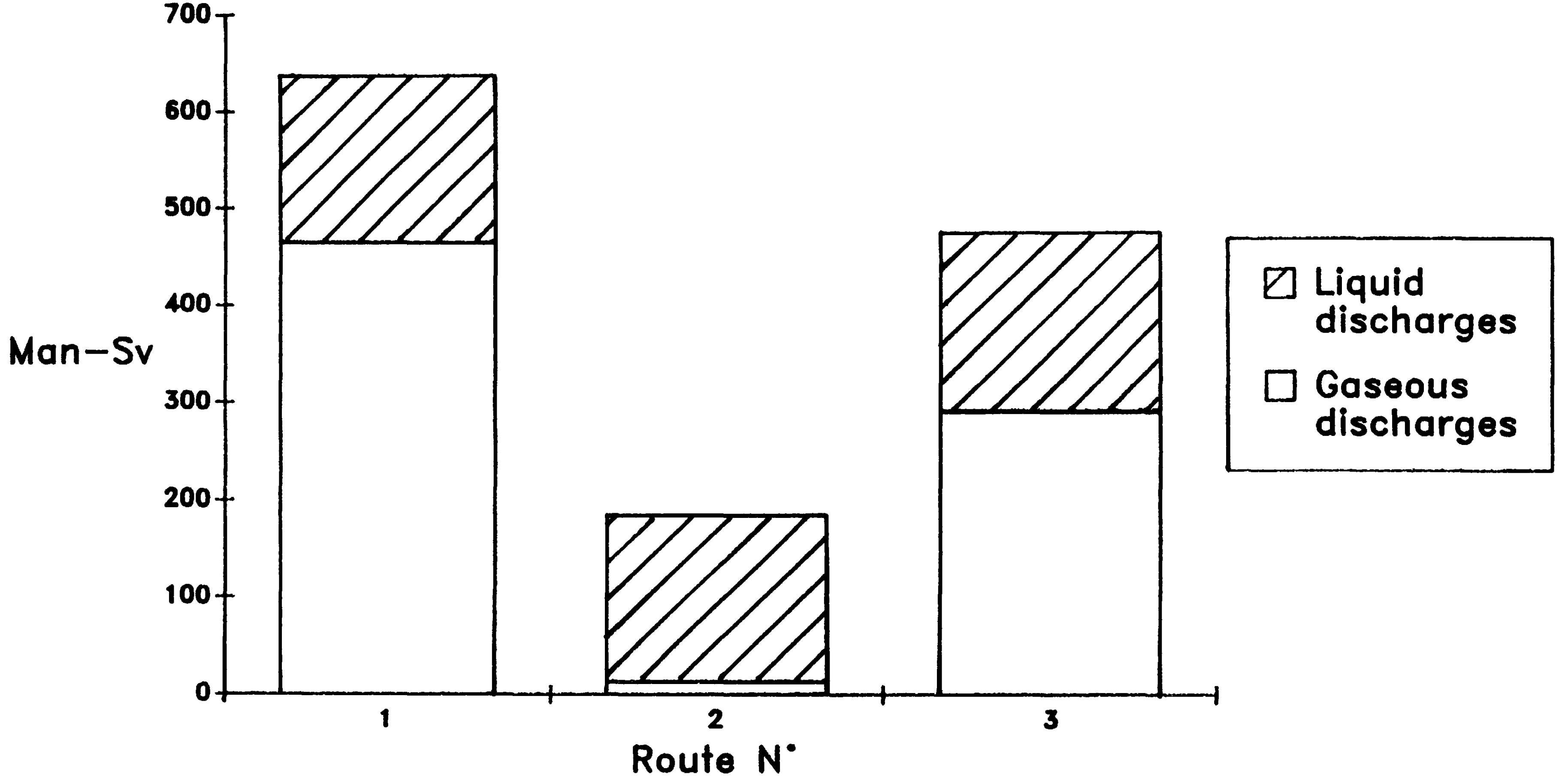
EXPOSURE PATHWAY	COLLECTIVE WHOLE BODY DOSE (Man-Sv)	MAIN ISOTOPES CONTRIBUTION (%)	COLLLECTIVE THYROID DOSE (Man-Sv)	MAIN ISOTOPES CONTRIBUTION (%)
DRINKING WATER	278	H-3 (38), Cs-134 (34), Cs-137, Cs-137 (20), Sr-90 (7)	105	H-3 (99)
FISH	161	Cs-134 (63), Cs-137 (37)	0.3	I-131 (81)
WATERING AND IRRIGATION PRODUCTS				
-milk	- 67 } 216.6	- H-3 (28), Cs-134 (44), Cs-137 (27)	- 20.6 } 68	- H-3 (91), I-131 (9)
-meat	- 21.7	- H-3 (52), Cs-134 (27), Cs-137 (17)	- 11.3	- H-3 (99)
-vegetables + fruits + grains	- 127.9	- Cs-134 (39), H-3 (28), Cs-137 (23)	- 36.1	- H-3 (99)
TOTAL Man-Sv	655.6		173.3	

TABLE 7.18 COLLECTIVE DOSES DUE TO LIQUID RELEASES TO BE EXPECTED FROM PWR ROUTE Nº2 OVER 30 YEARS OPERATION (20 GWe)

EXPOSURE PATHWAY	COLLECTIVE WHOLE BODY DOSE (Man-Sv)	MAIN ISOTOPES CONTRIBUTION (%)	COLLLECTIVE THYROID DOSE (Man-Sv)	MAIN ISOTOPES CONTRIBUTION (%)
DRINKING WATER	157.5	H-3 (66), Cs-134 (8), Cs-137 (16),	105	H-3 (99)
FISH	49.1	Cs-134 (62), Cs-137 (37)	0.1	H-3 (35), I-131 (65)
WATERING AND IRRIGATION PRODUCTS				
-milk	- 33.5	- H-3 (56), Cs-134 (27), Cs-137 (16)	- 19.6	- H-3 (99)
-meat	- 14.4 } 111.9	- H-3 (78), Cs-134 (12), Cs-137 (8)	- 11.24 } 66.9	- H-3 (99)
-vegetables + fruits + grains	- 64	- H-3 (56), Cs-134 (24), Cs-137 (14)	- 36.05	- H-3 (99)
TOTAL Man-Sv	318.5		172	

TABLE 7.21 RADIONUCLIDE INVENTORY FOR A DISPOSAL SITE COLLECTING ALL THE WASTE PRODUCTS GENERATED FROM THE OPERATION OF A 20 GWe NUCLEAR PARK FOR 30 YEARS

RADIONUCLIDES	SPANISH CONCEPT (TBq/30 years)	FRENCH CONCEPT (TBq/30 years)
H-3	4.11 x 10^{1}	1.41 x 10^{1}
C-14	8.40 x 10^{0}	1.09 x 10^{0}
Fe-55	5.96 x 10^{4}	5.77 x 10^{2}
Ni-59	4.22 x 10^{1}	6.90 x 10^{-1}
Co-60	5.40 x 10^{4}	1.12 x 10^{3}
Ni-63	5.51 x 10^{3}	2.13 x 10^{2}
Nb-94	5.48 x 10^{-1}	2.00 x 10^{-2}
Sr-90	1.50 x 10^{1}	3.27 x 10^{0}
Tc-99	1.21 x 10^{-1}	10^{-2}
I-129	3.26 x 10^{-1}	3.0 x 10^{-2}
Cs-135	1.21 x 10^{-1}	10^{-2}
Cs-137	3.24 x 10^{3}	2.44 x 10^{2}
U-238	1.34 x 10^{-2}	$<10^{-2}$
Pu-238	3.09 x 10^{1}	5.8 x 10^{-1}
Pu-239	4.07 x 10^{1}	5.4 x 10^{-1}
Pu-241	8.18 x 10^{2}	2.34 x 10^{1}
Am-241	2.05 x 10^{-1}	3.8 x 10^{-1}
Np-237	3.27 x 10^{-7}	$<10^{-2}$
U-235	1.69 x 10^{-3}	$<10^{-2}$
Pu-242	8.88 x 10^{-2}	$<10^{-2}$
Am-243	1.38 x 10^{-2}	3 x 10^{-2}
Cm-243	8.03 x 10^{-3}	$<10^{-2}$
Cm-244	1.74 x 10^{-1}	2.05 x 10^{-1}



COLLECTIVE THYROID DOSES RELATED TO MANAGEMENT ROUTES FOR LWR WASTES (30 Y OPERATION, 20 GWe)

COLLECTIVE WHOLE BODY DOSES RELATED TO MANAGEMENT ROUTES FOR LWR WASTES (30 Y OPERATION, 20 GWe)

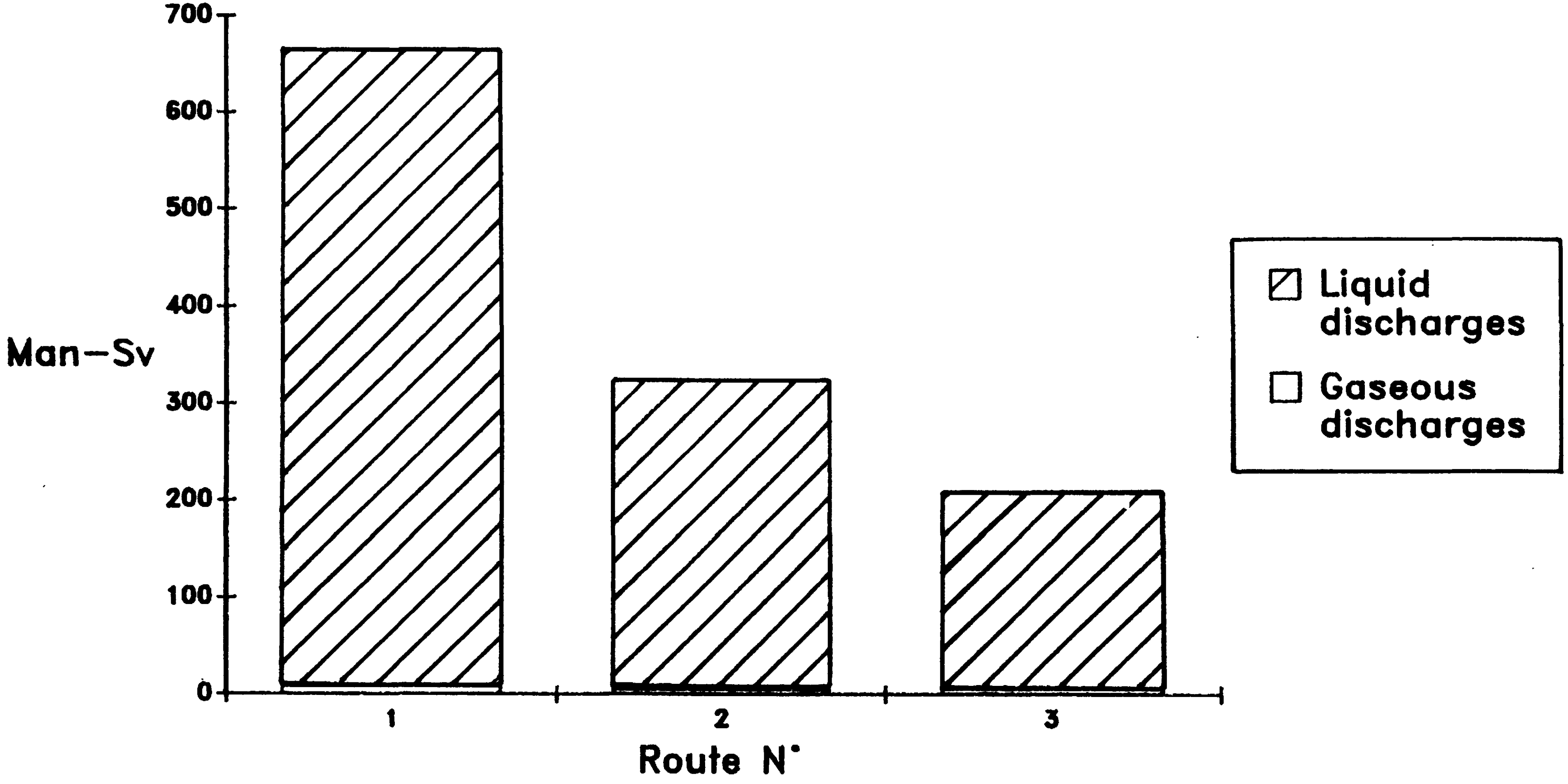


TABLE 7.20 MAIN CHARACTERISTICS OF THE NEAR SURFACE DISPOSAL SITES INVESTIGATED

SITE	CAPACITY (m^3)	NUCLEAR PARK	DISPOSAL STRUCTURES	VOLUME OF OF DISPOSAL MODULES (m^3)	DEPTH BELOW SURFACE (m)
SPANISH TYPE	120.000	20 GWe : 75% PWRs 25% BWRs	PARALLELEPIPEDIC MODULES WITH WALLS IN REINFORCED CONCRETE. CEMENT INJECTION IN VOIDS BETWEEN PACKAGES	4.500	40
FRENCH TYPE	134.700	20 GWe : 100% PWRs	PARALLELEPIPEDIC MODULES WITH WALLS IN REINFORCED CONCRETE. VOIDS BETWEEN PACKAGES BACKFILLED WITH CEMENT OR GRAVELS ACCORDING TO THE PACKAGE CHARACTERISTICS	4.200	10

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