ISSN 1018-5593

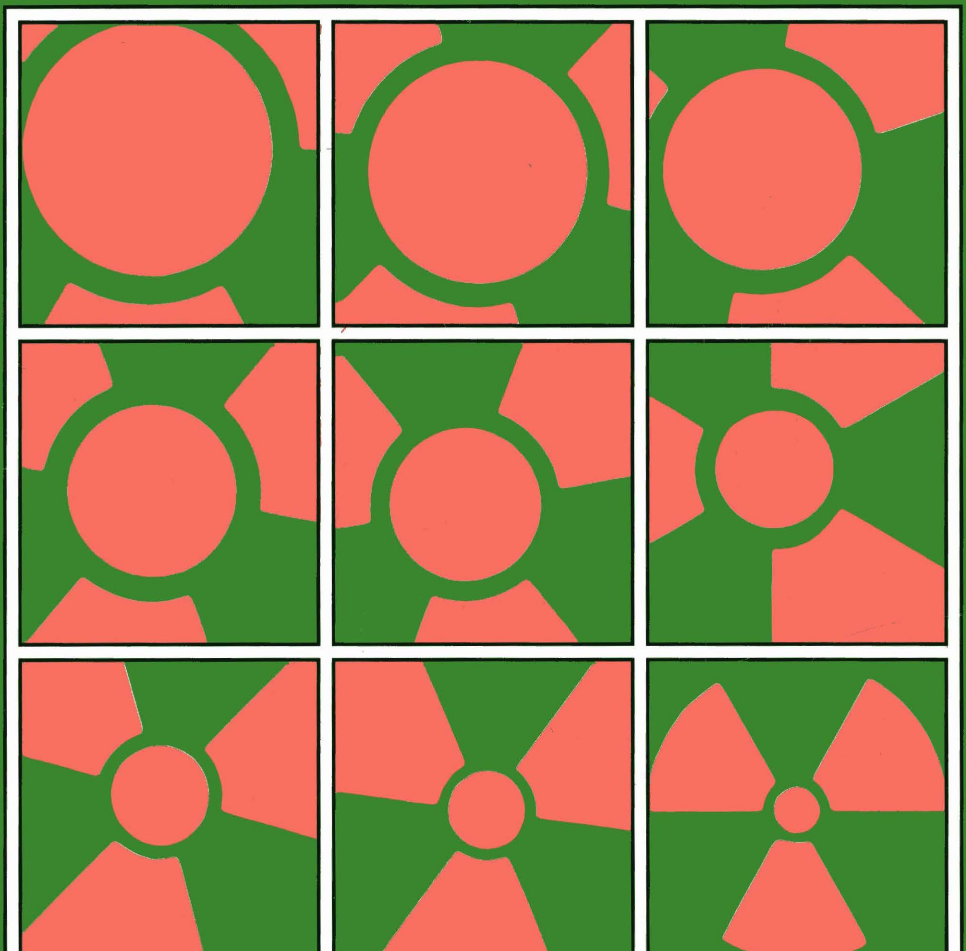
Commission of the European Communities

nuclear science and technology

Assessment of management alternatives for LWR wastes

(Volume 6)

Cost determination of the LWR waste management routes (treatment/conditioning/packaging/transport operations)



Report

EUR 14043/6 EN

3077

Commission of the European Communities

nuclear science and technology

Assessment of management alternatives for LWR wastes

(Volume 6)

Cost determination of the LWR waste management routes (treatment/conditioning/packaging/transport operations)

G. M. Thiels
Task R & S
Via Verbano 2
I-21027 Ispra

S. Kowa
KAH
Im Breitspiel 7
D-W-6900 Heidelberg I

Contract No FI1W/0125-C

Final report

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

Publication of this report has been supported by the Dissemination of Scientific and Technical Knowledge Unit, Directorate-General for Information Technologies and Industries, and Telecommunications, Commission of the European Communities, Luxembourg

Directorate-General
Science, Research and Development

1993

EUR 14043/6 EN

Published by the
COMMISSION OF THE EUROPEAN COMMUNITIES
Directorate-General XIII
Information Technologies and Industries, and Telecommunications
L-2920 Luxembourg

LEGAL NOTICE

Neither the Commission of the European Communities nor any person acting on behalf of the Commission is responsible for the use which might be made of the following information

ISBN 92-826-4884-2 (Volumes 1-8)

Cataloguing data can be found at the end of this publication

Luxembourg: Office for Official Publications of the European Communities, 1993

ISBN 92-826-4890-7

Printed in Luxembourg

FOREWORD

This report deals with the cost determination of a selection of LWR waste management routes drawn up on the basis of Belgian, French and German practices as defined in a joint assessment study conducted by the Commission of the European Communities.

Actually this assessment study was implemented through complementary contributions provided by nine organisations and companies, i.e.
CEN - Fontenay-aux-Roses, INITEC - Madrid, KAH - Heidelberg, BELGATOM - Brussels, TASK R&S - Ispra, SGN - St. Quentin-en-Yvelines, EDF/SEPTEN - Villeurbanne, FRAMATOME - Paris-la-Défense, GNS - Essen, co-ordinated by the Commission of the European Communities (Brussels).

The main achievements of the assessment study have been summarised by BELGATOM-Brussels.
These different contributions are published as EUR Reports in 1992 (listed as 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

SUMMARY

In the frame of the Third R&D Programme of the C.E.C. on the Management and Disposal of Radioactive Waste, a joint strategy study was performed to assess a number of schemes for the treatment, conditioning, packaging, interim storage, transport and disposal of Light Water Reactor wastes on the basis of economic and radiological criteria. TASK R&S and KAH contributed towards the costing of the management routes, which evolved from this study.

General procedures were elaborated for determining, actualising and scaling of plant and transport costs associated with the various schemes. An in-depth analysis was performed for three Pressure Water Reactor (PWR) waste management routes, whereas only some indicative data are reported for two Boiling Water Reactor (BWR) waste schemes due to sparse input received.

An appreciable divergence in the plant costs of the PWR management routes was found (maximum cost ratio of ≈ 1.6). This mainly originates from four unit operations - namely boron recycling and the treatment of the liquid, gaseous and dry solid wastes - and is caused by differences in the applied design criteria. The contribution of the transport costs is insignificant, remaining below 3 % of the total waste management cost.

TABLE OF CONTENTS

	NOMENCLATURE	IV
	RATES	XI
1.	INTRODUCTION	1
2.	DETERMINATION OF COSTS	2
	2.1 Plant Cost	2
	2.1.1 Definition of cost elements	2
	2.1.2 General assumptions	2
	2.1.3 Cost determination procedure	6
	2.2 Transport Cost	9
	2.2.1 Definition of cost elements	9
	2.2.2 General assumptions	9
3.	ACTUALISATION OF COSTS	11
	3.1 Economic Methods	11
	3.1.1 Pay back period or pay out time method	11
	3.1.2 Benefit-cost ratio	11
	3.1.3 Internal rate method	12
	3.1.4 Proportional gain method	12
	3.1.5 Annual value or annual cost method	12
	3.1.6 Present worth or net present value method	12
	3.2 Actualisation Procedure	13
	3.2.1 Assumptions	13
	3.2.2 Direct capital cost	13
	3.2.3 Indirect capital cost	16
	3.2.4 Annual operating cost	16
	3.2.5 Transport cost	16
	3.3 Constant Annual Cost	16
	3.3.1 Reference data	16
	3.3.2 Assumptions	17
	3.3.3 Conversion of annual operating cost into total operating cost	17
	3.3.4 Actualised total plant cost	17
	3.3.5 Conversion of total plant cost into a constant annual cost	18
	3.3.6 Conversion of transport costs into a constant annual cost	18
4.	SCALING OF COSTS	19

5. ASSESSMENT OF THE PLANT COSTS 22

5.1 Route LWR1-PWR 22

5.2 Route LWR2-PWR 27

5.3 Route LWR3-PWR 27

5.4 Route LWR4-BWR 33

5.5 Route LWR5-BWR 39

5.6 Constant Annual Plant Cost 39

6. ASSESSMENT OF THE TRANSPORT COSTS 47

6.1 Route LWR1-PWR 47

6.2 Route LWR2-PWR 47

6.3 Route LWR3-PWR 48

6.4 Routes LWR4-BWR and LWR5-BWR 48

7. COST SCALING 50

8. DISCUSSION OF THE RESULTS AND CONCLUSIONS 55

8.1 Cost Assessment of the PWR Waste Management Routes (20 GWe) 55
8.1.1 Assessment of the plant costs 55
8.1.2 Assessment of the transport costs 60

8.2 Cost Assessment of the BWR Waste Management Routes (20 GWe) 60

8.3 Cost Scaling 60

9. REFERENCES 63

NOMENCLATURE

a	=	Indirect capital cost factor
B	=	Base Value (ECU_{88})
B_t	=	Benefits incurred at time t (ECU)
C	=	Actualised total capital cost (ECU)
C_j	=	Actualised total cost of j^{th} cost element (ECU)
C_n	=	Cost of new facility (ECU_{88})
C_o	=	Cost of reference facility (ECU_{88})
C_t	=	Costs incurred at time t (ECU)
D	=	Total direct capital cost (ECU_{88})
D_a	=	Actualised total direct capital cost (ECU)
e	=	Annual rate of inflation
f	=	Total number of operating cost elements
f_j	=	Fraction of "Base Value" for j^{th} cost element
I	=	Indirect capital cost (ECU_{88})
I_a	=	Actualised indirect capital cost (ECU)
I_n	=	Indirect capital cost for new plant capacity (ECU_{88})
i	=	Annual rate of interest
k	=	Total number of direct capital cost elements
L	=	Duration of plant operation (a)
L_a	=	Actualised total labour cost (ECU)
L_j	=	Actualised labour cost of j^{th} cost element (ECU)
M_a	=	Actualised total material cost (ECU)
M_j	=	Actualised material cost of j^{th} cost element (ECU)
m	=	Scaling factor
m_j	=	Material fraction of the total actualised cost of j^{th} cost element
n	=	Total duration of plant construction (a)
O	=	Actualised total operating cost (ECU)
O_a	=	Actualised annual operating cost ($ECU \cdot a^{-1}$)
P_j	=	Nominal total cost of j^{th} cost element (ECU_{88})
p	=	Life of the project (a)
R_n	=	Capacity of new facility (GWe)
R_o	=	Capacity of reference facility (GWe)

T	=	Actualised total cost (ECU)
t	=	Constant annual expenditure ($ECU \cdot a^{-1}$)
V_n	=	Total volume of the interim storage for new facility (m^3)
V_s	=	Volume of storage area of the interim storage for reference facility (m^3)
V_w	=	Volume of work area of the interim storage for reference facility (m^3)
x	=	Time duration between the start of plant construction and the middle of the activity for the j^{th} cost element (a)

RATES

Exchange Rates:

1 ECU_{88}	= 7.013	FRF_{88}
	= 2.074	DEM_{88}
	= 43.41	BEF_{88}
	= 141	ESP_{88}

Annual Rate of Inflation on the ECU_{88}:

e = 2.2 $\% \cdot a^{-1}$

Annual Rate of Interest on the ECU_{88}:

i = 8.3 $\% \cdot a^{-1}$

1. INTRODUCTION

In the frame of the Third R&D Programme of the C.E.C. on the Management and Disposal of Radioactive Waste (Task I - System Studies), a joint strategy study was performed to assess a number of schemes for the management of LWR wastes. In this context, TASK R&S and KAH contributed towards the costing of the management routes, which evolved from this study.

The present report describes the application of the cost procedures to five LWR waste management routes, namely:

- Route LWR1-PWR:
  based on the French practice for Pressure Water Reactors (PWRs)

- Route LWR2-PWR:
  based on the German practice for PWRs

- Route LWR3-PWR:
  based on the Belgian practice for PWRs

- Route LWR4-BWR:
  based on the Spanish practice for Boiling Water Reactors (BWRs)

- Route LWR5-BWR:
  based on the German practice for BWRs

The process engineering of route LWR1-PWR was developed by SGN-EDF, while that of route LWR3-PWR by BELGATOM. Detailed descriptions of these two routes can be found in the reports issued by these organisations [1-15]. The economic assessments of the routes LWR2-PWR and LWR5-BWR are partially based on the costs provided by GNS-FRAMATOME [16-18] and partially on TASK R&S-KAH estimates. Finally, the evaluation of route LWR4-BWR is based on the information given by SGN-INYPSA [19]; missing process data have been substituted by TASK R&S-KAH estimates.

2. DETERMINATION OF COSTS

Chemical block diagrams and engineered flow sheets are essential requirements to perform an economic assessment. Standardisation of the engineering data should allow a fair and impartial comparison between the various management schemes. Nevertheless, it should be kept in mind that equipment specifications are related to the functions and requirements of a certain circuit or system. Consequently, the level of redundancy, safety, etc. of a circuit or system influences the equipment specifications and thus the corresponding costs.

2.1 Plant Cost

To evaluate the plant costs of the various management schemes, a number of cost elements were identified. Moreover, various assumptions were established to obtain the cost of each element in 1988.

2.1.1 Definition of cost elements

Both the capital and operating costs were evaluated for each management route, taking into account the cost elements illustrated in Figure 1 [20-23]. Further details are provided in Tables I and II.

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 of the proposed plant.

2.1.2 General assumptions

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

- The cost estimates are based on proven, present-day technology;

- Severe work interruptions during plant construction or operation do not occur;

- Labour keeps to a normal weekly work schedule, i.e.:
  1 man-year = $8\ h \cdot d^{-1} \times 230\ d \cdot a^{-1} = 1\ 840\ h \cdot a^{-1}$;

- Salary scales for operators = $17\ ECU \cdot h^{-1}$ and higher labour categories = $35\ ECU \cdot h^{-1}$;

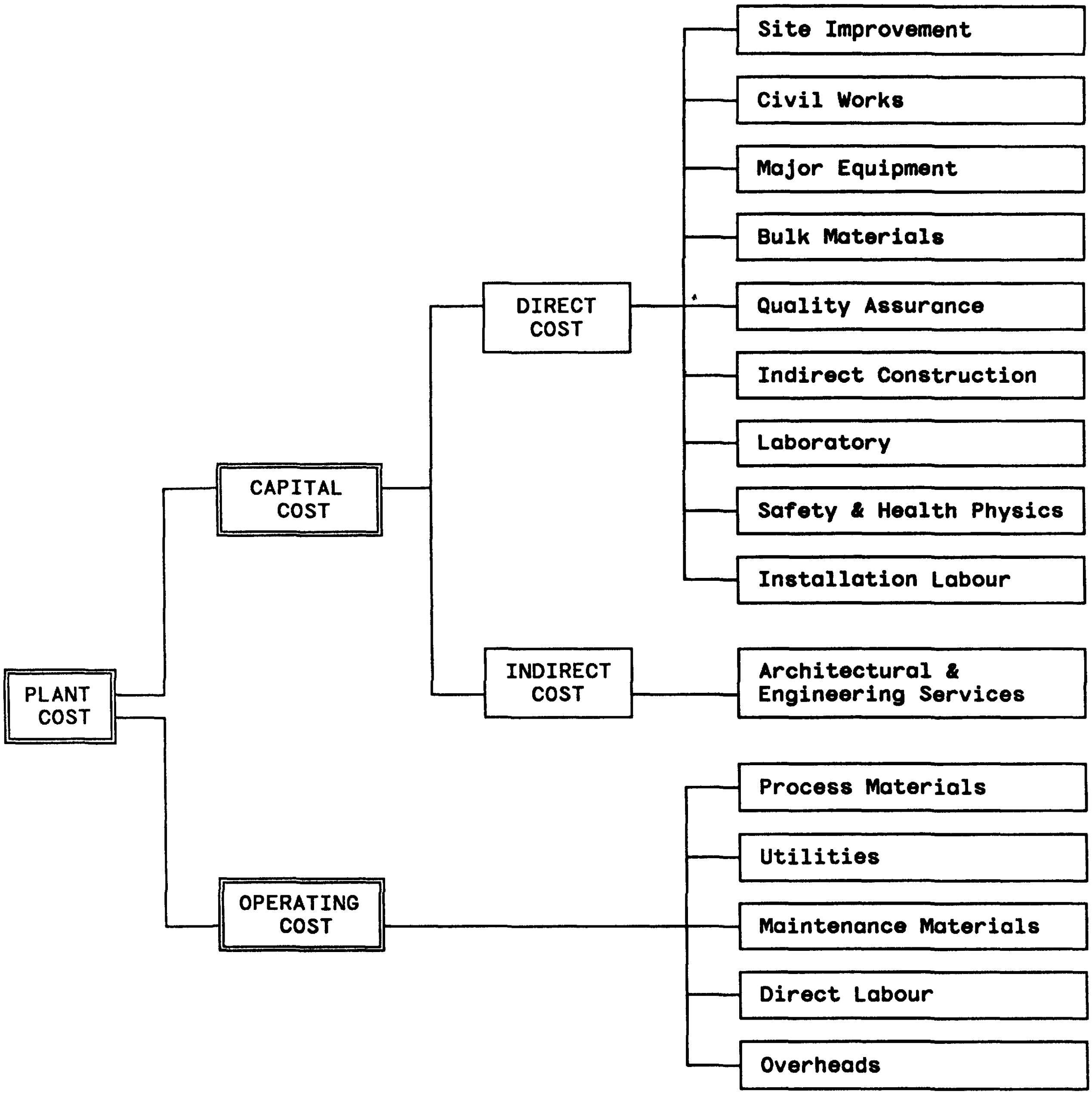


Figure 1 - Elements considered for the evaluation of the plant cost.

Table I - Elements considered for the evaluation of the capital cost.

ELEMENT	DEFINITION
Site Improvement	Site cleaning, site classification, railroads, pavements, roads, fences, sewage and fire fighting systems.
Civil Works	Building materials and equipment, excavation, foundations, ditches, erection of building, interim storage of drums.
Major Equipment	Pressure vessels, pumps, compressors, heat exchangers, filters, storage tanks and other process components, containment of specific components.
Bulk Materials	Piping, fittings, valves, instrumentation, electric equipment and commercial electrical auxiliaries.
Quality Assurance	Certificates from manufacturer and/or technical control association, inspection during and after mounting, incl. X-ray, non-destructive and surface crack tests.
Indirect Construction	Tools, temporary constructions, material storage and transport, rents, field office.
Laboratory	Analytical equipment for the process and commercial devices for analytical lab (e.g. glass ware, fume cupboards, glove boxes, furniture)
Safety & Health Physics	Systems related to safety and health, e.g. monitors, clinical installation, medical equipment, room fire fighting systems, first aid kits.
Installation Labour	Man-power involved in site improvement, civil works, installation of major equipment and bulk materials, QA, indirect construction, installation of the lab and safety & health physics.
Architectural & Engineering Services	Planning of building and process, technical analysis of components, safety recommendations and component testing.

Table II - Elements considered for the evaluation of the operating cost.

ELEMENT	DEFINITION
Process Materials	All specific process materials employed during plant operation, e.g. containers, chemicals, cement, drums.
Utilities	Consumption of electricity, combustible oil, natural gas, nitrogen, process and cooling water, etc.
Maintenance Materials	Spare parts and repair material for major equipment, bulk materials and electrical apparatus.
Direct Labour	Man-power involved in plant operation, maintenance and health physics.
Overheads	Man-power for administration and medical service.

- The LWR waste treatment and conditioning units are housed in a separate building on the reactor plant site; the piping to be considered starts from the waste head storage tanks.

- 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 unless otherwise specified.

2.1.3 Cost determination procedure

The capital cost in 1988 is derived from the delivered material cost of the Major Equipment and the expenditure required for the Civil Works. These direct cost values are then factored to generate the other direct and indirect costs. More specifically, the following procedure is applied:

- The material cost of the Major Equipment, based on the delivered, fabricated component prices in 1988, is used as "Base Value"; this Base Value is linearly adjusted to a nuclear reactor park size of 20 GWe. Where specific design information is limited, costs are calculated utilising engineering judgement and recent nuclear experience or are based on cost data provided by the other organisations.

- The other direct cost elements, except the Civil Works, are expressed as a percentage of the "adjusted" Base Value (Table III). It should be noted that the values given in Table III refer to the year 1988.

- The cost for the Civil Works is obtained by applying a unit volume cost to the estimated external volumes of the process building and interim storage facility respectively.

- The cost of each element is further divided into material and labour costs as shown in Table III.

- Since the LWR waste treatment plant is associated with either one or two reactors with a capacity ranging between 0.9 to 1.8 GWe, the calculation of the indirect capital cost, consisting of the Architectural & Engineering Services, is performed as follows. The indirect capital cost is derived from the direct capital cost associated with one module (i.e. capacity 0.9 - 1.8 GWe) using the formula illustrated in Figure 2 [24]:

$$a = 1.36 - (0.0687 \cdot \ln D) \qquad (1)$$

Table III - Percentages applied to calculate the elements of the direct capital cost of the LWR waste management routes. The Base Value corresponds to the material cost of the Major Equipment in 1988.

CATEGORY	% of Base Value	% Material	% Labour
Site improvement	12.5	30	70
Bulk materials			
. Piping	85	50	50
. Instrumentation	40	50	50
Quality assurance	40	30	70
Indirect construction	17.5	20	80
Laboratory	2.5	0	0
Safety & Health Physics	7.5	90	10
Civil works		40	60

Labour associated with Major Equipment: 30 % of Base Value

Cost of Civil Works = 135 $ECU_{88} \cdot m^{-3}$

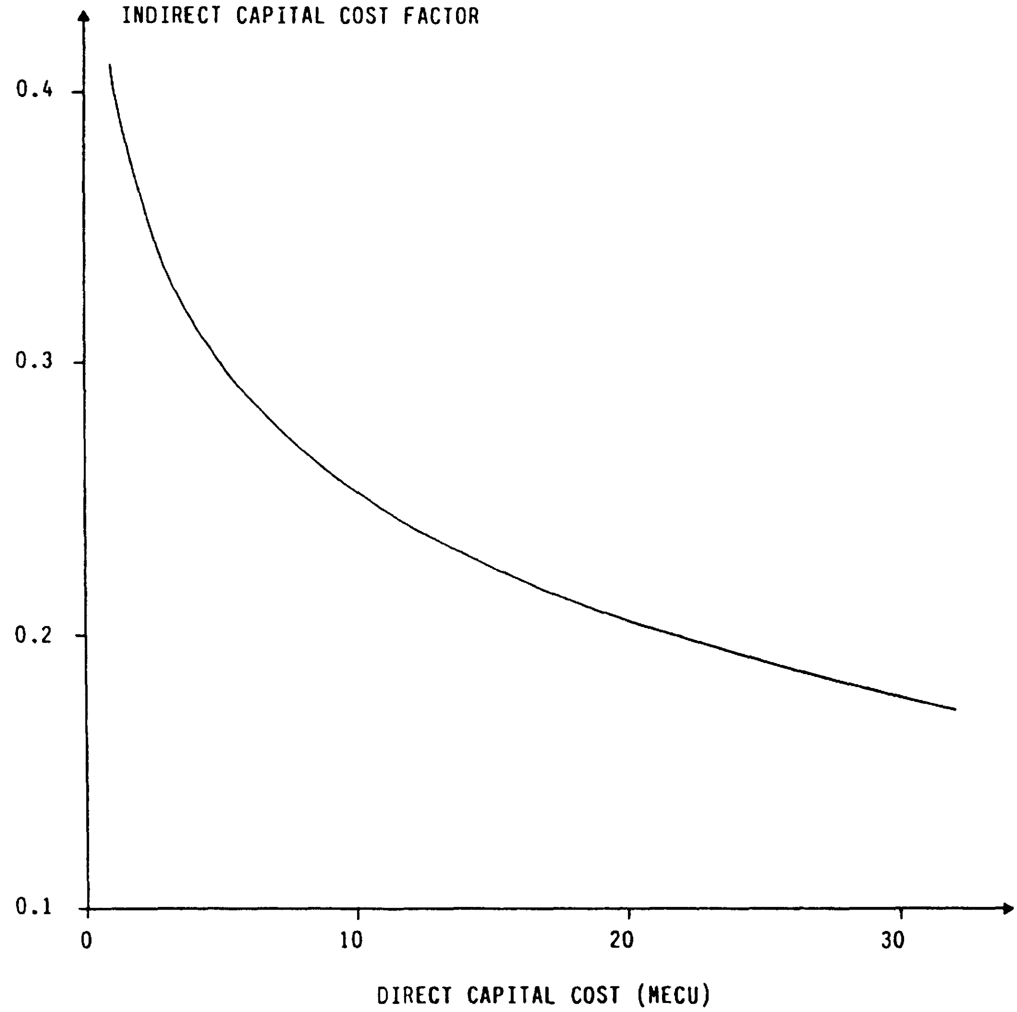


Figure 2 - Indirect capital cost factor expressed as a percentage of the direct capital cost according to equation (1).

and

$$I = a \cdot D \qquad (2)$$

where:

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

The indirect capital cost thus obtained is then scaled to a reactor park size of 20 GWe using the following equation:

$$I_n = I \cdot \left[\frac{R_n}{R_o} \right]^{0.6} \qquad (3)$$

where:

I_n = indirect capital cost for new plant capacity (ECU_{88});
R_n = capacity of new facility (GWe);
R_o = capacity of reference facility (GWe).

- For the operating cost the criteria given in Table IV are used to calculate the annual cost of the different elements in 1988. The annual expenditures are then linearly adjusted to a nuclear reactor park size of 20 GWe.

2.2 Transport Cost

2.2.1 Definition of cost elements

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 by either road or rail, custom duties and insurance.

2.2.2 General assumptions

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. The type of transport casks and the transport medium conform to the national practices for waste transport as proposed by the other participating organisations.

Table IV - Criteria applied for the calculation of the elements of the operating cost.

ELEMENT	CRITERIA VALID FOR 1988
Process Materials	Unit price x Annual quantity ($ECU \cdot a^{-1}$)
Utilities	10 $\% \cdot a^{-1}$ of the cost of [Process Materials + Maintenance Materials + Operators]
Maintenance Materials	5 $\% \cdot a^{-1}$ of the material cost of [Major Equipment + Bulk Materials]
Direct Labour	17 $ECU \cdot h^{-1}$ x Man-hours$\cdot a^{-1}$ (operators) 35 $ECU \cdot h^{-1}$ x Man-hours$\cdot a^{-1}$ (supervisors, health physicists)
Overheads	35 $ECU \cdot h^{-1}$ x Man-hours$\cdot a^{-1}$

3. ACTUALISATION OF COSTS

From an economic point of view, the envisaged management schemes consist of an initial investment for construction followed by one for operation; the costs for the latter are distributed over the operational life time of the plant. Therefore, other parameters, such as plant life, interest and inflation rates, must be considered in addition to the capital and operating costs.

3.1 Economic Methods

Many methods have been developed to evaluate investment costs [25-28], the most common being described below.

3.1.1 Pay back period or pay out time method

This method is used to determine the fastest profit making project among a number of options. The pay out time is calculated by cumulating year by year - for the initial years of the project - the sum of profits plus depreciation. The scope is to determine during which year the total of profits and depreciation exceeds the amount of initial depreciable investment.

The major shortcoming of this method is that after reaching the pay back time it ignores the remaining years of the project.

3.1.2 Benefit-cost ratio

Normally, this method is defined in terms of discounted values. The formula to calculate the benefit-cost ratio is the following:

$$B/C = \frac{\sum_{t=o}^{p} [B_t/(1 + i)^t]}{\sum_{t=o}^{p} [C_t/(1 + i)^t]} \tag{4}$$

where:

B_t = benefits incurred at time t;
C_t = costs incurred at time t;
i = annual rate of interest;
p = life of the project (a).

However, this method cannot be utilised for the comparison of two or more projects, because the benefit-cost ratio gives the actualised benefits per actualised costs. Thus, the smaller of two projects may have a higher benefit-cost ratio, yet yield a smaller total net benefit.

3.1.3 *Internal rate method*

This method, also known as discounted cash flow or interest rate of return, postulates that the algebraic sum of the compound amounts of all the cash flows for a project is zero at some internal rate of return, r, found by trial-and-error solution. More specifically, the cash flows are set forth before discounting from the start of construction to recovery of land and working capital after the project is terminated. Trial discounting rates are then applied to determine which rate makes the present value of earnings equivalent to the present value of all investments.

This method has two inherent defects, i.e. it requires trial-and-error solution and the solution for r may be indeterminate (imaginary or multiple roots), since the equation is of the n^{th} degree.

3.1.4 *Proportional gain method*

This method avoids trial-and-error solutions and is suitable for choosing between mutually exclusive alternatives or for ranking an array of investment opportunities. It postulates that the net returns are accumulated in one account and the net investments in another, both at the same interest rate. When the project is terminated after a number of years, the relative gain is the ratio of the two present worth accounts.

Since this method is biased in favour of long-term investments, it is generally reliable only for comparing investments with nearly equal life spans.

3.1.5 *Annual value or annual cost method*

This procedure is equivalent to the present worth method. Essentially, it transforms a fluctuating annual cost stream into an equivalent uniform annual cost. It is also used to choose between alternative projects for obtaining a specified result, when the differences between alternatives are mainly due to differences in payments.

3.1.6 *Present worth or net present value method*

In this method, compound interest factors are used to compound or discount all cash flows to their equivalent value at time zero, using a minimum acceptable rate of return as the interest rate. Time zero may be chosen arbitrarily, but the start of operation is usually taken.

A problem associated with this method is the determination of the appropriate interest rate. However, this is not a fault of the method itself. Considering a range of reasonable values is often sufficient in a cost-benefit analysis.

3.2 Actualisation Procedure

The choice of any method largely depends on available information and type of project to be evaluated. Preference has been given to the present worth method, because it is the most generally used procedure for cost-benefit analysis. Moreover, it is suitable for projects, which do not have positive returns, a situation in which the application of the other methods is uncertain.

3.2.1 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 routes.

- Annual rate of interest (ECU) = 8.3 $\% \cdot a^{-1}$
  Annual rate of inflation (ECU) = 2.2 $\% \cdot a^{-1}$

- For the capital cost, working capital is borrowed at the middle of the duration period of each cost element and paid back at the end of the construction period. For this purpose a construction schedule is used for the actualisation of the capital cost. The bar chart shown in Figure 3 is applicable to all the LWR waste management routes.

3.2.2 Direct capital cost

Except for the Installation Labour, the nominal total cost of each element with reference to the year 1988 is calculated as follows:

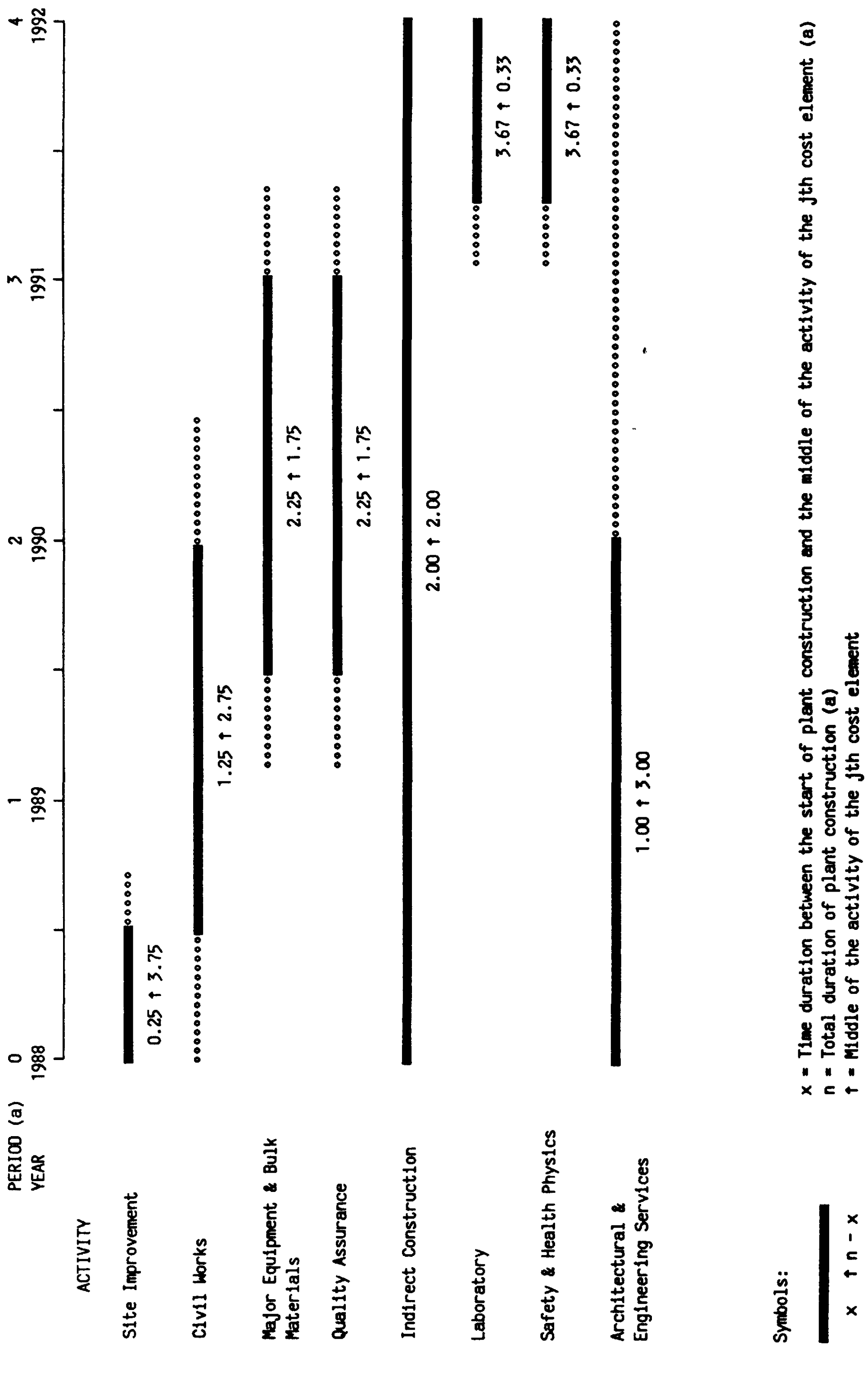


Figure 3 - Bar chart applicable to all the LWR waste management routes.

Civil works:

$$P_j = (\text{cost per unit volume}) \cdot (\text{volume of building}) \quad (5)$$

Other cost elements:

$$P_j = f_j \cdot B \quad (6)$$

where:

P_j = nominal total cost of the j^{th} cost element with reference to the year 1988 (ECU_{88});
f_j = fraction of "Base Value" for j^{th} cost element;
B = Base Value (ECU_{88}).

All cost elements are then actualised to the start-up date of the plant using expression (7):

$$C_j = P_j \cdot (1 + e)^x \cdot (1 + i)^{(n-x)} \quad (7)$$

where:

C_j = actualised total cost of the j^{th} element (ECU);
x = time duration between the start of plant construction and the middle of the activity of the j^{th} cost element (a);
n = total duration of plant construction (a);
e = annual rate of inflation;
i = annual rate of interest.

Each actualised cost element is further divided into material and labour costs using expressions (8) and (9):

$$M_j = C_j \cdot m_j \quad (8)$$

$$L_j = C_j - M_j \quad (9)$$

where:

M_j = actualised material cost of j^{th} cost element (ECU);
m_j = material fraction of the total actualised cost of the j^{th} element;
L_j = actualised labour cost of j^{th} cost element (ECU).

Finally, the actualised direct capital cost is given by:

$$D_a = \sum_{j=1}^{k} M_j + \sum_{j=1}^{k} L_j \quad (10)$$

or

$$D_a = M_a + L_a \quad (11)$$

where:

D_a = actualised direct capital cost (ECU);
k = total number of direct capital cost elements;
M_a = actualised total material cost (ECU);
L_a = actualised total labour cost (ECU).

3.2.3 *Indirect capital cost*

The nominal value of the indirect capital cost in 1988, calculated using equations (1) to (3), is actualised using expression (12):

$$I_a = I_n \cdot (1 + e)^x \cdot (1 + i)^{(n-x)} \quad (12)$$

where:
I_a = actualised indirect capital cost (ECU);
I_n = indirect capital cost for new (i.e. 20 GWe) plant capacity (ECU_{88}).

3.2.4 *Annual operating cost*

Since the annual operating cost is required at the start-up date of the plant, the nominal values of the cost elements in 1988 are actualised using expression (13):

$$C_j = P_j \cdot (1 + e)^n \quad (13)$$

Thus, the actualised annual operating cost is given by:

$$O_a = \sum_{j=1}^{f} C_j \quad (14)$$

where:
O_a = actualised annual operating cost ($ECU \cdot a^{-1}$);
f = total number of operating cost elements.

3.2.5 *Transport cost*

It has been assumed that the transport casks will be acquired at the start-up date of the plant. Therefore, both the capital and annual operating costs are actualised using equation (13).

3.3 Constant Annual Cost

To convert the actualised capital and annual operating costs into a constant annual cost, the "Annual Cost" method is applied.

3.3.1 *Reference data*

The following data form the basis for the conversion:

- Total duration of plant operation = 30 a.

- All costs are actualised to the start-up date of the plant.

3.3.2 *Assumptions*

The following assumptions were made:

- An investment is required for the operating cost, since no returns are foreseen.

- The money to cover the total operating cost is invested at the start-up date of the plant. Therefore, both interest and inflation rates have to be taken into account.

- Annual rate of interest (ECU) $= 8.3\,\% \cdot a^{-1}$
  Annual rate of inflation (ECU) $= 2.2\,\% \cdot a^{-1}$

3.3.3 *Conversion of annual operating cost into total operating cost*

Since the operating cost is a constant annual expenditure, equation (15) is applied to obtain the total operating cost actualised to the start-up date of the plant:

$$O = O_a \cdot \left[\frac{1 + e}{i - e}\right] \cdot \left[1 - \left[\frac{1 + e}{1 + i}\right]^L\right] \qquad (15)$$

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

where:
- O = actualised total operating cost (ECU);
- L = duration of plant operation (a).

3.3.4 *Actualised total plant cost*

The total cost of the plant is the summation of the actualised total capital cost and the actualised total operating cost:

$$T = C + O \qquad (16)$$

where:
- T = actualised total cost (ECU);
- C = actualised total capital cost (ECU) $= D_a + I_a$

3.3.5 *Conversion of total cost into a constant annual cost*

Using equation (17), the actualised total cost is transformed into a constant annual expenditure throughout the life span of the plant.

$$t = T \cdot \frac{i}{1 - (1 + i)^{-L}} \qquad (17)$$

where:

t = constant annual expenditure ($ECU \cdot a^{-1}$).

3.3.6 *Conversion of transport cost into a constant annual cost*

Equations (15) to (17) are also applied to convert the actualised capital and annual operating costs associated with the transport into a constant annual transport cost.

4. SCALING OF COSTS

It has been shown [28-30] that the "sixth-tenth" rule satisfactorily describes the correlation between cost and plant capacity:

$$C_n = C_o \cdot \left[\frac{R_n}{R_o}\right]^m \qquad (18)$$

where:

C_n = cost of new facility (ECU_{88});
C_o = cost of reference facility (ECU_{88});
R_n = capacity of new facility (GWe);
R_o = 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 (Figure 4).

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 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 equation (18), using a value of 0.6 for m

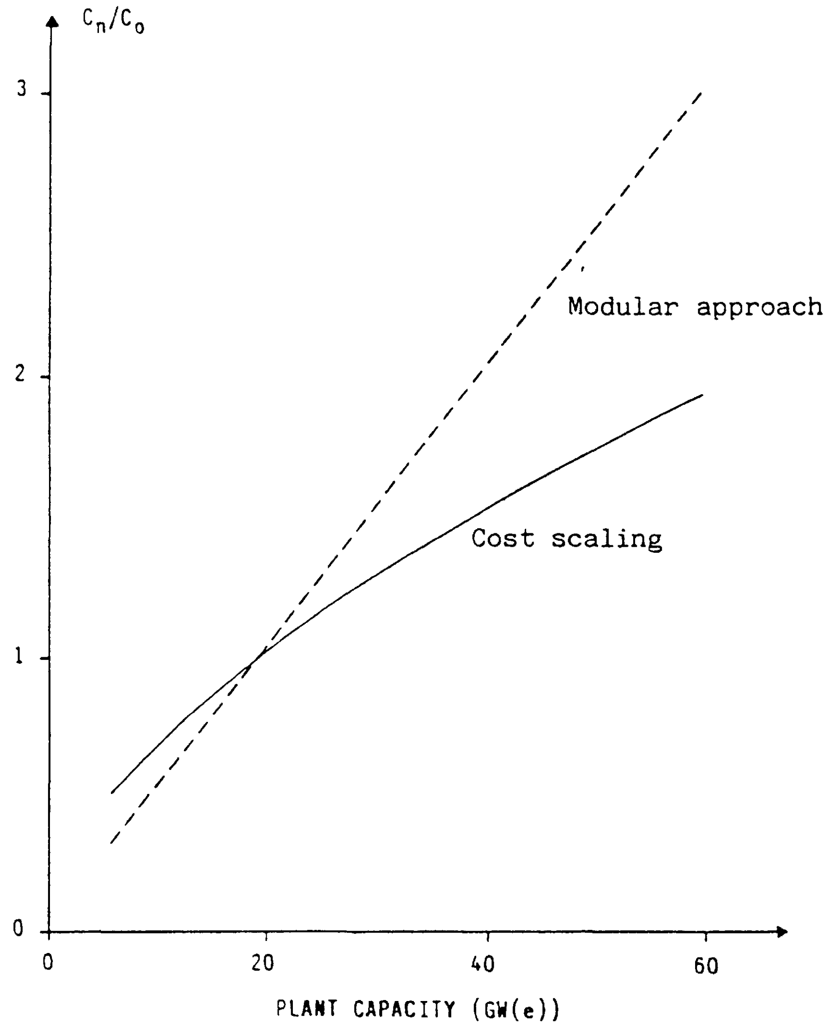


Figure 4 - Comparison between the cost scaling methodology and the modular approach.

- Interim storage building volume:

$$V_n = \left[V_s \cdot \frac{R_n}{R_o} \right] + \left[V_w \cdot \left[\frac{R_n}{R_o}\right]^m \right] \quad (19)$$

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

where:

V_n = total volume of the interim storage of new facility (m^3);
V_s = volume of storage area of the interim storage for reference facility (m^3);
V_w = volume of work area of the interim storage for reference facility (m^3).

Finally, the indirect capital cost was re-calculated using equations (1) to (3).

5. ASSESSMENT OF THE PLANT COSTS

The cost estimates of the LWR waste management routes refer to the treatment of the radioactive effluents arising from a 20 GWe nuclear park of standard PWRs or BWRs. 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 all the LWR waste management routes:

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

Thus, the bar chart shown in Figure 3 is valid for all the routes.

5.1 Route LWR1-PWR

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

- Basic data provided for a 2 x 0.9 GWe unit
  Adjustment factor to 20 GWe = 11.111

- Building volumes for 20 GWe capacity:
  Process building = 738 889 m^3
  Interim storage = 34 310 m^3 (1 a capacity)
  Total volume = 773 199 m^3

- Average cost for Civil Works = 135 $ECU \cdot m^{-3}$

- Architectural & Engineering Services = 5.9 % of the direct capital cost

- Mobile conditioning unit for spent resins is bought.

The material costs of the Major Equipment of the various unit operations and the Base Value are shown in Table V. Additional details on the unit operations are given in Table VI. Finally, the actualised capital and annual operating costs for route LWR1-PWR are reported in Table VII.

Table V - Material cost of the Major Equipment for the different unit operations and Base Value of route LWR1-PWR (20 GWe). All the figures are quoted for 1988.

UNIT OPERATION	TOTAL COST (MECU$_{88}$)
Boron recycling system	54.484
Liquid waste treatment	17.920
Liquid waste storage before discharge	5.907
Gaseous waste treatment	5.759
Ventilation	6.412 †
Solid waste treatment	13.310
Technological waste pre-compaction	0.200 •
Interim storage (1 a capacity)	1.843
BASE VALUE	105.835

† Derived from the cost provided by SGN - EDF

• TASK R&S-KAH estimate

Table VI - Analysis of the various unit operations of route LWR1-PWR (20 GWe). All figures are given in $MECU_{88}$ for the capital cost and in $MECU_{88} \cdot a^{-1}$ for the operating cost.

UNIT OPERATION: Boron recycling system			
Major Equipment	54.484	Process Mat.	1.210
Bulk Materials	35.415	Utilities	0.692
		Maint. Mat.	4.495
Install. Labour	51.760	Direct Labour	1.216
Capital Cost	141.659	Operating Cost	7.613
UNIT OPERATION: Liquid waste treatment			
Major Equipment	17.920	Process Mat.	0.686
Bulk Materials	11.648	Utilities	0.338
		Maint. Mat.	1.478
Install. Labour	17.024	Direct Labour	1.216
Capital Cost	46.592	Operating Cost	3.718
UNIT OPERATION: Liquid waste storage before discharge			
Major Equipment	5.907	Process Mat.	---
Bulk Materials	3.840	Utilities	0.049
		Maint. Mat.	0.487
Install. Labour	5.611	Direct Labour	---
Capital Cost	15.358	Operating Cost	0.536
UNIT OPERATION: Gaseous waste treatment			
Major Equipment	5.759	Process Mat.	0.509
Bulk Materials	3.743	Utilities	0.220
		Maint. Mat.	0.475
Install. Labour	5.471	Direct Labour	1.216
Capital Cost	14.973	Operating Cost	2.420
UNIT OPERATION: Ventilation			
Major Equipment	6.412	Process Mat.	0.603
Bulk Materials	4.168	Utilities	0.113
		Maint. Mat.	0.529
Install. Labour	6.091	Direct Labour	---
Capital Cost	16.671	Operating Cost	1.245

Table VI - (cont'd)

UNIT OPERATION: Solid waste treatment			
Major Equipment Bulk Materials Install. Labour	13.310 8.652 12.645	Process Mat. Utilities Maint. Mat. Direct Labour	4.577 0.846 1.098 2.780
Capital Cost	34.607	Operating Cost	9.301
UNIT OPERATION: Technological waste pre-compaction			
Major Equipment Bulk Materials Install. Labour	0.200 0.130 0.190	Process Mat. Utilities Maint. Mat. Direct Labour	0.520 0.099 0.017 0.452
Capital Cost	0.520	Operating Cost	1.088
UNIT OPERATION: Interim storage (1 a capacity)			
Major Equipment Bulk Materials Install. Labour	1.843 1.198 1.751	Process Mat. Utilities Maint. Mat. Direct Labour	--- 0.057 0.152 0.417
Capital Cost	4.792	Operating Cost	0.626

Table VII - Actualised capital and annual operating costs for route LWR1-PWR (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 ($MECU_{92} \cdot a^{-1}$)
SITE IMPROVEMENT	17.941	---
CIVIL WORKS	133.561	---
UNIT OPERATIONS §		
Boron recycling system	171.049	8.306
Liquid waste treatment	56.259	4.057
Liquid waste storage	18.543	0.585
Gaseous waste treatment	18.080	2.641
Ventilation	20.130	1.358
Solid waste treatment	41.786	10.148
Techn. waste pre-compaction	0.628	1.186
Interim storage (1 a)	5.785	0.683
QUALITY ASSURANCE	51.117	---
INDIRECT CONSTRUCTION	22.691	---
LABORATORY	2.950	0.781
SAFETY & HEALTH PHYSICS	8.850	2.732
ARCHITECTURAL & ENGINEERING SERVICES	35.559	---
LABOUR ASSOCIATED WITH PLANT OPERATION *	---	2.732
OVERHEADS	---	3.903
TOTAL	604.929	39.112

§ The capital cost of each unit operation includes the material cost of the Major Equipment and Bulk Materials and the labour cost for their installation. The annual operating cost represents the cost for Process Materials, Utilities and Maintenance Materials and the labour cost for the operators directly involved in the mentioned unit operations (cf. Table VI)

* The labour associated with plant operation represents the labour cost for shift leaders, maintenance crew and transport registrars.

5.2 Route LWR2-PWR

The assessment of the German route is based on the cost data provided by GNS-FRAMATOME. However, since no costs nor a technical description were provided for certain unit operations, TASK R&S-KAH have inserted estimates for the lacking data. Therefore, the error already associated with the Base Value is further amplified in the overall cost assessment. This should be taken into account, when comparing the economic aspects of the various routes.

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 = 815 385 m^3
  Interim storage = 21 295 m^3 (1 a capacity)
  Total volume = 836 680 m^3

- Average cost for Civil Works = 135 ECU $\cdot$ m^{-3}

- Architectural & Engineering Services = 4.6 % of the direct capital cost

- Mobile conditioning units and the incinerator facility are rented

The material costs of the Major Equipment of the various unit operations and the Base Value are shown in Table VIII. Additional details on the unit operations are given in Table IX. Finally, the actualised capital and annual operating costs for route LWR2-PWR are reported in Table X.

For comparative reasons, the acquisition of all the mobile conditioning units and incinerator by the plant owner was also evaluated. The resulting actualised costs are detailed in Table XI.

5.3 Route LWR3-PWR

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

- Basic data provided for a 2 x 0.9 GWe unit with the exception of the Off Gas Treatment (0.9 GWe)
  Adjustment factor to 20 GWe = 11.111

Table VIII - Indicative material cost of the Major Equipment for the different unit operations and Base Value of route LWR2-PWR (20 GWe). All the figures are quoted for 1988.

UNIT OPERATION	TOTAL COST ($MECU_{88}$)
Primary coolant treatment	61.148 ┼
Liquid waste treatment	62.115 ┼
Liquid waste storage before discharge	3.400 •
Off gas treatment	65.515 ┼
Ventilation	11.619 •
Solid waste treatment:	
. Concentrate treatment	6.115 ┼
. Wet waste conditioning (rented)	---
Technological waste treatment:	
. Technological waste pre-compaction	0.277 ┼
. Supercompaction & incineration (rented)	---
Interim storage (1 a capacity)	1.506
BASE VALUE	211.695

┼ Directly derived from the costs provided by GNS - FRAMATOME

• TASK R&S-KAH estimates

Table IX - Analysis of the various unit operations of route LWR2-PWR (20 GWe). All figures are given in $MECU_{88}$ for the capital cost and in $MECU_{88} \cdot a^{-1}$ for the operating cost.

UNIT OPERATION: Primary coolant treatment			
Major Equipment	61.148	Process Mat.	0.486
Bulk Materials	39.746	Utilities	0.574
		Maint. Mat.	5.045
Install. Labour	58.090	Direct Labour	0.214
Capital Cost	158.984	Operating Cost	6.319
UNIT OPERATION: Liquid waste treatment			
Major Equipment	62.115	Process Mat.	0.156
Bulk Materials	40.375	Utilities	0.549
		Maint. Mat.	5.125
Install. Labour	59.010	Direct Labour	0.214
Capital Cost	161.500	Operating Cost	6.044
UNIT OPERATION: Liquid waste storage before discharge			
Major Equipment	3.400	Process Mat.	---
Bulk Materials	2.210	Utilities	0.028
		Maint. Mat.	0.281
Install. Labour	3.230	Direct Labour	---
Capital Cost	8.840	Operating Cost	0.309
UNIT OPERATION: Off gas treatment			
Major Equipment	65.515	Process Mat.	0.387
Bulk Materials	42.585	Utilities	0.601
		Maint. Mat.	5.405
Install. Labour	62.240	Direct Labour	0.214
Capital Cost	170.340	Operating Cost	6.607
UNIT OPERATION: Ventilation			
Major Equipment	11.619	Process Mat.	0.796
Bulk Materials	7.553	Utilities	0.197
		Maint. Mat.	0.959
Install. Labour	11.038	Direct Labour	0.214
Capital Cost	30.210	Operating Cost	2.166

Table IX - (cont'd)

UNIT OPERATION: Concentrate treatment			
Major Equipment Bulk Materials Install. Labour	6.115 3.975 5.809	Process Mat. Utilities Maint. Mat. Direct Labour	--- 0.072 0.504 0.214
Capital Cost	15.898	Operating Cost	0.790
UNIT OPERATION: Wet waste conditioning			
Major Equipment Bulk Materials Install. Labour	Rented --- ---	Process Mat. Utilities Maint. Mat. Rent Direct Labour	7.045 0.705 --- 2.866 ---
Capital Cost	0.000	Operating Cost	10.616
UNIT OPERATION: Technological waste pre-compaction			
Major Equipment Bulk Materials Install. Labour	0.277 0.180 0.263	Process Mat. Utilities Maint. Mat. Direct Labour	0.323 0.097 0.023 0.628
Capital Cost	0.720	Operating Cost	1.071
UNIT OPERATION: Supercompaction & incineration			
Major Equipment Bulk Materials Install. Labour	Rented --- ---	Process Mat. Utilities Maint. Mat. Rent Direct Labour	2.163 0.420 --- 5.573 2.040
Capital Cost	0.000	Operating Cost	10.196
UNIT OPERATION: Interim storage (1 a capacity)			
Major Equipment Bulk Materials Install. Labour	1.506 0.979 1.431	Process Mat. Utilities Maint. Mat. Direct Labour	--- 0.082 0.124 0.692
Capital Cost	3.916	Operating Cost	0.898

Table X - Actualised capital and annual operating costs for route LWR2-PWR (20 GWe) (mobile conditioning units and incinerator rented). 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 ($MECU_{92} \cdot a^{-1}$)
SITE IMPROVEMENT	35.886	---
CIVIL WORKS	144.527	---
UNIT OPERATIONS §		
Primary coolant treatment	191.969	6.894
Liquid waste treatment	195.007	6.594
Liquid waste storage	10.674	0.337
Off gas treatment	205.681	7.208
Ventilation	36.478	2.363
Solid waste treatment:		
Concentrate treatment	19.197	0.863
Wet waste conditioning	---	11.581
Techn. waste treatment:		
Pre-compaction	0.869	1.168
Supercomp. & incineration	---	11.124
Interim storage (1 a)	4.729	0.980
QUALITY ASSURANCE	102.247	---
INDIRECT CONSTRUCTION	45.388	---
LABORATORY	5.901	1.081
SAFETY & HEALTH PHYSICS	17.703	2.702
ARCHITECTURAL & ENGINEERING SERVICES	49.730	---
LABOUR ASSOCIATED WITH PLANT OPERATION *	---	2.702
OVERHEADS	---	3.243
TOTAL	1 065.986	58.840

§ See footnote of Table VII

* See footnote of Table VII

Table XI - Actualised capital and annual operating costs for route LWR2-PWR (20 GWe) (mobile conditioning units and incinerator bought). 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 ($MECU_{92} \cdot a^{-1}$)
SITE IMPROVEMENT	36.952	---
CIVIL WORKS	144.527	---
UNIT OPERATIONS §		
Primary coolant treatment	191.969	6.894
Liquid waste treatment	195.007	6.594
Liquid waste storage	10.674	0.337
Off gas treatment	205.681	7.208
Ventilation	36.478	2.363
Solid waste treatment:		
Concentrate treatment	19.197	0.863
Wet waste conditioning	8.021	9.021
Techn. waste treatment:		
Pre-compaction	0.869	1.168
Supercomp. & incineration	11.723	7.231
Interim storage (1 a)	4.729	0.980
QUALITY ASSURANCE	105.284	---
INDIRECT CONSTRUCTION	46.736	---
LABORATORY	6.076	1.081
SAFETY & HEALTH PHYSICS	18.229	2.702
ARCHITECTURAL & ENGINEERING SERVICES	49.899	---
LABOUR ASSOCIATED WITH PLANT OPERATION *	---	2.702
OVERHEADS	---	3.243
TOTAL	1 092.051	52.387

§ See footnote of Table VII

* See footnote of Table VII

- Building volumes for 20 GWe capacity:
  Process building = 855 556 m^3 (135 ECU·m^{-3})
  Interim storage (10 a capacity) consisting of:
  - LLW building = 87 942 m^3 (57.2 ECU·m^{-3})
  - MLW bunker = 24 582 m^3 (230.4 ECU·m^{-3})

  Total volume = 968 080 m^3

- Average cost for Civil Works = 130.355 ECU·m^{-3}

- Architectural & Engineering Services = 5.0 % of the direct capital cost

- Only fixed conditioning stations are employed.

The material costs of the Major Equipment of the various unit operations and the Base Value are shown in Table XII. Additional details on the unit operations are given in Table XIII. Finally, the actualised capital and annual operating costs for route LWR3-PWR are reported in Table XIV.

The cost data for this route, utilising an interim storage facility with a capacity of only 1 year (building volume = 33 284 m^3) and calculated in the same manner as for routes LWR1-PWR and LWR2-PWR, are detailed in Table XV.

5.4 Route LWR4-BWR

The assessment of the Spanish route is based on the engineering data provided by SGN-INYPSA. However, since a technical description for certain unit operations was lacking, TASK R&S-KAH have inserted estimates for the missing data. Therefore, the costs thus obtained for this route should only be considered indicative.

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

- Basic data provided for a 0.975 GWe unit
  Adjustment factor to 20 GWe = 20.513

- Building volumes for 20 GWe capacity **(TASK R&S-KAH estimates):**
  Process building = 798 086 m^3
  Interim storage = 51 914 m^3 (1 a capacity)
  Total volume = 850 000 m^3

- Average cost for Civil Works = 135 ECU·m^{-3}

Table XII - Material cost of the Major Equipment for the different unit operations and Base Value of route LWR3-PWR (20 GWe). All the figures are quoted for 1988.

UNIT OPERATION	TOTAL COST ($MECU_{88}$)
Boron recycling system	36.661
Liquid waste treatment	24.294
Liquid waste storage before discharge	8.298
Off gas treatment	29.755
Ventilation	11.842
Solid waste treatment	15.209
Central solid waste treatment	27.220 †
Interim storage (10 a capacity)	5.077
BASE VALUE	158.356

† Directly derived from the cost provided by BELGATOM

Table XIII - Analysis of the various unit operations of route LWR3-PWR (20 GWe). All figures are given in $MECU_{88}$ for the capital cost and in $MECU_{88} \cdot a^{-1}$ for the operating cost.

UNIT OPERATION: Boron recycling system			
Major Equipment Bulk Materials Install. Labour	36.661 23.830 34.828	Process Mat. Utilities Maint. Mat. Direct Labour	0.131 0.437 3.024 1.213
Capital Cost	95.319	Operating Cost	4.805
UNIT OPERATION: Liquid waste treatment			
Major Equipment Bulk Materials Install. Labour	24.294 15.791 23.080	Process Mat. Utilities Maint. Mat. Direct Labour	0.369 0.359 2.004 1.213
Capital Cost	63.165	Operating Cost	3.945
UNIT OPERATION: Liquid waste storage before discharge			
Major Equipment Bulk Materials Install. Labour	8.298 5.393 7.883	Process Mat. Utilities Maint. Mat. Direct Labour	--- 0.068 0.685 ---
Capital Cost	21.574	Operating Cost	0.753
UNIT OPERATION: Off gas treatment			
Major Equipment Bulk Materials Install. Labour	29.755 19.341 28.268	Process Mat. Utilities Maint. Mat. Direct Labour	0.806 0.382 2.455 0.559
Capital Cost	77.364	Operating Cost	4.202
UNIT OPERATION: Ventilation			
Major Equipment Bulk Materials Install. Labour	11.842 7.698 11.250	Process Mat. Utilities Maint. Mat. Direct Labour	1.536 0.307 0.977 0.559
Capital Cost	30.790	Operating Cost	3.379

Table XIII - (cont'd)

UNIT OPERATION: Solid waste treatment			
Major Equipment Bulk Materials Install. Labour	15.209 9.886 14.449	Process Mat. Utilities Maint. Mat. Direct Labour	1.534 0.560 1.255 2.815
Capital Cost	39.544	Operating Cost	6.164
UNIT OPERATION: Central solid waste treatment			
Major Equipment Bulk Materials Install. Labour	27.220 17.693 25.859	Process Mat. Utilities Maint. Mat. Direct Labour	1.997 0.534 2.246 1.095
Capital Cost	70.772	Operating Cost	5.872
UNIT OPERATION: Interim storage (10 a capacity)			
Major Equipment Bulk Materials Install. Labour	5.077 3.300 4.823	Process Mat. Utilities Maint. Mat. Direct Labour	--- 0.094 0.419 0.521
Capital Cost	13.200	Operating Cost	1.034

Table XIV - Actualised capital and annual operating costs for route LWR3-PWR (20 GWe) (Interim Storage = 10 a capacity). 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 ($MECU_{92} \cdot a^{-1}$)
SITE IMPROVEMENT	26.844	---
CIVIL WORKS	161.471	---
UNIT OPERATIONS §		
Boron recycling system	115.095	5.242
Liquid waste treatment	76.271	4.303
Liquid waste storage	26.049	0.822
Off gas treatment	93.415	4.585
Ventilation air treatment	37.178	3.687
Solid waste treatment	47.748	6.726
Central solid waste treatm.	85.455	6.405
Interim storage (10 a)	15.938	1.128
QUALITY ASSURANCE	76.485	---
INDIRECT CONSTRUCTION	33.952	---
LABORATORY	4.414	0.781
SAFETY & HEALTH PHYSICS	13.242	2.732
ARCHITECTURAL & ENGINEERING SERVICES	42.710	---
LABOUR ASSOCIATED WITH PLANT OPERATION *	---	2.732
OVERHEADS	---	3.903
TOTAL	856.267	43.046

§ See footnote of Table VII

* See footnote of Table VII

Table XV - Actualised capital and annual operating costs for route LWR3-PWR (20 GWe) (Interim Storage = 1 a capacity). 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 ($MECU_{92} \cdot a^{-1}$)
SITE IMPROVEMENT	26.283	---
CIVIL WORKS	153.537	---
UNIT OPERATIONS §		
Boron recycling system	115.095	5.242
Liquid waste treatment	76.271	4.303
Liquid waste storage	26.049	0.822
Off gas treatment	93.415	4.585
Ventilation air treatment	37.178	3.687
Solid waste treatment	47.748	6.726
Central solid waste treatm.	85.455	6.405
Interim storage (1 a)	5.555	0.801
QUALITY ASSURANCE	74.887	---
INDIRECT CONSTRUCTION	33.243	---
LABORATORY	4.322	0.781
SAFETY & HEALTH PHYSICS	12.966	2.732
ARCHITECTURAL & ENGINEERING SERVICES	42.178	---
LABOUR ASSOCIATED WITH PLANT OPERATION *	---	2.732
OVERHEADS	---	3.903
TOTAL	834.182	42.719

§ See footnote of Table VII

* See footnote of Table VII

- Architectural & Engineering Services = 5.1 % of the direct capital cost

The material costs of the Major Equipment of the various unit operations and the Base Value are shown in Table XVI. Additional details on the unit operations are given in Table XVII. Finally, the actualised capital and annual operating costs for route LWR2-PWR are reported in Table XVII.

5.5 Route LWR5-BWR

The limited amount of information provided by GNS-FRAMATOME did not allow the evaluation of route LWR5-BWR. Only the Base Value for four unit operations can be reported for this route (Table XIX).

5.6 Constant Annual Plant Cost

The constant annual plant costs for the various LWR waste management routes together with the actualised capital, annual operating and total plant costs for 30 years of operation are summarised in Table XX.

A comparison between the total plant costs of the LWR waste management routes for thirty years of operation is illustrated in Figure 5.

Table XVI - Material cost of the Major Equipment for the different unit operations and Base Value of route LWR4-BWR (20 GWe). All the figures are quoted for 1988.

UNIT OPERATION	TOTAL COST ($MECU_{88}$)
Coolant cleaning system	17.256 •
Low conductivity system	41.497
High conductivity system	42.853
Detergents system	14.859
Off gas treatment	22.854
Ventilation	11.373 •
Solid waste treatment	10.401
Technological waste pre-compaction	0.369 •
Interim storage (1 a capacity)	2.028 •
BASE VALUE	163.490

• TASK R&S-KAH estimates

Table XVII - Analysis of the various unit operations of route LWR4-BWR (20 GWe). All figures are given in $MECU_{88}$ for the capital cost and in $MECU_{88} \cdot a^{-1}$ for the operating cost.

UNIT OPERATION: Coolant cleaning			
Major Equipment	17.256	Process Mat.	0.545
Bulk Materials	11.216	Utilities	0.261
		Maint. Mat.	1.424
Install. Labour	16.392	Direct Labour	0.641
Capital Cost	44.864	Operating Cost	2.871
UNIT OPERATION: Low conductivity system			
Major Equipment	41.497	Process Mat.	4.609
Bulk Materials	26.973	Utilities	0.932
		Maint. Mat.	3.424
Install. Labour	39.423	Direct Labour	1.283
Capital Cost	107.893	Operating Cost	10.248
UNIT OPERATION: High conductivity system			
Major Equipment	42.853	Process Mat.	0.986
Bulk Materials	27.855	Utilities	0.581
		Maint. Mat.	3.535
Install. Labour	40.711	Direct Labour	1.283
Capital Cost	111.419	Operating Cost	6.385
UNIT OPERATION: Detergents system			
Major Equipment	14.859	Process Mat.	0.145
Bulk Materials	9.659	Utilities	0.201
		Maint. Mat.	1.226
Install. Labour	14.117	Direct Labour	0.642
Capital Cost	38.635	Operating Cost	2.214
UNIT OPERATION: Off gas treatment			
Major Equipment	22.854	Process Mat.	1.026
Bulk Materials	14.855	Utilities	0.323
		Maint. Mat.	1.885
Install. Labour	21.712	Direct Labour	0.321
Capital Cost	59.421	Operating Cost	3.555

Table XVII - (cont'd)

UNIT OPERATION: Ventilation			
Major Equipment Bulk Materials Install. Labour	11.373 7.392 10.804	Process Mat. Utilities Maint. Mat. Direct Labour	0.893 0.215 0.938 0.321
Capital Cost	29.569	Operating Cost	2.367
UNIT OPERATION: Solid waste treatment			
Major Equipment Bulk Materials Install. Labour	10.401 6.761 9.881	Process Mat. Utilities Maint. Mat. Direct Labour	4.275 0.834 0.858 3.208
Capital Cost	27.043	Operating Cost	9.175
UNIT OPERATION: Technological waste pre-compaction			
Major Equipment Bulk Materials Install. Labour	0.369 0.240 0.351	Process Mat. Utilities Maint. Mat. Direct Labour	0.942 0.161 0.030 0.642
Capital Cost	0.960	Operating Cost	1.775
UNIT OPERATION: Interim storage (1 a capacity)			
Major Equipment Bulk Materials Install. Labour	2.028 1.318 1.927	Process Mat. Utilities Maint. Mat. Direct Labour	--- 0.081 0.167 0.642
Capital Cost	5.273	Operating Cost	0.890

Table XVIII - Actualised capital and annual operating costs for route LWR4-BWR (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 ($MECU_{92} \cdot a^{-1}$)
SITE IMPROVEMENT	27.714	---
CIVIL WORKS	146.827	---
UNIT OPERATIONS §		
Coolant cleaning system	54.173	3.133
Low conductivity system	130.278	11.180
High conductivity system	134.535	6.967
Detergents system	46.650	2.416
Off gas treatment	71.750	3.879
Ventilation	35.704	2.583
Solid waste treatment	32.653	10.010
Techn. waste pre-compaction	1.159	1.937
Interim storage (1 a)	6.366	0.971
QUALITY ASSURANCE	78.964	---
INDIRECT CONSTRUCTION	35.053	---
LABORATORY	4.557	1.441
SAFETY & HEALTH PHYSICS	13.672	3.603
ARCHITECTURAL & ENGINEERING SERVICES	44.403	---
LABOUR ASSOCIATED WITH PLANT OPERATION *	---	3.603
OVERHEADS	---	4.324
TOTAL	864.458	56.047

§ See footnote of Table VII

* See footnote of Table VII

Table XIX - Material cost of the Major Equipment for four unit operations of route LWR5-BWR (20 GWe). All the figures are quoted for 1988.

UNIT OPERATION	TOTAL COST ($MECU_{88}$)
Coolant cleaning system	17.256 +
Water treatment	41.504 +
Off gas treatment	42.853 +
Ventilation system	1 538.462 +

+ Directly derived from the costs provided by GNS - FRAMATOME

Table XX - Actualised capital and annual operating costs together with the corresponding total plant cost for 30 years of operation and constant annual cost for the LWR waste management routes. The costs do not include the transport of the treated waste.

Actualisation date: 01.01.92

ROUTE	ACTUALISED CAPITAL COST (MECU)	ACTUALISED ANNUAL OPERATING COST ($MECU \cdot a^{-1}$)	TOTAL PLANT COST FOR 30 YEARS OF OPERATION (MECU)	CONSTANT ANNUAL COST ($MECU \cdot a^{-1}$)
Route LWR1-PWR	604.929	39.112	1 145.108	104.610
Route LWR2-PWR [a]	1 065.986	58.840	1 878.629	171.620
Route LWR2-PWR [b]	1 092.051	52.387	1 815.572	165.859
Route LWR3-PWR [c]	856.267	43.046	1 450.778	132.534
Route LWR3-PWR [d]	834.182	42.719	1 424.177	130.104
Route LWR4-BWR	864.458	56.047	1 638.527	149.685
Route LWR5-BWR	?	?	?	?

[a] All mobile units and incinerator rented
[b] All mobile units and incinerator bought
[c] Interim storage capacity = 10 a
[d] Interim storage capacity = 1 a

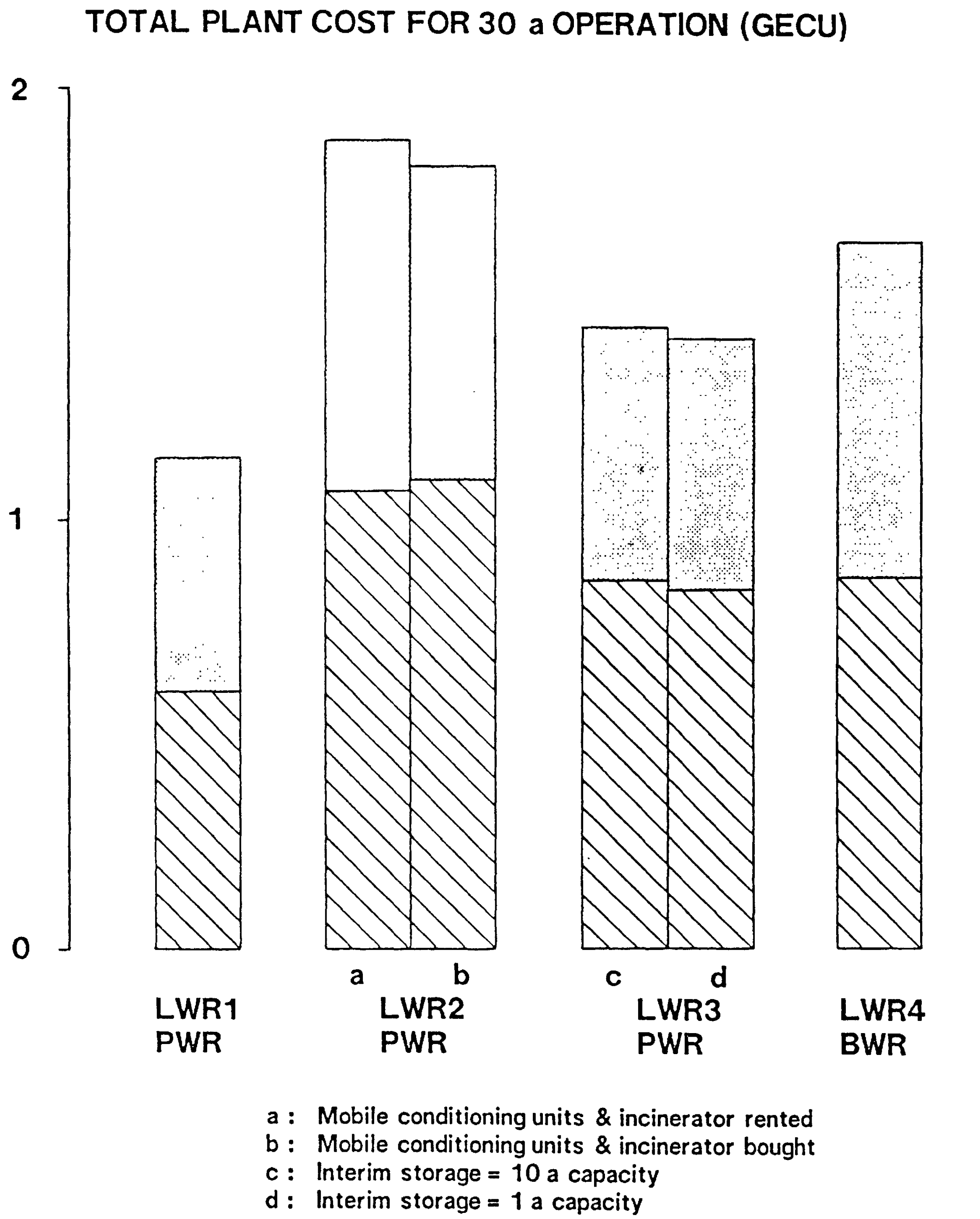


Figure 5 - Total plant costs for 30 years of operation for the various LWR waste management routes (20 GWe).

Total capital cost

Total operating cost for 30 a operation

6. ASSESSMENT OF THE TRANSPORT COSTS

A transport journey has been defined as the transport of the casks/containers to the disposal site and their return the LWR waste treatment plant, each covering a distance of 500 km (except for LWR3-PWR). The crossing of one border has been taken into account. However, a different transport scheme for route LWR3-PWR is utilised.

The type of casks and transport medium conform to the national practice for waste transport for each route.

The capital cost for the transport reflects the acquisition of the casks at the start of the plant operation, whereas the annual operating cost consists of the freight costs, custom duties and insurance. The methods used for the actualisation and calculation of the constant annual transport cost are described in detail in § 3.

6.1 Route LWR1-PWR

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

- Annual waste production for 20 GWe:
  C1 = 533 containers • a^{-1}
  C4 = 1 356 containers • a^{-1}
  200 l drums = 17 933 drums • a^{-1}

- The C1 and C4 containers are transported without transport cask and the 200 l drums in 20' containers.

- Transport means: truck (maximum 26 t of packaged waste per truck)

The actualised costs associated with the transport are shown in Table XXI.

6.2 Route LWR2-PWR

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

- Annual waste production for 20 GWe:
  Type II = 508 containers • a^{-1}

Type IV	=	200 containers $\cdot a^{-1}$
Type V	=	123 containers $\cdot a^{-1}$

- The waste containers are transported in 20' containers:
  - 3 type II containers/20' container
  - 2 type IV containers/20' container
  - 2 type V containers/20' container

- Transport means: train (maximum two 20' containers per train wagon)

The actualised costs associated with the transport are shown in Table XXI.

6.3 Route LWR3-PWR

In Belgium, the following transport scheme is used:

PWR site —(100 km)→ Interim storage (10 a) —(100 km)→ Final disposal site

Moreover, the transport of radioactive waste is sub-contracted to TRANSNUBEL. Therefore, for the plant owner no capital cost is involved.

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

- Annual waste production for 20 GWe:

400 l drums	=	245 drums $\cdot a^{-1}$ for TNB 167 S transport
	=	1 689 drums $\cdot a^{-1}$ for TNB 167 NS transport
	=	11 689 drums $\cdot a^{-1}$ for TNB 178 transport

- The waste drums are transported in special vehicles:
  - 7 drums/TNB 167 S transport
  - 14 drums/TNB 167 NS transport
  - 20 drums/TNB 178 transport

- Transport means: special vehicles for road transport

The actualised costs associated with the transport are shown in Table XXI.

6.4 Routes LWR4-BWR and LWR5-BWR

Since no specific information was provided by the organisations responsible for the engineering of these routes, the transport costs could not be evaluated.

Table XXI - Actualised capital and annual operating costs together with the corresponding total transport cost for 30 years of operation and constant annual cost for the three PWR waste management routes.

Actualisation date: 01.01.92

ROUTE	ACTUALISED CAPITAL COST (MECU)	ACTUALISED ANNUAL OPERATING COST ($MECU \cdot a^{-1}$)	TOTAL TRANSPORT COST FOR 30 YEARS OF OPERATION (MECU)	CONSTANT ANNUAL COST ($MECU \cdot a^{-1}$)
Route LWR1-PWR	0.091	1.048	14.565	1.331
Route LWR2-PWR	1.125	1.259	18.513	1.691
Route LWR3-PWR	0.000	3.134	43.284	3.954

7. COST SCALING

To illustrate the effect of scaling, two cases, i.e. 6 and 60 GWe, were evaluated. The modular approach was applied to the treatment/conditioning plant as well as the transport, whereas the cost scaling was employed for the associated interim storage (cf. § 4). The costs were actualised on the basis of the assumptions established for the reference capacity. The resulting expenditures, summarised in Tables XXII to XXV, represent the costs associated with the construction and operation of the plant at its new capacity.

Table XXII - Cost estimation for different plant capacities based on the process of route LWR1-PWR.

Date of actualisation: 01.01.92

COSTS ASSOCIATED WITH THE PLANT	UNIT	PLANT CAPACITY	
		6 GWe	60 GWe
Direct capital cost	MECU	172.613	1 702.023
Indirect capital cost	MECU	17.175	68.454
TOTAL CAPITAL COST	MECU	189.788	1 770.477
ANNUAL OPERATING COST	MECU/a	11.764	117.158
TOTAL PLANT COST FOR 30 a OPERATION	MECU	352.264	3 388.553
CONSTANT ANNUAL PLANT COST	MECU/a	32.181	309.556

COSTS ASSOCIATED WITH THE WASTE TRANSPORT	UNIT	PLANT CAPACITY	
		6 GWe	60 GWe
TOTAL CAPITAL COST	MECU	0.027	0.273
ANNUAL OPERATING COST	MECU/a	0.314	3.143
TOTAL TRANSPORT COST FOR 30 a OPERATION	MECU	4.368	43.680
CONSTANT ANNUAL TRANSPORT COST	MECU/a	0.399	3.990

TOTAL CONSTANT ANNUAL COST	MECU/a	32.580	313.546

Table XXIII - Cost estimation for different plant capacities based on the process of route LWR2-PWR (mobile conditioning units & incinerator rented).

Date of actualisation: 01.01.92

COSTS ASSOCIATED WITH THE PLANT	UNIT	PLANT CAPACITY	
		6 GWe	60 GWe
Direct capital cost	MECU	306.227	3 041.943
Indirect capital cost	MECU	24.107	74.776
TOTAL CAPITAL COST	MECU	330.334	3 116.719
ANNUAL OPERATING COST	MECU/a	17.678	176.379
TOTAL PLANT COST FOR 30 a OPERATION	MECU	574.480	5 552.708
CONSTANT ANNUAL PLANT COST	MECU/a	52.481	507.260

COSTS ASSOCIATED WITH THE WASTE TRANSPORT	UNIT	PLANT CAPACITY	
		6 GWe	60 GWe
TOTAL CAPITAL COST	MECU	0.337	3.375
ANNUAL OPERATING COST	MECU/a	0.378	3.777
TOTAL TRANSPORT COST FOR 30 a OPERATION	MECU	5.554	55.539
CONSTANT ANNUAL TRANSPORT COST	MECU/a	0.507	5.074

TOTAL CONSTANT ANNUAL COST	MECU/a	52.988	512.334

Table XXIV - Cost estimation for different plant capacities based on the process of route LWR3-PWR (<u>Interim Storage = 10 a capacity</u>).

Date of actualisation: 01.01.92

COSTS ASSOCIATED WITH THE PLANT	UNIT	PLANT CAPACITY	
		6 GWe	60 GWe
Direct capital cost	MECU	251.363	2 410.829
Indirect capital cost	MECU	20.785	81.823
TOTAL CAPITAL COST	MECU	272.148	2 492.652
ANNUAL OPERATING COST	MECU/a	12.999	128.653
TOTAL PLANT COST FOR 30 a OPERATION	MECU	451.676	4 269.482
CONSTANT ANNUAL PLANT COST	MECU/a	41.262	390.032

COSTS ASSOCIATED WITH THE WASTE TRANSPORT	UNIT	PLANT CAPACITY	
		6 GWe	60 GWe
TOTAL CAPITAL COST	MECU	0.000	0.000
ANNUAL OPERATING COST	MECU/a	0.940	9.402
TOTAL TRANSPORT COST FOR 30 a OPERATION	MECU	12.985	129.849
CONSTANT ANNUAL TRANSPORT COST	MECU/a	1.186	11.862

TOTAL CONSTANT ANNUAL COST	MECU/a	42.448	401.894

Table XXV - Cost estimation for different plant capacities based on the process of route LWR4-BWR.

Date of actualisation: 01.01.92

COSTS ASSOCIATED WITH THE PLANT	UNIT	PLANT CAPACITY	
		6 GW(e)	60 GW(e)
Direct capital cost	MECU	248.207	2 455.680
Indirect capital cost	MECU	21.611	86.027
TOTAL CAPITAL COST	MECU	269.818	2 541.707
ANNUAL OPERATING COST	MECU/a	16.847	167.939
TOTAL PLANT COST FOR 30 a OPERATION	MECU	502.497	4 861.130
CONSTANT ANNUAL PLANT COST	MECU/a	45.905	444.082

COSTS ASSOCIATED WITH THE WASTE TRANSPORT	UNIT	PLANT CAPACITY	
		6 GW(e)	60 GW(e)
TOTAL CAPITAL COST	MECU	?	?
ANNUAL OPERATING COST	MECU/a	?	?
TOTAL TRANSPORT COST FOR 30 a OPERATION	MECU	?	?
CONSTANT ANNUAL TRANSPORT COST	MECU/a	?	?

TOTAL CONSTANT ANNUAL COST	MECU/a	?	?

8. DISCUSSION OF THE RESULTS AND CONCLUSIONS

The cost evaluations are either derived from cost figures provided by others, calculated from engineering data or estimated by TASK R&S - KAH. Since the basis for the costing is not uniform, a detailed comparison of the costs for the different LWR waste management routes is not feasible. Nevertheless, certain observations can be made concerning the economic behaviour of the plant and transport costs.

8.1 Cost Assessment of the PWR Waste Management Routes (20 GWe)

8.1.1 Assessment of the plant costs

CAPITAL COST:

The actualised capital costs of the three PWR waste management routes can only be compared with caution. Not considering the uncertainties associated with estimates or the possible different basis used for the cost figures provided by the other organisations, route LWR1-PWR requires the lowest capital investment, followed by route LWR3-PWR, with route LWR2-PWR being the highest (Figure 5). The maximum cost ratio observed is ≈ 1.8 (Table XX). The reason for the different capital investment required lies mainly in the material cost of the Major Equipment (Table XXVI), the maximum cost ratio being 2.

Although the processes applied in the routes LWR1-PWR and LWR3-PWR are alike, this is not necessarily the case for the design criteria. Variation in the components' material, capacity and quantity has a direct impact on the Base Value. This is illustrated by the following analysis:

- Boron Recycling System:
  In general, the capacities of the components and the throughputs of the process streams are smaller in route LWR3-PWR than in LWR1-PWR.

- Liquid Waste Treatment:
  The liquid wastes collection vessels and associated components, with the exception of the laundry waste, have practically twice the capacity in route LWR3-PWR as that in route LWR1-PWR. Furthermore, the reagents preparation in the former route contains a flocculation step, which is missing in the latter route. The costs for evaporation are comparable for both routes.

Table XXVI - Comparison of the material costs of the Major Equipment utilised in the three basic PWR waste management routes (20 GWe) and the corresponding Base Values. All the figures are quoted for 1988.

UNIT OPERATION	TOTAL COST ($MECU_{88}$)		
	LWR1-PWR	LWR2-PWR	LWR3-PWR
Boron recycling system/Primary coolant treatment	54.484	61.148 +	36.661
Liquid waste treatment	17.920	62.115 +	24.294
Liquid waste storage before discharge	5.907	3.400 •	8.298
Off gas treatment	5.759	65.515 +	29.755
Ventilation	6.412 +	11.619 •	11.842
Solid waste treatment	13.310	6.115 +*	15.209
Technological waste treatment:			
. Technological waste pre-compaction	0.200 •	0.277 +	---
. Supercompaction & incineration	---	--- *	---
Central solid waste treatment	---	---	27.220 +
Interim storage (1 a capacity)	1.843	1.506	---
Interim storage (10 a capacity)	---	---	5.077
BASE VALUE	105.835	211.695	158.356

+ Derived from the costs provided by the other organisations

* Mobile conditioning units and incinerator rented

• TASK R&S-KAH estimates

- Liquid Waste Storage before Discharge:
  In this case, the reason for the difference between the two routes mainly lies in the different material and quantity used for the storage tanks for a 1.8 GWe module, i.e. concrete tanks (3 x 750 m^3) in LWR1-PWR versus coated carbon steel tanks (4 x 400 m^3) in LWR3-PWR.

- Off Gas Treatment:
  In route LWR1-PWR the gaseous effluents are compressed and stored in vessels; they are then released, when their activity is sufficiently low. The Off Gas Treatment of route LWR3-PWR has been designed for a 0.9 GWe unit as compared to the 1.8 GWe module of route LWR1-PWR, thus practically doubling the amount of compressors and storage vessels for 1 module. In addition, route LWR3-PWR incorporates recombiner units for H_2 and O_2 (the cost of which is elevated) to limit explosion risks.

- Ventilation:
  No comparison can be made between the two routes, since only the cost for the system was provided for route LWR1-PWR.

- Solid Waste Treatment:
  The costs for this unit operation are very comparable, as the main conditioning method is cementation. Nevertheless, route LWR1-PWR utilises polymer embedding of the spent resins in contrast to the cementation employed in route LWR3-PWR. LWR3-PWR also foresees the conditioning of the flocculates and magnetic filtration residues.

- Central Solid Waste Treatment & Interim Storage:
  Route LWR3-PWR incorporates a Central Solid Waste Treatment unit and an Interim Storage having a capacity of 10 years.

The differences in design criteria in the common unit operations and the addition of a Central Solid Waste Treatment influence the Base Value of route LWR3-PWR and consequently all the cost elements, which are directly derived from the Base Value. Moreover, the larger storage capacity of the Interim Storage augments the cost for the Civil Works. As a result, the actualised capital cost for LWR3-PWR is a factor of 1.4 higher than that of LWR1-PWR (Table XX).

Due to the limited engineering information provided for LWR2-PWR, a comparison of the costs with the other PWR waste management routes cannot be performed by TASK R&S - KAH. Nevertheless, FRAMATOME has provided an analysis of the cost differences between routes LWR1-PWR and LWR2-PWR [31], which are summarised below:

- General observations:
  - The waste treatment described for routes LWR1-PWR and LWR3-PWR are common to a 1.8 GWe module, resulting in an adjustment factor of 11.11 to arrive at a 20 GWe capacity. In contrast, each German reactor, having a capacity of 1.3 GWe, has its own waste treatment plant (adjustment factor of 15.38). Thus, the engineering basis is influenced by the capacity of the treatment/conditioning plant, the costs of which do not change linearly with plant capacity [26,28,31,32].
  - The safety regulations and industrial practices vary from country to country. For example, explosion risks due to H_2 must be avoided in the F.R.G., resulting in a much more sophisticated off gas system than in France. Moreover, German plants are designed to resist aircraft impact, which further influences the design of the components.
  - German components are generally more expensive than French ones.

- Primary Coolant Treatment:
  LWR1-PWR (1.8 GWe):
  - Head storage: 2 x 80 m^3 (without demineralised water storage)
  - Evaporation: 2 x 3.5 $t \cdot h^{-1}$ (boron content of distillate = 5 ppm)
  - Degassing: two degassers (2 x 27 $m^3 \cdot h^{-1}$) purify all the effluents entering the Boron Recycling System, even during reactor cool-down

  LWR2-PWR (1.3 GWe):
  - Head storage: 660 m^3 (some of the tanks are used to store distillates arising from evaporation)
  - Evaporation: 8 $t \cdot h^{-1}$ (boron content of distillate = 1 ppm)
  - Degassing: two degassers. One "upstream" degasser (70 $m^3 \cdot h^{-1}$) is connected to the primary coolant purification system and used during reactor cool-down. It is not directly a part of the Primary Coolant Treatment, because the effluents return without further treatment to the primary coolant purification system. Another "downstream" degasser (8 $m^3 \cdot h^{-1}$) purifies distillates coming from the evaporator, which are directed to the Liquid Waste Treatment system.

- Liquid Waste Treatment:
  The capacity of evaporator station is three times higher in route LWR2-PWR than that in route LWR1-PWR (8 $m^3 \cdot h^{-1}$ for 1.3 GWe and 3.5 $m^3 \cdot h^{-1}$ for 1.8 GWe respectively). Moreover, the concentrates are stored in this system, whereas in LWR1-PWR they are collected in the Solid Waste Treatment system.

- Off Gas Treatment:
  As already discussed before, the gaseous waste treatment in route LWR1-

PWR is limited to storage and release. In route LWR2-PWR, however, H_2 and O_2 are recombined to limit explosion risks. The relevant system is complex - comprising recombiners, dryers, heat exchangers, etc. - and represents 27 % of the Base Value for this unit operation. Moreover, because of leakage risks, the gaseous effluents (without H_2, O_2 and H_2O) are continuously fed to a delay column, the cost of which corresponds to 35 % of the Base Value of this unit operation.

- Solid Waste Treatment:
  In LWR2-PWR, only the pre-treatment of the concentrates is considered as capital investment. Conditioning of the wet wastes is performed by rented mobile conditioning units (FAFNIR and FAVORIT); the latter cost has been taken into account in the annual operating cost. On the other hand, the conditioning of all wet wastes, with the exclusion of the spent resins, of LWR1-PWR is performed by installed components, resulting in a higher capital cost. Moreover, the conditioning of the spent resins is performed in a mobile unit, which is also acquired by the plant owner.

- Technological Waste Treatment:
  Only a pre-compaction step has been considered in route LWR1-PWR, as these wastes are shipped in metallic drums to the La Manche Centre, where they are further compacted. Route LWR2-PWR foresees the pre-compaction of some of the waste, followed by the supercompaction in a mobile unit (FAKIR), which is rented. Moreover, the combustible waste is incinerated, a service which is also rented.

- Interim Storage:
  The equipment costs for the Interim Storage are comparable for both routes.

ANNUAL OPERATING COST:

The operating costs for the three LWR waste management routes display a maximum cost ratio of ≈ 1.5. The differences are mainly caused by the contribution of the annual cost for the Maintenance Materials, which is directly derived from the Base Value, and to a much lesser extent by the type, capacity and quantity of the waste containers employed. The higher operating cost of LWR2-PWR is further caused by the rental of the mobile waste conditioning units and the incinerator facility.

TOTAL PLANT COST:

The total plant costs for 30 years of operation reflect the combination of the total capital and operating costs and show a maximum cost ratio of ≈ 1.6 (Table XX). It is interesting to note that the contribution of the capital costs of the three PWR waste management routes ranges between 52 and 60 % of the total plant cost for 30 a of operation. This is rather surprising in view of the different waste treatment/conditioning philosophies and design criteria implemented in the routes.

8.1.2 *Assessment of the transport costs*

Due to the application of the national practices for waste transport, a direct comparison of the costs related to the transport of the conditioned waste for the PWR waste management routes is difficult (Table XXI). In short, the transport costs reflect a combination of the following parameters:

- responsibility for the transport, i.e. plant owner or sub-contractor;
- type and capacity of the waste containers;
- transport distance covered;
- transport means.

Nevertheless, the results obtained indicate that the transport costs play an insignificant part in the total cost of the PWR waste management routes, namely:

- LWR1-PWR: 1.3 % of the total cost for 30 a of operation;
- LWR2-PWR: 1.0 % of the total cost for 30 a of operation;
- LWR3-PWR: 2.9 % of the total cost for 30 a of operation.

8.2 Cost Assessment of the BWR Waste Management Routes (20 GWe)

Because the cost data for LWR5-BWR are incomplete (Table XIX) and those for LWR4-BWR must be considered indicative (Table XVIII), their analysis is not possible. Moreover, the transport costs associated with these two routes could not be evaluated due to the lack of the necessary input information.

8.3 Cost Scaling

The variation in the cost behaviour of the LWR waste management routes is not greatly influenced by changes in plant capacity (Table XXII to XXV), as mainly a linear approach was used. Only minor variations in the cost ratios are found for the cases of 6 and 60 GWe.

9. REFERENCES

[1] DE SAULIEU E., "French reference management route for PWR radioactive effluents.", SGN - EDF, Second Progress Report (Part I), Doc. N° 3174A 00 002, Rev. 2, June 1989

[2] CRUSTIN J., "General description of basic management routes. 3.1.1. General description of basic management routes for gaseous effluents.", Belgatom, Doc. N° 098.71.17/n/8029, 18.08.88

[3] CRUSTIN J., "General description of basic management routes. 3.1.2. General description of basic management routes for liquid effluents.", Belgatom, Doc. N° 098.71.17/n/8035, 20.09.88

[4] RENARD C., CRUSTIN J., "General description of basic management routes. 3.1.3. General description of basic management routes for solid effluents.", Belgatom, Doc. N° 03230/095, 13.02.89

[5] GILSON C., "Technical description. 3.2.1. Gaseous effluents in PWR. 3.2.1.1. Off-gas treatment.", Belgatom, Document N° 098.71/17/n/8012, 07.06.88

[6] CRUSTIN J., "Technical description of effluents management routes. 3.2.1. Gaseous effluents. 3.2.1.2. Ventilation air treatment - Base: Tihange 2 and 3.", Belgatom, Document N° 098.71/17/n/8040, 10.10.88

[7] CENTNER B., CRUSTIN J., "Ventilation systems. Safety design bases.", Belgatom, Doc. N° 098.71/17/n/8043, 12.10.88

[8] RENARD C., CRUSTIN J., "Technical description of effluents management routes. 3.2.2. Technical description of liquid effluents treatment.", Belgatom, Document N° 03408/095, 13.02.89

[9] NOLET G., CRUSTIN J., "Technical description. 3.2.3. Solid waste in PWR. 3.2.3.1 Part one: on-site installations.", Belgatom, Document N° 03426/095, 13.02.89

[10] CRUSTIN J., RENARD C., "Data for costing study. 6.1.1 Data related to chapter 3.2.1.1.: gaseous effluents - part one (off gases). 6.1.1.1. Equipment costs.", Belgatom, Doc. N° 01104/095, 17.01.89

[11] MATHIEU P., CRUSTIN J., "Data for costing study. 6.1.2 Data related to chapter 3.2.1.2.: ventilation air treatment system. 6.1.2.1. Equipment costs.", Belgatom, Doc. N° 01240/095, 17.01.89

[12] CRUSTIN J., RENARD C., "Data for costing study. 6.2 Data related to chapter 3.2.2.: liquid effluents treatment. 6.2.1. Equipment costs.", Belgatom, Doc. N° 01242/095, 17.01.89

[13] RENARD C., CRUSTIN J. "Data for costing study. 6.3. Data related to chapter 3.1.3.: solid effluents. 6.3.1. Equipment costs.", Belgatom, Doc. N° 01244/095, 17.01.89

[14] CRUSTIN J., RENARD C., "Data for costing study. 6.4. Operating costs - waste treatment. 6.4.1. Gaseous and liquid waste.", Belgatom, Doc. N° 01246/095, 17.01.89

[15] CRUSTIN J., DEBLEVE P.., "Data for costing study. 6.4. Operating costs - waste treatment. 6.4.2. Solid waste 6.4.2.1. On-site installations.", Belgatom, Doc. N° 01106/095, 17.01.89

[16] JANBERG K., GEISER H., SANTRAILLE S., "Assessment of management alternatives for reactor waste. Reference waste management scheme.", Final Report (First Draft), 1989 & Revision 1 of 25.10.89

[17] GNS - Framatome, Working Document N° Dr. G/pü/5024, 18.10.89

[18] GNS - Framatome, Working Document N° Dr. G/ho, 30.05.90

[19] SIRE J.M., BARQUERO R., "Spanish reference management route for BWR Cofrentes NPP.", SGN - Inypsa, Second Progress Report (Part II), December 1988

[20] ANONYMOUS, "Il contributo dell'A.I.E.A. allo studio dei costi nucleari.", Comitato Nazionale Energia Nucleare, 1961

[21] ANONYMOUS, "Economic evaluation of bids for nuclear power plants. A guidebook.", Techn. Rep. Series N° 175, IAEA, Vienna, 1976

[22] ANONYMOUS, "Technology for commercial radioactive waste management.", Vol. 2, U.S. Dept. of Energy, Report DOE/ET-0028, 1978

[23] PETERS M.S., TIMMERHAUS K.D., "Plant design and economics for chemical engineers.", Third Edition, McGraw-Hill Book Comapny, International Edition, 1981

[24] CRAN J., "Improved factored method gives better preliminary cost estimates.", Chem. Eng. April 6, 1981, 65-79

[25] ANONYMOUS, "Handbook of engineering fundamentals.", (Eshbach O.W., Souders M., Eds.), 3rd Edition, John Wiley & Sons, New York, London, Sydney, Toronto, 1974

[26] COLI G., PARESCHI A., "Impianti ad energie integrative: valutazioni economiche.", Energie Alternative H.T.E. 30 (6), 1984, 326-335

[27] SASSONE P.G., SCHAFFER W.A., "Cost benefit analysis - a handbook.", Academic Press, New York, San Francisco, London, 1978

[28] PERRY R.H., CHILTON C.H., "Chemical engineer's handbook.", 5th Edition, McGraw-Hill Book Company Inc., New York, Toronto, London, 1973

[29] BACKHURST J.R., HARKER J.H., "Process plant design.", Heineman Educational Books, London, 1973

[30] CARTER W.L., RAINEY R.H., "Methodology for estimating reprocessing costs for nuclear fuels.", Oak Ridge National Laboratory, Report N° ORNL/TM-6648, 1980

[31] FRAMATOME, Working Document N° IT/S.90.406/DIM, 01.06.90

European Communities – Commission

EUR 14043 – Assessment of management alternatives for LWR wastes
(Volume 6)
Cost determination of the LWR waste management routes (treatment/conditioning/packaging/transport operations)

G. M. Thiels, S. Kowa

Luxembourg: Office for Official Publications of the European Communities

1993 – XI, 65 pp., num. tab., fig. – 21.0 × 29.7 cm

Nuclear science and technology series

ISBN 92-826-4890-7

Price (excluding VAT) in Luxembourg: ECU 9

This report deals with the cost determination of a number of schemes for the treatment, conditioning, packaging, interim storage and transport operations of LWR wastes drawn up on the basis of Belgian, French and German practices in this particular area.

In addition to the general procedure elaborated for determining, actualizing and scaling of plant and transport costs associated with the various schemes, in-depth calculations of each intermediate management stage are included in this report.

This study is part of an overall theoretical exercise aimed at evaluating a selection of management routes for LWR waste based on economical and radiological criteria.

Venta y suscripciones • Salg og abonnement • Verkauf und Abonnement • Πωλήσεις και συνδρομές
Sales and subscriptions • Vente et abonnements • Vendita e abbonamenti
Verkoop en abonnementen • Venda e assinaturas

BELGIQUE / BELGIË

Moniteur belge / Belgisch Staatsblad
Rue de Louvain 42 / Leuvenseweg 42
B-1000 Bruxelles / B-1000 Brussel
Tél. (02) 512 00 26
Fax (02) 511 01 84

Autres distributeurs / Overige verkooppunten

Librairie européenne/ Europese boekhandel
Rue de la Loi 244/Wetstraat 244
B-1040 Bruxelles / B-1040 Brussel
Tél. (02) 231 04 35
Fax (02) 735 08 60

Jean De Lannoy
Avenue du Roi 202 /Koningslaan 202
B-1060 Bruxelles / B-1060 Brussel
Tél. (02) 538 51 69
Télex 63220 UNBOOK B
Fax (02) 538 08 41

Document delivery:

Credoc
Rue de la Montagne 34 / Bergstraat 34
Bte 11 / Bus 11
B-1000 Bruxelles / B-1000 Brussel
Tél. (02) 511 69 41
Fax (02) 513 31 95

DANMARK

J. H. Schultz Information A/S
Herstedvang 10-12
DK-2620 Albertslund
Tlf. 43 63 23 00
Fax (Sales) 43 63 19 69
Fax (Management) 43 63 19 49

DEUTSCHLAND

Bundesanzeiger Verlag
Breite Straße 78-80
Postfach 10 80 06
D-W-5000 Köln 1
Tel. (02 21) 20 29-0
Telex ANZEIGER BONN 8 882 595
Fax 2 02 92 78

GREECE/ΕΛΛΑΔΑ

G.C. Eleftheroudakis SA
International Bookstore
Nikis Street 4
GR-10563 Athens
Tel. (01) 322 63 23
Telex 219410 ELEF
Fax 323 98 21

ESPAÑA

Boletín Oficial del Estado
Trafalgar, 29
E-28071 Madrid
Tel. (91) 538 22 95
Fax (91) 538 23 49

Mundi-Prensa Libros, SA
Castelló, 37
E-28001 Madrid
Tel. (91) 431 33 99 (Libros)
431 32 22 (Suscripciones)
435 36 37 (Dirección)
Télex 49370-MPLI-E
Fax (91) 575 39 98

Sucursal:

Librería Internacional AEDOS
Consejo de Ciento, 391
E-08009 Barcelona
Tel. (93) 488 34 92
Fax (93) 487 76 59

Llibreria de la Generalitat de Catalunya
Rambla dels Estudis, 118 (Palau Moja)
E-08002 Barcelona
Tel. (93) 302 68 35
302 64 62
Fax (93) 302 12 99

FRANCE

Journal officiel
Service des publications des Communautés européennes
26, rue Desaix
F-75727 Paris Cedex 15
Tél. (1) 40 58 75 00
Fax (1) 40 58 77 00

IRELAND

Government Supplies Agency
4-5 Harcourt Road
Dublin 2
Tel. (1) 61 31 11
Fax (1) 78 06 45

ITALIA

Licosa SpA
Via Duca di Calabria 1/1
Casella postale 552
I-50125 Firenze
Tel. (055) 64 54 15
Fax 64 12 57
Telex 570466 LICOSA I

GRAND-DUCHÉ DE LUXEMBOURG

Messageries du livre
5, rue Raiffeisen
L-2411 Luxembourg
Tél. 40 10 20
Fax 40 10 24 01

NEDERLAND

SDU Overheidsinformatie
Externe Fondsen
Postbus 20014
2500 EA 's-Gravenhage
Tel. (070) 37 89 911
Fax (070) 34 75 778

PORTUGAL

Imprensa Nacional
Casa da Moeda, EP
Rua D. Francisco Manuel de Melo, 5
P-1092 Lisboa Codex
Tel. (01) 69 34 14

Distribuidora de Livros Bertrand, Ld.ª

Grupo Bertrand, SA
Rua das Terras dos Vales, 4-A
Apartado 37
P-2700 Amadora Codex
Tel. (01) 49 59 050
Telex 15798 BERDIS
Fax 49 60 255

UNITED KINGDOM

HMSO Books (Agency section)
HMSO Publications Centre
51 Nine Elms Lane
London SW8 5DR
Tel. (071) 873 9090
Fax 873 8463
Telex 29 71 138

ÖSTERREICH

Manz'sche Verlags- und Universitätsbuchhandlung
Kohlmarkt 16
A-1014 Wien
Tel. (0222) 531 61-0
Telex 112 500 BOX A
Fax (0222) 531 61-39

SUOMI/FINLAND

Akateeminen Kirjakauppa
Keskuskatu 1
PO Box 128
SF-00101 Helsinki
Tel. (0) 121 41
Fax (0) 121 44 41

NORGE

Narvesen Info Center
Bertrand Narvesens vei 2
PO Box 6125 Etterstad
N-0602 Oslo 6
Tel. (22) 57 33 00
Telex 79668 NIC N
Fax (22) 68 19 01

SVERIGE

BTJ
Tryck Traktorwägen 13
S-222 60 Lund
Tel. (046) 18 00 00
Fax (046) 18 01 25
30 79 47

SCHWEIZ / SUISSE / SVIZZERA

OSEC
Stampfenbachstraße 85
CH-8035 Zürich
Tel. (01) 365 54 49
Fax (01) 365 54 11

ČESKÁ REPUBLIKA

NIS ČR
Havelkova 22
130 00 Praha 3
Tel. (2) 235 84 46
Fax (2) 235 97 88

MAGYARORSZÁG

Euro-Info-Service
Club Sziget
Margitsziget
1138 Budapest
Tel./Fax 1 111 60 61
1 111 62 16

POLSKA

Business Foundation
ul. Krucza 38/42
00-512 Warszawa
Tel. (22) 21 99 93, 628-28-82
International Fax&Phone
(0-39) 12-00-77

ROMÂNIA

Euromedia
65, Strada Dionisie Lupu
70184 Bucuresti
Tel./Fax 0 12 96 46

BĂLGARIJA

Europress Klassica BK Ltd
66, bd Vitosha
1463 Sofia
Tel./Fax 2 52 74 75

RUSSIA

Europe Press
20 Sadovaja-Spasskaja Street
107078 Moscow
Tel. 095 208 28 60
975 30 09
Fax 095 200 22 04

CYPRUS

Cyprus Chamber of Commerce and Industry
Chamber Building
38 Grivas Dhigenis Ave
3 Deligiorgis Street
PO Box 1455
Nicosia
Tel. (2) 449500/462312
Fax (2) 458630

TÜRKIYE

Pres Gazete Kitap Dergi Pazarlama Dağitim Ticaret ve sanayi AŞ
Narlibahçe Sokak N. 15
Istanbul-Cağaloğlu
Tel. (1) 520 92 96 - 528 55 66
Fax 520 64 57
Telex 23822 DSVO-TR

ISRAEL

ROY International
PO Box 13056
41 Mishmar Hayarden Street
Tel Aviv 61130
Tel. 3 496 108
Fax 3 544 60 39

UNITED STATES OF AMERICA / CANADA

UNIPUB
4611-F Assembly Drive
Lanham, MD 20706-4391
Tel. Toll Free (800) 274 4888
Fax (301) 459 0056

CANADA

Subscriptions only
Uniquement abonnements

Renouf Publishing Co. Ltd
1294 Algoma Road
Ottawa, Ontario K1B 3W8
Tel. (613) 741 43 33
Fax (613) 741 54 39
Telex 0534783

AUSTRALIA

Hunter Publications
58A Gipps Street
Collingwood
Victoria 3066
Tel. (3) 417 5361
Fax (3) 419 7154

JAPAN

Kinokuniya Company Ltd
17-7 Shinjuku 3-Chome
Shinjuku-ku
Tokyo 160-91
Tel. (03) 3439-0121

Journal Department
PO Box 55 Chitose
Tokyo 156
Tel. (03) 3439-0124

SOUTH-EAST ASIA

Legal Library Services Ltd
STK Agency
Robinson Road
PO Box 1817
Singapore 9036

AUTRES PAYS
OTHER COUNTRIES
ANDERE LÄNDER

Office des publications officielles des Communautés européennes
2, rue Mercier
L-2985 Luxembourg
Tél. 499 28-1
Télex PUBOF LU 1324 b
Fax 48 85 73/48 68 17

3/93

NOTICE TO THE READER

All scientific and technical reports published by the Commission of the European Communities are announced in the monthly periodical **'euro abstracts'**. For subscription (1 year: ECU 118) please write to the address below.

Price (excluding VAT) in Luxembourg: (Volume 6) ECU 9
(Volumes 1-8) ECU 85

OFFICE FOR OFFICIAL PUBLICATIONS
OF THE EUROPEAN COMMUNITIES

L-2985 Luxembourg

ISBN 92-826-4890-7

9 789282 648902

CD-NF-14043-EN-C