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Estimating the Cost of Disposal for Canada's Nuclear Fuel Waste

Estimation des coûts du stockage permanent des déchets de combustible nucléaire du Canada

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AECL

ESTIMATING THE COST OF DISPOSAL FOR CANADA'S NUCLEAR FUEL WASTE

by

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ABSTRACT

Atomic Energy of Canada Ltd (AECL) prepared an Environmental Impact Statement and nine supporting Primary Reference Documents on the concept for disposal of Canada's nuclear fuel waste. This report summarizes the basis of the cost estimate which is provided in the primary reference document on engineering for a disposal facility. The scope of the cost estimate is explained by describing the key features of the disposal facility design, by noting the major assumptions made in preparing the estimates, and by listing the included and excluded cost components. An activity-based project planning and control method is explained whereby the project schedule, costs, and personnel requirements are interlinked; forming an integrated perspective on the total project life cycle. The summary and distribution of costs in each project stage by major facility or activity are presented. The results of studies which reviewed the overall cost estimate are also described. These studies indicate that, within the scope, the estimate is reasonable and compares well with similar international studies.

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ESTIMATION DES COÛTS DU STOCKAGE PERMANENT DES DÉCHETS DE COMBUSTIBLE NUCLÉAIRE DU CANADA

par

Y. Ates

RÉSUMÉ

Énergie atomique du Canada limitée (EACL) a préparé une Étude d'impact sur l'environnement et neuf Rapports de référence principaux sur le concept proposé pour le stockage permanent des déchets de combustible nucléaire du Canada. Le présent rapport résume les principes de base sur lesquels repose l'estimation des coûts qui est fournie dans le rapport de référence principal sur l'ingénierie d'une installation de stockage permanent. On met ici en contexte l'estimation des coûts en décrivant les principales caractéristiques de conception de l'installation de stockage permanent, en indiquant les principales hypothèses qui ont servi à la préparation des estimations et en dressant la liste des éléments qui sont ou non inclus dans les coûts. On décrit aussi une méthode de planification et de contrôle du projet en fonction des activités, qui permet d'interrelier le calendrier du projet, les coûts et les besoins en main-d'oeuvre, de manière à en arriver à une perspective intégrée du cycle de vie complet du projet. Pour chaque installation ou activité principale, le sommaire et la répartition des coûts sont présentés à chaque étape du projet. Enfin, on décrit aussi les conclusions des études qui ont porté sur l'estimation globale des coûts. Selon ces études, et compte tenu de la portée du projet, l'estimation des coûts est raisonnable et se compare favorablement aux conclusions d'autres études internationales semblables.

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1. INTRODUCTION

Atomic Energy of Canada Ltd (AECL) issued an Environmental Impact Statement (EIS) on the Concept for Disposal of Canada's Nuclear Fuel Waste (AECL 1994). The EIS is supported by nine primary reference documents. One of these primary reference documents, The Disposal of Canada's Nuclear Fuel Waste: Engineering for a Disposal Facility (Simmons and Baumgartner 1994), includes the cost estimate for a reference conceptual engineering design of a disposal facility. Simmons and Baumgartner drew information from a series of the conceptual-level engineering design studies, primarily from the Used-Fuel Disposal Centre - A Reference Concept (AECL CANDU et al. 1992), which included a cost estimate. The objective of this document is to summarize the basis of the cost estimates of AECL CANDU et al. (1992) and Simmons and Baumgartner (1994) by describing the relevant engineering studies performed, major assumptions made, methods used, and by explaining the overall scope of the cost estimates.

2. ENGINEERING DESIGN STUDIES AND COST ESTIMATES

2.1 BACKGROUND

Engineering design and research and development activities have been conducted in parallel over the course of the Canadian Nuclear Fuel Waste Management Program. As the Program advanced, the findings from the research activities were integrated into engineering studies. In turn, these engineering studies (e.g., Acres et al. 1980a, 1980b; Acres et al. 1985; Wardrop et al. 1985) helped to define a more focused research and development program. Technical specifications for a conceptual-level design study of a Used-Fuel Disposal Centre (Baumgartner et al. 1993) were developed on the basis of the state-of-the-art information and judgment available as of 1985 December. Based on the specifications and scope defined by Baumgartner et al. (1993), a study (AECL CANDU et al. 1992) was completed that described the construction, operation and decommissioning of a used-fuel disposal facility. Simmons and Baumgartner (1994) adapted and extended the elements of the AECL CANDU et al. (1992) study by including the site screening, site evaluation, and the closure of the Used-Fuel Disposal Centre; by adding further activities related to ongoing research and development, site monitoring, performance assessment, and component testing; and by making modifications to some of the construction, operation, and decommissioning activities. Thus, the Simmons and Baumgartner (1994) study is the most up-to-date study describing the conceptual-level design for a Used-Fuel Disposal Centre.

A conceptual-level design for the Used-Fuel Disposal Centre was developed primarily to

- provide the information necessary for the preclosure and postclosure environmental and safety assessments, and

Estimating cost for a disposal facility was part of these engineering studies. However, no formal design optimization or a cost reduction analysis have been done. The cost information is needed in order to

- provide a base cost estimate of a disposal facility that may be used by the nuclear power-generating utilities to derive appropriate charges for nuclear fuel disposal to be included in rates charged to the consumers of electricity;
- provide cost and personnel estimates required for the socio-economic impact assessment of a disposal facility; and
- provide a personnel estimate and job function distribution to allow assessment of occupational health and safety effects.

After a draft report of the AECL CANDU et al. (1992) study was available, the development of an activity-based project planning tool, STADE (Storage, Transportation, And Disposal Economics), was also initiated by AECL to manage the estimation of the costs and schedules for a UFDC. AECL CANDU et al (1992) included a detailed cost database and an overall cost estimate for a UFDC. This cost data and the additional components which were introduced by Simmons and Baumgartner (1994) form the basis of the current estimate. A brief description of these two studies and of the STADE model are provided below to help in explaining the general basis of the cost estimates.

2.2 USED-FUEL DISPOSAL CENTRE STUDY - A REFERENCE CONCEPT

The specific objective of the Used-Fuel Disposal Centre study (AECL CANDU et al. 1992) was to provide a description of a facility for the disposal of used-fuel that would include a used-fuel packaging plant, a disposal vault, and general infrastructure. The disposal vault design would be suitable for locations in plutonic rock of the Canadian Shield. The scope of the study was to provide general engineering descriptions of the surface and underground facilities; operating procedures; personnel requirements; schedules; capital, operating, and maintenance cost estimates, and radiation protection and control measures.

A Used-Fuel Disposal Centre conceptual design was produced that has the capacity to dispose of 191 000 Mg of uranium in the form of 10.1 million used-fuel bundles. The disposal centre (Figure 1) would be designed to receive, package, and dispose of used-fuel bundles irradiated to an average burnup of 685 GJ/kg U and cooled for 10 a after their discharge from a CANDU® reactor. The used-fuel would be received at the used-fuel packaging plant in transport casks, transferred to and sealed in titanium containers, and sent to the underground vault for disposal. The disposal vault was assumed to be constructed at 1000 m depth in a plutonic rock body of the Canadian Shield. The disposal container was assumed to be a packed-particulate design fabricated from ASME Grade-2 titanium, which would hold 72 fuel bundles. The annual throughput would be about 250 000 used-fuel bundles which is the assumed capacity of the used-fuel transportation system. This annual amount fills about 3470 disposal containers, resulting in a

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disposal vault operating duration of over 40 years. Detailed transportation studies were performed separately by Ontario Hydro (1989).

The absence of a specific location for a disposal site required that assumptions be made in this regard. The following assumptions were made about the site when preparing the cost estimate:

- relatively flat,
- within 300 km of a populated centre (~15 000 inhabitants),
- within 25 km of rail and highway access,
- adjacent to a source of fresh water, and
- located in stable plutonic rock of the Canadian Shield.

The facilities of the disposal centre would be located both on surface and underground. The facilities at surface would include administrative buildings, a used-fuel packaging plant, a rock crushing plant, shaft headframes and their auxiliary facilities, a rock disposal area, and general support facilities that provide services to both the surface and the underground facilities. The underground facilities, which are collectively referred to as the disposal vault, would be accessed through five shafts: a service shaft for personnel, materials and equipment; a waste shaft dedicated to the transport of used-fuel; a downcast ventilation shaft and two upcast ventilation shafts located at the opposite end of the vault from the location of the other three shafts (Figure 1). The disposal vault would include access tunnels, waste disposal rooms, a component test area, a buffer and backfill plant to prepare the sealing materials, shaft complexes and service bays, water sumps and other support facilities.

A cost estimate was prepared that included the costs for the design, construction, commissioning, operation and decommissioning of a used-fuel disposal facility. The estimate also included the costs for building a new townsite. The nominal estimated costs from this study are presented in Table 1 in 1987 dollars for reference. The labour rate structure developed for the cost estimating purpose is for midsize Ontario communities, and it represents the cost of hiring the workers from contractors. Statistics Canada Socio Economic Information Management System (CANSIM) database was used in derivation of the rates. The overall project schedule for the scope of the study is shown in Figure 2.

2.3 DISPOSAL OF CANADA'S NUCLEAR WASTE: ENGINEERING FOR A DISPOSAL FACILITY

The scope of the study by AECL CANDU et al. (1992) did not include all the project stages and their activities. Simmons and Baumgartner (1994) extended the work of AECL-CANDU et al. (1992) by

- including the project activities that would be required to screen and evaluate candidate disposal sites, select a preferred site, and conduct underground exploration of the preferred site to prove its suitability;
- identifying further supporting activities including site monitoring, research, component testing and performance assessment; and
- modifying the overall used-fuel disposal project implementation schedule to include siting, extended monitoring, and closure stages.

The overall disposal project implementation stages (Figure 3), as defined by Simmons and Baumgartner (1994) are

1. Siting Stage, which includes
   - Site Screening,
   - Site Evaluation (Surface-based), and
   - Site Evaluation (Underground);
2. Construction (Development) Stage;
3. Operation Stage;
4. Extended Monitoring Stage I (optional);
5. Decommissioning (includes sealing) Stage;
6. Extended Monitoring Stage II (optional); and
7. Closure Stage.

2.3.1 Siting Stage

The objective of the first stage, the siting stage, is to obtain permission to commence the construction of a specifically designed disposal facility at a specific site on the Canadian Shield. The siting stage would initially involve site screening and site evaluation substages. Site evaluation will be done by performing exploration work from the surface, and by developing access to the underground and by performing further exploration work underground. Greater descriptive details can be found in Simmons and Baumgartner (1994) and Davison et al. (1994).

2.3.1.1 Site Screening

The objective of the site screening would be to identify a small number of candidate areas that have the characteristics desired for a disposal site, and warrant detailed investigation, within siting regions on the Canadian Shield. The activities would include analyzing existing regional-scale data, performing some reconnaissance surveys to gather additional data, developing and applying criteria for accepting or rejecting locations and ranking them for further investigation. Conceptual-level design work on surface and underground facilities would likely begin during this substage and would be used to develop documentation for regulatory approval for site evaluation work.

2.3.1.2 Surface-based Site Evaluation

Site evaluation follows from site screening. The objective of site evaluation would be to identify a preferred location for a disposal site and to obtain approval to construct a disposal facility at that site (Davison et al. 1994). The activities would include thorough site characterization, disposal facility design, and performance assessment. Work would first begin at a relatively larger regional scale to identify preferred disposal locations in the broader context of the geological setting, and then in more detail in the area surrounding the location of the preferred site(s). Site characterization would involve airborne and surface investigations and borehole studies first at the regional areas, then at those smaller areas where potentially suitable sites might exist.

2.3.1.3 Underground Site Evaluation

Underground evaluation would extend the surface-based site evaluation by constructing access into the volume of rock at the site being confirmed as a disposal site. By that time the surface-based site evaluation program is completed, a preferred disposal site has been selected, and much of the geotechnical characteristics of the preferred site are known and understood. The purpose of the Underground Evaluation substage is

- to verify and refine the surface-based evaluation interpretation of site conditions and behaviours;
- to delineate, in detail, the acceptable areas for waste emplacement;
- to perform geotechnical mapping, characterization and component testing for deriving engineering design values and constraints;
- to develop final construction and operation designs of the disposal vault and its components, and to carry out overall performance assessment studies to ensure the suitability of the site; and
- to obtain regulatory approval for the construction stage.

For the cost estimate purposes, it is assumed that a vault layout had been prepared during the surface-based site evaluation substage and a volume of rock required for a vault would be further explored during the underground evaluation substage for detailed characterization. Two exploration shafts located at the opposite ends of the prospective vault would provide access to a depth of 1000 m. These shafts would be constructed at locations such that, should the site be confirmed as the disposal site, the shafts could be converted from the exploration shafts into the actual disposal facility shafts. Exploratory access tunnels would be developed underground at locations of prospective vault access tunnels. These tunnels would be constructed at a smaller size than the actual tunnels that would be developed during the construction stage.

2.3.2 Construction Stage

The construction stage would involve constructing the infrastructure and surface facilities needed to receive and dispose of the nuclear fuel waste, the underground accesses and service areas, and a portion of the underground disposal rooms. The design and the overall performance assessment studies would continue during this stage and include documentation necessary for obtaining regulatory approval for the operation stage. The construction stage schedule and costs were modified from AECL CANDU et al. (1992) to reflect the facilities constructed during the underground evaluation substage.

2.3.3 Operation Stage

The operation stage would involve receiving nuclear fuel waste transported to the disposal facility, sealing it in corrosion-resistant containers, sealing the containers in disposal rooms, and constructing the remaining disposal rooms. The scope of the operation stage was modified from AECL CANDU et al. (1992) such that the sealing of the panel tunnels was deferred from the operation stage to the decommissioning stage to allow easy access to the panels for longer period of time; thus enhancing the ability to monitor the performance of the panels during the balance of operation stage.

2.3.4 Decommissioning Stage

The decommissioning stage would involve the decontamination and removal of the surface and subsurface facilities; sealing of the tunnels, shafts and underground exploration boreholes; and the return of the site to a state suitable for public use at surface. The scope of the decommissioning stage was modified from AECL CANDU et al. (1992) as noted in Section 2.2.3.

2.3.5 Extended Monitoring Stage

Two optional extended monitoring stages were identified to provide opportunities to gain additional data on the performance of the partially sealed and/or sealed disposal vault should this be required. The first optional extended monitoring stage is scheduled to take place after the completion of the operation stage and before the start of the decommissioning stage. The second optional extended monitoring stage is between the decommissioning and closure stages. These stages would be required if the regulators and public required additional data on the performance of the partially sealed and/or sealed disposal vault.

2.3.6 Closure Stage

The closure stage would involve removing the monitoring instruments from surface-based boreholes that could potentially jeopardize the performance of the disposal vault if they were not properly maintained and eventually sealed, sealing the boreholes and preparing the site for the final release.

Based on these definitions of the stages and activities for disposal project implementation, the cost estimate developed by AECL CANDU et al. (1992) was updated and extended to include new items. The updated costs are presented in Table 2, and more detailed information is given in Table 3. Further cost details are provided in Simmons and Baumgartner (1994). The following section describes methods and techniques used in deriving the cost data.

3. ACTIVITY-BASED PROJECT PLANNING PROCESS AND COSTS

As the concept and design-related studies were advancing, the difficulty of visualizing or managing a complex project with a large number of activities, spanning about 90 years became apparent. A decision was made to develop a project management tool whereby the schedule, costs, and personnel requirements related to disposal are interlinked; forming an integrated perspective on the total project life cycle. In this way, making a change in one aspect of an activity would have an appropriate and immediate effect throughout the system. For example, changing the duration of an activity would have an immediate and traceable effect on the overall project schedule, total costs, personnel requirements, and on the project cash flow. The activity-based application that is developed in Primavera Project Management (Primavera 1991) software for this purpose is called the STADE (Storage, Transportation, And Disposal Economics) model. The end product is a model without the storage and transportation components. The storage and transportation costs were considered separately and outside the STADE model by Ontario Hydro (1989).

3.1 DEVELOPMENT OF THE ACTIVITY-BASED SYSTEM

AECL CANDU et al. (1992) provided descriptions of the facilities and activities of a UFDC and the associated cost database. By adapting this information to an activity-based project management system, the relationship of each project activity to other activities, their duration and their resource estimates could be clearly defined. In the STADE model, once the relationships and the progression of the activities were defined and a "project" was set up according to the software rules, it was relatively easy to obtain a pictorial overview of the project(s) in the form of activity logic networks and Gantt charts, cash flows and personnel requirements (Figures 4,5,6). The flexibility of the system is also a useful feature for the database updates, escalation calculations, and generating sensitivity case studies.

The cost of completing an activity was calculated by specifying activity duration, the individual resources (i.e., labour and non-labour) required to complete that activity, quantities (material, equipment or personnel) and their respective cost rates. In the cases where the specific rate and quantity information was not available, total lump-sum estimates were allocated to activities as "budget" costs. Each activity was assigned a unique identifier code such that the activities can be grouped or sorted as desired (e.g., construction and operating activities) for specific cost analyses and reporting. Further coding was added to differentiate the activities on the basis of facility category (e.g., Surface facilities, Underground facilities and Ancillary support services). Figure 7 shows Work Breakdown Structure and the activity coding system. There are about 1100 different activities with about 3000 resources in the STADE model.

3.2 DATA

The initial data of the disposal module of STADE model was based on the cost estimate for a used-fuel disposal centre presented by AECL CANDU et al. (1992). The application for the

STADE model started by analyzing the UFDC study and reorganizing the design description and associated cost information in terms of unique activities. These activities were then logically linked to produce appropriate project networks. A Work Breakdown Structure (WBS) was established and the activities were coded according to the WBS. Activity networking and coding was followed by the establishment of activity duration and identification of the required resources. The transformation of the UFDC study data was completed by comparing the overall schedule (Figure 2), cost, and the personnel requirements as given in the study with those from the activity-based model. After the differences were resolved, the model was adjusted and extended to include the effects of the modifications (Section 2.2) introduced by Simmons and Baumgartner (1994).

The overall siting approach adapted by Simmons and Baumgartner (1994) for the UFDC is based on an assumption that more than one site will be characterised during the surface-based site evaluation substage. The cost estimate assumes that three sites will be characterized before a decision is made to choose one site for the underground evaluation substage. The general scope of the siting activities is described above (Section 2.2). In addition to the modifications made to the project stages, Simmons and Baumgartner introduced the following major activities:

- Site monitoring,
- Performance assessment,
- Research, and
- Component testing

The definitions for these activities are provided in Simmons and Baumgartner (1994). In general, the site monitoring relates to the continuous monitoring of site(s) for various parameters which are required to assess the performance of the disposal facility. The performance assessment refers to the evaluation of the functioning of a disposal system or system components in terms of one or more standards and criteria. The research activities refer to investigations on various aspects of the concept implementation as the need may occur throughout the various implementation stages. For the cost estimating purposes, the research activities are considered to be external to the disposal site, performed by contract researchers working in off-site facilities. Thus in Simmons and Baumgartner (1994), these costs (labour and non-labour) are reported under the contracts category, and the personnel associated with these contracts are excluded from the personnel requirement tables. The component testing activities would consist of conducting tests to measure the performance of the rock mass and components of the disposal system, and to demonstrate the construction and operation equipment and procedures . These tests would be initiated during the underground site evaluation substage and could continue through the construction and operation stages to provide long-term data. For example, the performance of the container, the sealing systems, and the rock surrounding the excavations would be studied in underground test areas. Prior to the operation stage, heaters could be used to simulate the heat that would be produced by nuclear fuel waste; or containers with the used-fuel may be used to accurately simulate the conditions. The cost estimates for the components testing, research, site monitoring, and performance assessment are derived from work performed and experience gained at the Whiteshell Research Area (WRA) and the Underground Research Laboratory (URL). These costs were obtained by soliciting estimates from the waste management research groups at AECL's Whiteshell Laboratories. Each group provided estimates in various forms but mainly categorized them as labour and non-labour costs, including any contingency amounts that they judged to be appropriate for their data. These data were incorporated into the STADE model structure.

The overall project schedule in STADE model was further adjusted to reflect the changes made to the scope of the operation and decommissioning stages (Section 2.2) and the addition of the closure stage.

The costs for extended monitoring are not included in the estimate. The duration of these optional stages, unlike the other project stages, are not clear; an element that is likely to depend on the regulatory and approvals process for the disposal of used fuel. However, annual costs have been estimated (Table 2). In the STADE model, activities with the resource bases are established for the extended monitoring stages; so that, when the duration are specified, the costs can readily be calculated.

3.3 FURTHER APPLICATIONS

The STADE activity-based model was also used as a starting base for other sensitivity studies. Two specific cases, where the quantities of the used fuel were changed from the base case, are a 5-million-fuel-bundle case and a 7.5-million-fuel-bundle case. The costs for these two cases were obtained by adjusting the activity-based system described above so that they reflect the reduced vault sizes resulting from using the different fuel quantities for disposal. The overall cost estimates for the base estimate and for the two sensitivity studies are plotted on Figure 8. The trend from these estimates shows a fixed cost amount independent of the quantity of used fuel. This reflects the costs for the siting activities, the surface infrastructure, the used-fuel packaging plant, the shafts, and for a portion of the access tunnel activities. Once these facilities are in place, the costs increase linearly with the amount of fuel.

Another sensitivity study, where the disposal depth was 500 m (instead of 1000 m), was also carried out. The total cost for this case was about $210 million less then the base cost estimate of $13 320 billion (1991 Can $); primarily due the shorter shaft lengths and the shortened schedule caused by this.

4. ALLOWANCE FACTORS USED IN THE COST ESTIMATES

The activity cost estimates include costs that are derived from their original estimate by application of allowance factors. These allowances factors are necessary for several reasons. In some cases, the design details are insufficient because of limited scope of the design; but an estimate is needed. In other cases, an allowance is used as a form of safety factor to prevent an underestimate. This section describes some allowance factors that are used (or not used) in the estimate.

4.1 ACCURACY OF THE ESTIMATE

The accuracy of the overall estimate is based on the level of the design detail on which the estimate is based. The level of design detail for the components presented ranges from a budgetary to a preliminary level on different components of the disposal facility. According to established practices (AECL CANDU et al. 1992), the overall estimate based on this level of design detail is considered to be accurate within -15% to +40% of its calculated value.

4.2 ALLOWANCE FOR INDETERMINANTS

The allowance for indeterminants (AFIs) is an allowance allocated for a known purpose, the final cost of which is uncertain at the time of the estimate. It is known that money will be spent for the purpose, but the exact amount cannot readily be calculated with the available level of detail in the design. The AFI's were generally applied to the capital costs (i.e., they were applied to the construction of facilities and process systems). The AFIs were calculated by taking into account the category of estimate, the source of data used for the estimate, and the contribution of the this estimate to the overall cost estimate (AECL CANDU et al. 1992). The following are the allowances for indeterminants factors applied to specific categories:

Construction Related Site and Site Improvements	18%,
Buildings and Structures	22%,
Used-Fuel Packaging Facilities,	17%,
Basket (materials)	5%,
Container (materials)	3%,
Underground Excavation and Backfill	6%,
Electric Power Systems	16%,
Instrumentation and Control	6%,
Common Processes and Services,	16%, and
Townsite	16%.

The AFIs have not been applied to site screening, surface-based site evaluation, research and development, and component testing activities (Table 3). In estimating the costs of these activities, the experience from AECL's Research Area activities and the Underground Research Laboratory was used. The cost data has relatively high charge rates for labour due to specialty services. In addition, the estimators included generous allowances to cover the costs of unspecified items. Therefore, no additional AFIs are added to avoid compounding these factors.

The AFIs were also not applied to the management and administration, engineering design and licensing, and operating costs of the facilities[1].

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[1] Note the distinctions between the Operation Stage and operating activity, and between the Construction Stage and construction activity. For example, room excavation (a construction activity) continues during the Operation Stage. The AFI is applied to room excavation activity during the Operation Stage.

4.3 CONTINGENCY

AECL CANDU et al. (1992) defined the contingency as an allowance allocated to mitigate the effects of unforeseen circumstances, which historically have been shown to have occurred in projects. There is no prior intent to spend contingency and efforts are normally made not to spend it. The amounts are usually related to experience and the level of detail in the design; generally the higher the degree of completeness of the design, the lower is the contingency allowance. Other examples of contingency amounts would include the funds that will be needed to cover unforeseen costs due to weather-related delays in the project schedule, labour disputes, expediting delays, and component re-design and re-work. In general, a 17% contingency is applied to the estimated cost of the activities. However, the contingency is not applied to the estimates for the site screening, surface-based site evaluation, and research; in order to avoid compounding as noted in Section 4.2. The component testing costs are considered in two categories: one category is an estimate for the underground excavations required for the test area, and second is an allowance for the implementation of the tests. The contingency is applied to the first category activities. Where the cost of an activity was subjected both to AFI and contingency, the AFI factor was applied first, followed by the contingency at 17%. Thus the contingency was applied to the estimated costs and to the AFIs.

Contingency definitions and costing approaches vary widely in various industries. The discussion above reflects the approach used in estimating the costs for the disposal of the nuclear fuel waste described by AECL CANDU et al. (1992) and some of the additional elements added by Simmons and Baumgartner (1994). The individual company experience and cost estimation methods should be considered when deciding whether sufficient funds have been allocated for contingency. Two definitions of contingency are quoted from literature to illustrate the different approaches.

"The contingency is an allowance for smaller elements and activities that have not been estimated in detail but are a necessary part of the project, and for the general degree of uncertainty associated with the details of the project, the unit costs and the cost factors applied to the project. The size of the contingency will depend on the number of factors including the level of detail and the knowledge about the facility and/or process studied, experience from similar work, the research and development work needed before the design is finalized, and the purpose of the estimate" (OECD/NEA 1993).

"... contingency should be added to cover any inadequacies in estimate basis definition (both design and construction) and inadequacies in estimating methods and data" (Ahmad 1992).

In these two definitions, contingency is used to cover aspects of both AFI and contingency definitions used in cost estimate summarized by Simmons and Baumgartner (1994). In Simmons and Baumgartner (1994), the cost estimate includes an AFI factor ranging from 0% to 22% (buildings - Section 4.2). Because the 17% contingency is compounded on the AFIs for those cost estimates that have an AFI, the above definitions imply that some elements in the estimate include a contingency of 20% (e.g., container materials) to 42 % (e.g., buildings). However, because of the exceptions described in the first paragraph of this section, the combined and separately identifiable share of both the AFIs and the contingency in the overall estimate is about 15.7% (Table 2).

The design assumption that three sites would be characterized simultaneously, rather than one site, may be considered to be a further item of conservatism or contingency in the cost estimate. Thus, although an overall contingency factor of 15.7 % may appear low when compared to those used in other cost estimates, it is reasonable given the unspecified contingencies and the specified error of the estimate which is -15% to +40% ($ 11 320 to $ 18 650).

4.4 ESCALATION CHARGES

All the reported costs are in constant dollars for the year they are presented. The original costs presented in AECL CANDU et al. (1992) were in 1987 constant dollars. The costs of the components which were added later on by Simmons and Baumgartner (1994), such as those for the siting and research, were prepared in 1991 constant dollars. In order to bring all the costs to 1991 constant dollars, escalation factors were derived from the Construction Price Indices (Statistics Canada 1991). Specifically, price changes in the construction, manufacturing and mining sectors were adopted. As a result, escalation factors of 18% for labour costs and 1% for non-labour costs were used to update the 1987 costs to 1991 costs.

Financial analyses including the costs of financing the work and the time-based expenditure of funds were not considered because these analyses should be performed by the various used-fuel owners according to their specific nuclear fuel waste management strategies. However, a cost base for such calculations can be produced from the STADE model scaled for a given quantity of waste, the method and rate at which the waste is transported to the disposal site, and the schedule for implementation of disposal.

4.5 RISK

There has been no attempt to quantify risk factors as part of the cost estimate. The most significant risks factors include

- Social, political or economic factors - changes in social, political or economic environment and trends that could result in significant changes to project assumptions, designs and activities;

- Site related factors - conditions at the site selected for the underground evaluation could require a significantly different design than that proposed by Simmons and Baumgartner (1994) or prove not suitable for waste disposal; and

- Process related factors - significant delays in approvals and licensing could increase costs beyond the range that can be accommodated by the estimates and allowances.

4.6 OTHER EXCLUDED COST FACTORS

The process of licensing a used-fuel disposal facility has not been defined. Figure 3 indicates assumed times on the overall schedule that regulatory approvals and licences are likely to be required. Although an allowance is made in the cost estimate for the provision of safety and licensing procedures and related engineering effort, no other cost associated with approvals and licensing have been estimated, nor have the fees that a regulatory agency may charge for directing this process been included.

The estimate does not include the cost of non-routine activities such as waste retrieval. Also; no property taxes, Provincial Sales Taxes, Goods and Services Tax, or any other form of taxes are included because the applicability of these is not known.

5. REVIEW AND COMPARISON OF COST ESTIMATES

The development of an activity-based cost model provided a framework for the review of the costs supplied in a draft version of AECL CANDU et al. (1992). The network and coding of the activities in STADE model allowed error checking at various levels of detail. Some errors and omissions were detected and subsequently resolved with corrections being incorporated into the final report. This structured method of establishing activity-based data in STADE was continued when the new data for the siting and closure stages and for research, component testing, and performance assessment activities were developed.

A further review of the cost basis of the AECL CANDU et al. (1992) was made by an independent cost-estimating engineer[2]. His review suggested a costing deficiency of $ 129 million (in 1987 Can dollars) mainly in the capital construction areas of buildings, townsite, utilities, and roads. He stated that the rest of total estimate of about $ 9 000 million appears well prepared, conscientiously detailed and credible.

The Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD) performed a study on the costs of high-level-waste disposal in geological repositories (OECD/NEA 1993). As a result of participation by several member countries with a disposal program (including Canada), the agency gathered, analysed, and compared costs of disposal in those countries. Factors such as currency differences and inflation rates were taken into account. Costs were normalized to bases such as to the amount of electricity generated ($/TWh). Figure 9 shows a comparison where the estimated cost of used-fuel disposal, prepared by several countries, are plotted against the estimated electricity generated by the corresponding fuel. The costs considered for this comparison include design, construction, operation, decommissioning and closure related costs,and exclude site screening, site selection and evaluation, and research and development costs. The exclusion was required so that the costs can be compared on the same activity content basis. "The low figures of the Canadian and U.S. estimates may suggest the economy of scale in the packaging/disposal cost estimates, i.e. the

[2] McArthur B. 1994. Used-Fuel Disposal Centre TR-M-3 Estimate Review. Internal communication.

larger the disposal program, the cheaper the unit disposal cost. The nuclear programs assumed in U.S. and Canadian estimates are considerably larger than those of others."... The low figure of German estimate was explained by "..the assumption that a certain amount of reprocessing waste will be disposed of in the same repository as the spent fuel." Generally, the Canadian cost estimates were in reasonable agreement with the international studies.

6. SUMMARY

The estimated costs for disposal of Canada's nuclear fuel waste are presented. The scope of the estimate is explained by describing the related engineering designs for which the costs are prepared, by explaining the major assumptions made in preparing the estimates, and by providing listings of the included and excluded cost components. An activity-based project planning and control method is explained whereby the overall schedule, costs, and personnel requirements are interlinked; thus forming an integrated perspective on the total project life cycle. The results of the overall review of the estimate are also described showing that the estimates are reasonable within the scope of the studies and that they compare well with similar international studies.

The estimates are prepared without a specific site having been selected as the disposal site, and with the engineering studies that are prepared to a conceptual-level of detail. After the site specific data are available and the engineering studies evolve into site-specific feasibility studies, the error of estimate can be significantly reduced. The current estimates, based the conceptual engineering designs, are reasonable within the scope and compare well with similar international studies.

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** Unpublished contractor's report prepared for AECL, available from Library, Report Services, AECL, Whiteshell Laboratories, Pinawa, Manitoba R0E 1L0.

*** Unrestricted report available from Ontario Hydro, 700 University Avenue, Toronto, Ontario M5G 1X6.

TABLE 1

USED-FUEL DISPOSAL CENTRE COST SUMMARY

(AFTER AECL CANDU ET AL. 1992)

(Capacity = 10.1 million used-fuel bundles, depth = 1000 m)

	Duration (a)	Cost (1987 Canadian $ million)
Development (Construction)	14	1 592
Operation	41	5 978
Decommissioning and Sealing	13	142
Subtotal	**67**	**7 712**
Allowance for Indeterminants		(249)*
Contingency		1 311
TOTAL		9 024

* Included in subtotalled items

TABLE 2

USED-FUEL DISPOSAL FACILITY LIFE CYLE COST SUMMARY

(AFTER SIMMONS AND BAUMGARTNER 1994)

(Capacity = 10.1 million used-fuel bundles, depth = 1000 m)

Stage	Duration (a)	Cost (1991 Canadian $ million)
Siting - Screening*	5	289*
- Surface Site* Evaluation	12	1 210*
- Underground Evaluation	6	605
Construction	7	1 500
Operation	41	6 831
Extended Monitoring (Optional)	N/A**	(23 /a)
Decommissioning	16	1 070
Extended Monitoring (Optional)	N/A**	(9 /a)
Closure	2	25
Subtotal	**90**	**11 516**
Allowance for Indeterminants		284
Contingency		1 520
TOTAL		13 320

Notes

* The original cost estimate for the site screening and surface site evaluation substages included unspecified contingencies. Therefore, no further allowances such as allowance for indeterminants or contingencies are applied to these costs. The same applies to the research costs in all stages.

** NA : Not Applicable (No defined duration).

TABLE 3

DISTRIBUTION OF NOMINAL PROJECT COSTS IN EACH STAGE BY MAJOR FACILITY OR ACTIVITY - WITH AFI AND CONTINGENCY

(1991 CANADIAN $ MILLION)

Major Facility or Activity	Siting			Construction	Operation	Decommissioning	Closure	TOTAL
	Screening	Surface Evaluation	Underground Evaluation					
Management and Administration	47	158	40	125	247	102	5	725
Characterization	30	455	8	*	*	*		493
Engineering Design & Licensing	46	195	38	110	20	112	1	521
Performance Assessment	34	119	38	30	84	35	3	344
Research	132	232	180	168	580	53		1 345
Site Monitoring		51	28	44	149	60	7	340
Project Support			72	25	186	33	7	322
Component Testing			70	133	115	70		388
Buildings			13	72	26	16		127
Electrical Power Systems			6	65	27	**		98
Basket & Container				43	2 028	2		2 073
Used-Fuel Packaging Plant				47	1 026	15		1 088
Surface Infrastructure			10	178	1 104	233	7	1 532
Shafts			65	102	114	127		408
Tunnels			88	156		337		581
Vault Equipment			8	60	81	1		150
Buffer and Backfill Preparation Plant				13	15	10		38
Room Excavation				112	510			623
Room Prep. & Container Emplacem.				9	619			629
Room Sealing					991			991
Underground Infrastructure			5	81	15	2		103
Training			2	20	88	28		138
Townsite				171				171
Others (Insurance, Warranty, etc.)			8	44	30	12		94
Total	289	1 210	679	1 808	8 055	1 248	30	13 320

* Characterization cost is included in related excavation activities cost

** Cost included in appropriate building cost

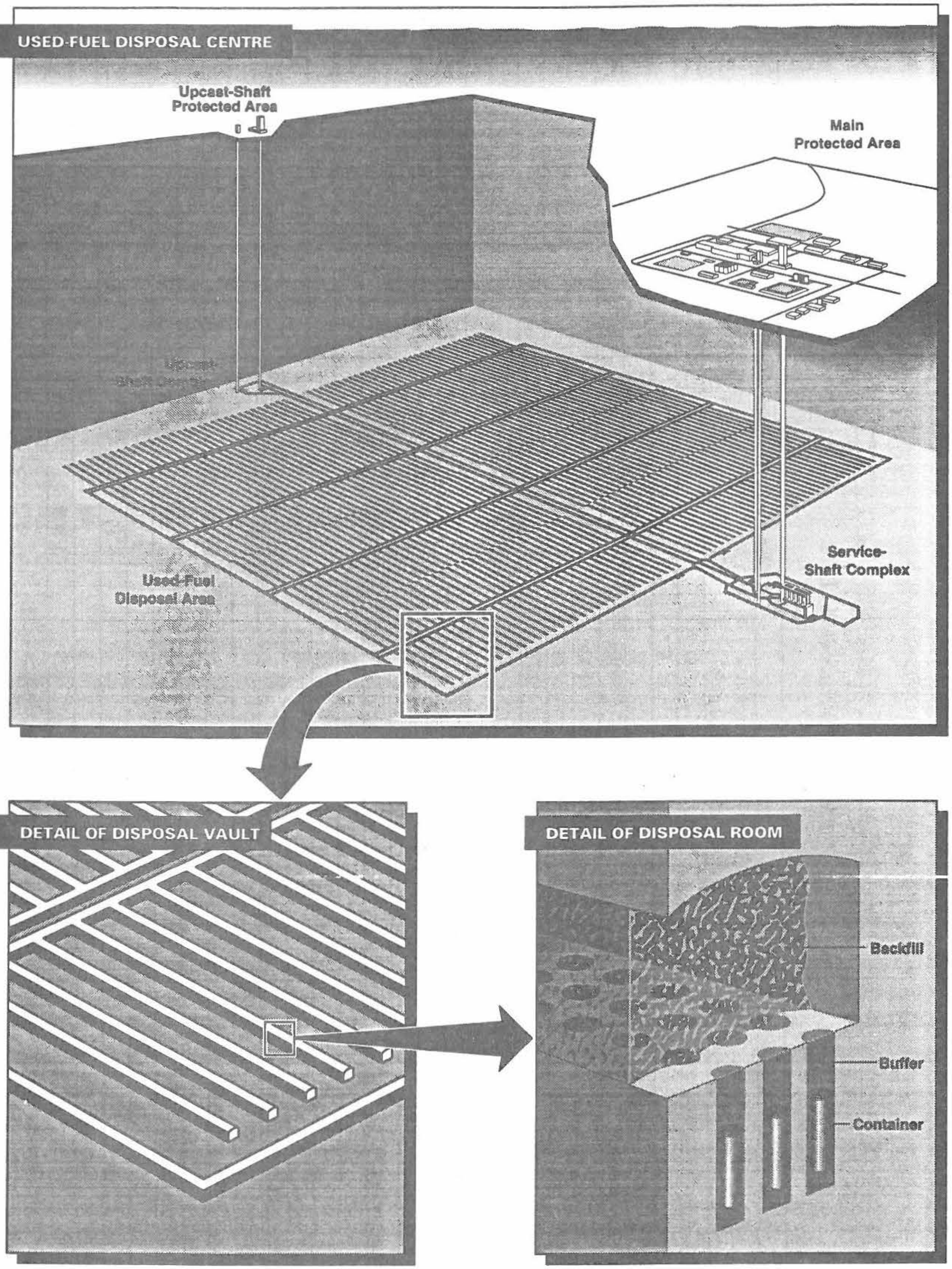

FIGURE 1: Used-Fuel Disposal Centre Components

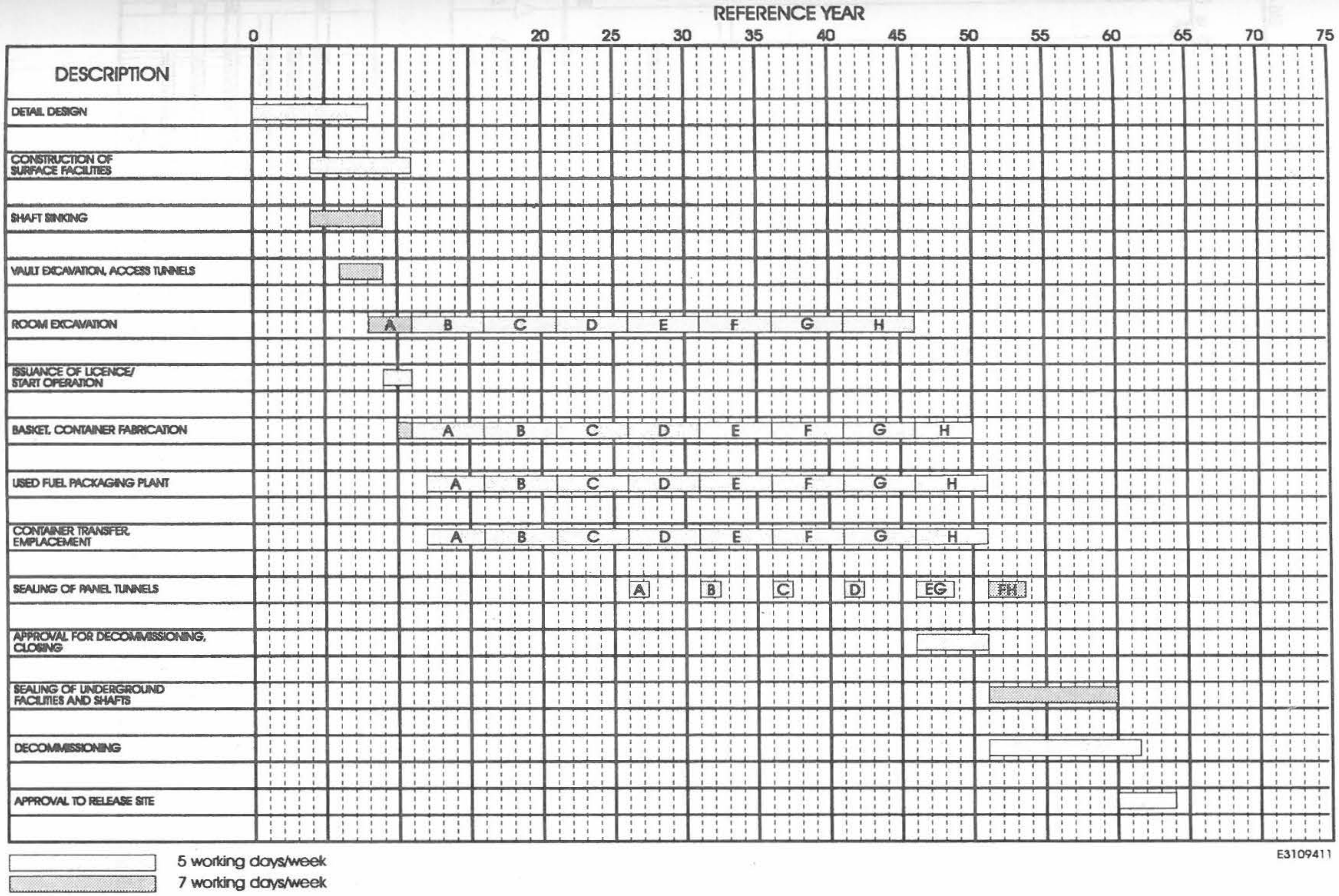

FIGURE 2: The Used-Fuel Disposal Centre Schedule (after AECL CANDU et al. 1992). This schedule was later modified (Simmons and Baumgartner 1994). The letters on the drawing identify the panels in the disposal vault.

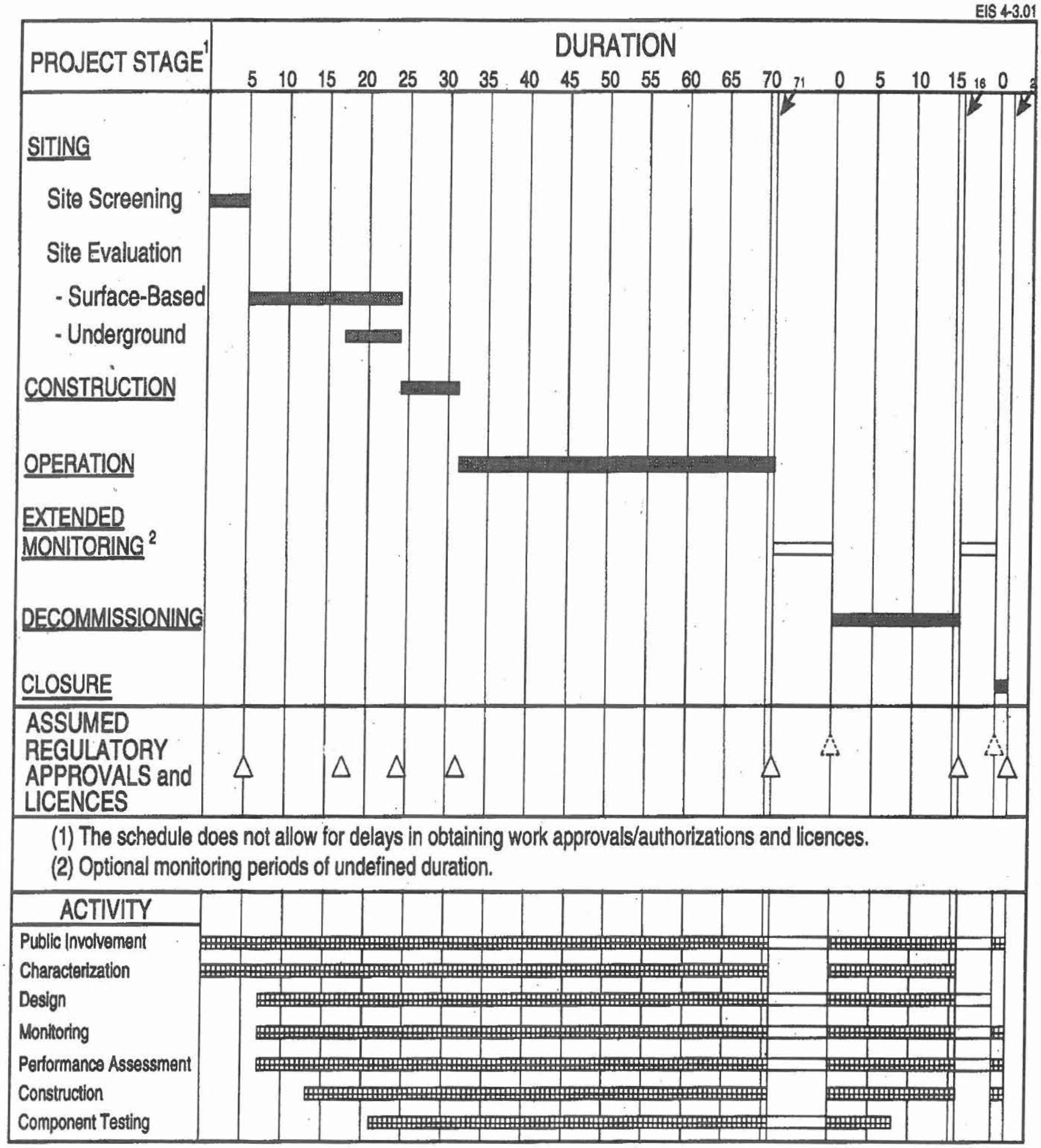

FIGURE 3: Disposal Centre Implementation Schedule (Simmons and Baumgartner 1994)

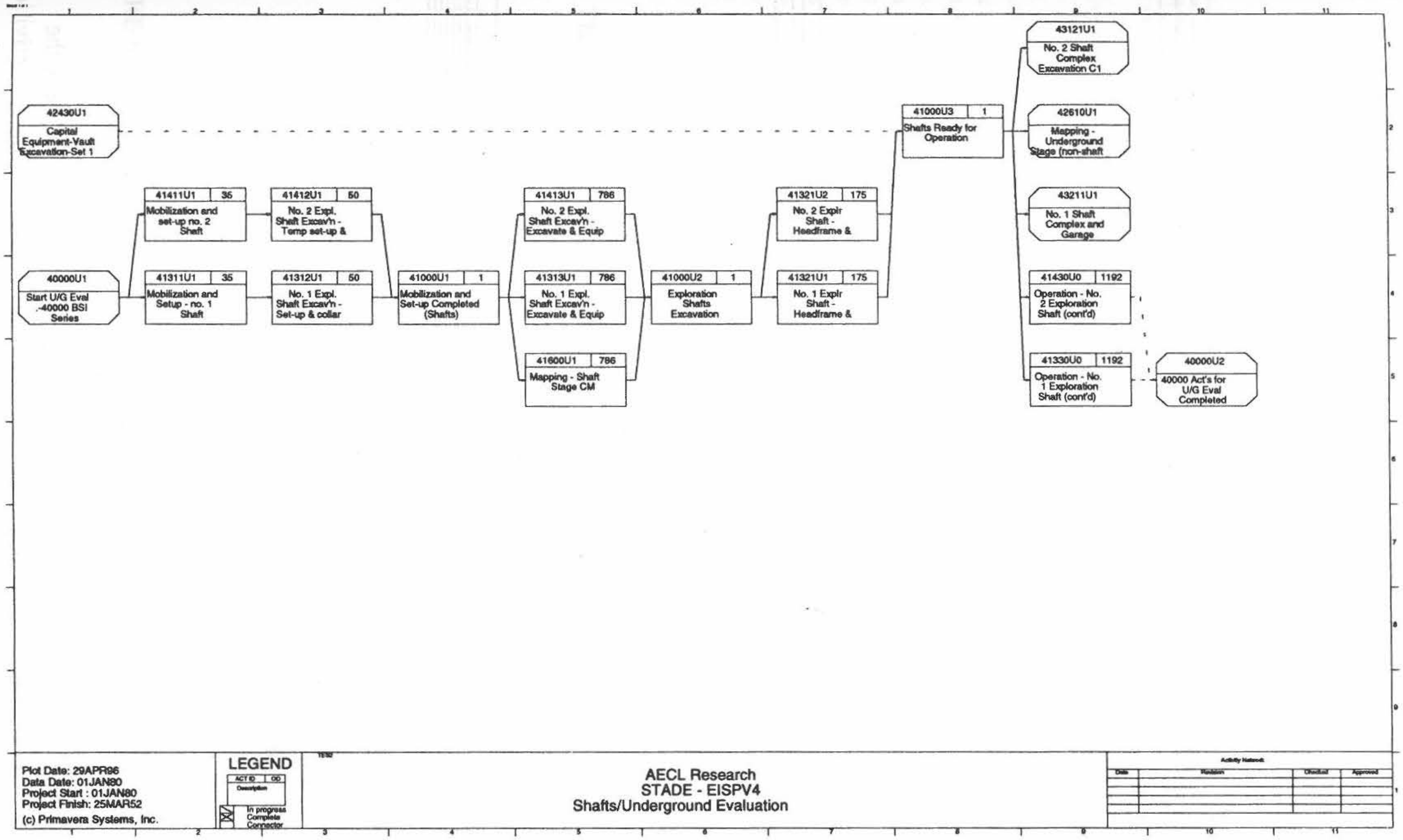

FIGURE 4: An Example Activity Network. This figure is designed to show only the shaft-related activities during the Underground Evaluation stage. The activities are selected from the activity-based system by identifying the appropriate codes.

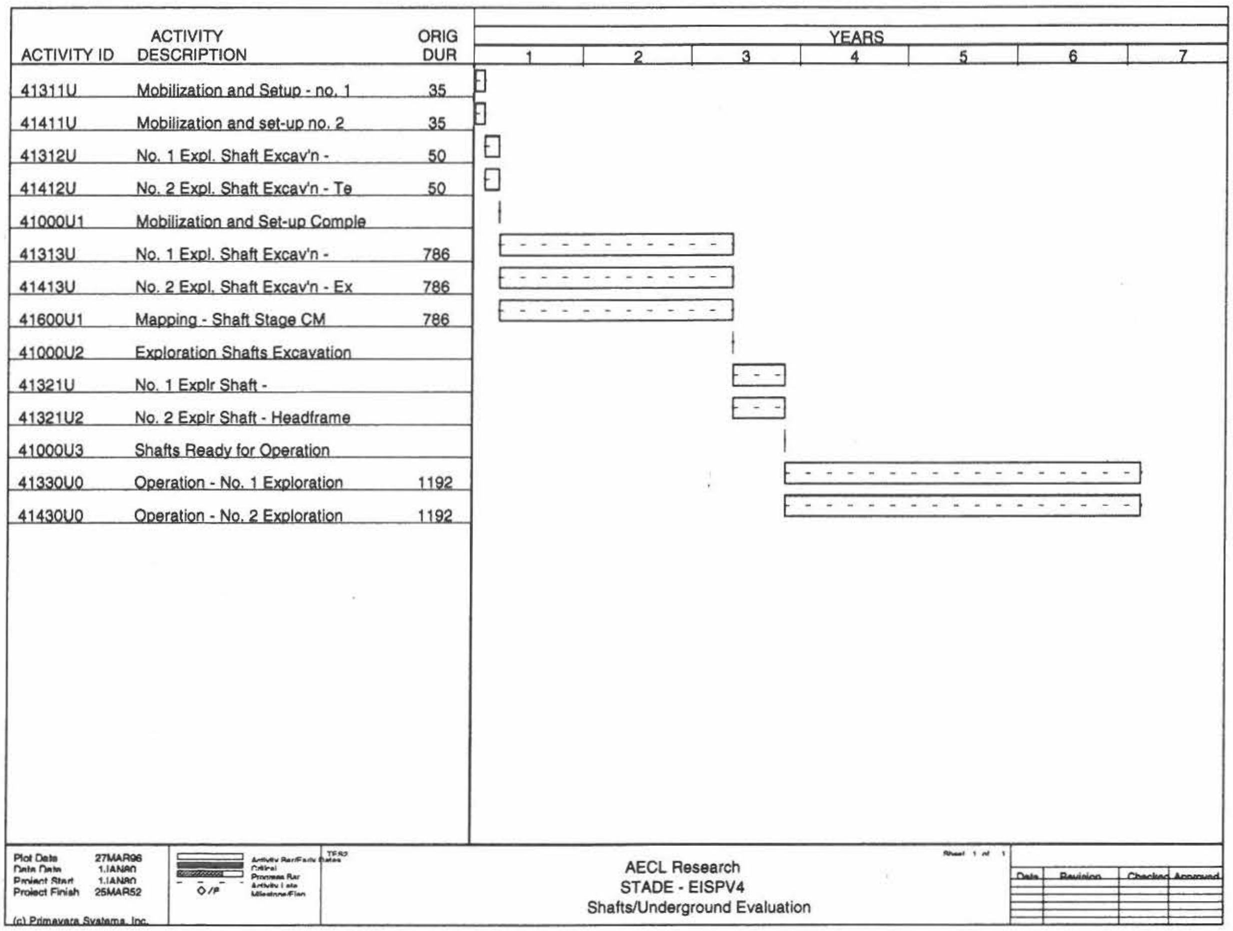

FIGURE 5: An Example Activity Gantt Chart. This figure is designed to show only the shaft-related activities during the Underground Evaluation stage. The activities are selected from the activity-based system by identifying the appropriate codes.

AECL Research	PRIMAVERA PROJECT PLANNER	STADE - EISPV4 (COST)	
REPORT DATE 14MAY96 RUN NO 438 12:54	COST LOADING REPORT	START DATE 01JAN80	FIN DATE 25MAR52
Shafts/Underground Evaluation	TOTAL USAGE FOR YEAR	DATA DATE 01JAN80	PAGE NO. 1

ACT ID	DESC	1980	1981	1982	1983	1984	1985	1986	TOTAL
41311U1	Mobilization and Setup - no. 1 Shaft	2273							2273
41312U1	No. 1 Expl. Shaft Excav'n - Set-up & collar	2062							2062
41313U1	No. 1 Expl. Shaft Excav'n - Excavate & Equip	7789	10263	4049					22100
41321U1	No. 1 Explr Shaft - Headframe & Collar House			4142					4142
41321U2	No. 2 Explr Shaft - Headframe & Collar House			4142					4142
41330U0	Operation - No. 1 Exploration Shaft (cont'd)			261	2168	2174	2168	309	7080
41411U1	Mobilization and set-up no. 2 Shaft	848							848
41413U1	No. 2 Expl. Shaft Excav'n - Excavate & Equip	6257	8245	3253					17756
41430U0	Operation - No. 2 Exploration Shaft (cont'd)			135	1117	1120	1117	159	3648
41600U1	Mapping - Shaft Stage CM	479	632	249					1360
	REPORT TOTAL	19708	19140	16230	3285	3294	3285	468	65410

Note: There is no definite project start date. The calendar dates used here are in relative sense.

FIGURE 6: An Example Activity Cost Loading Report. This figure is designed to show only the shaft-related activities during the Underground Evaluation stage. The activities are selected from the activity-based system by identifying the appropriate codes.

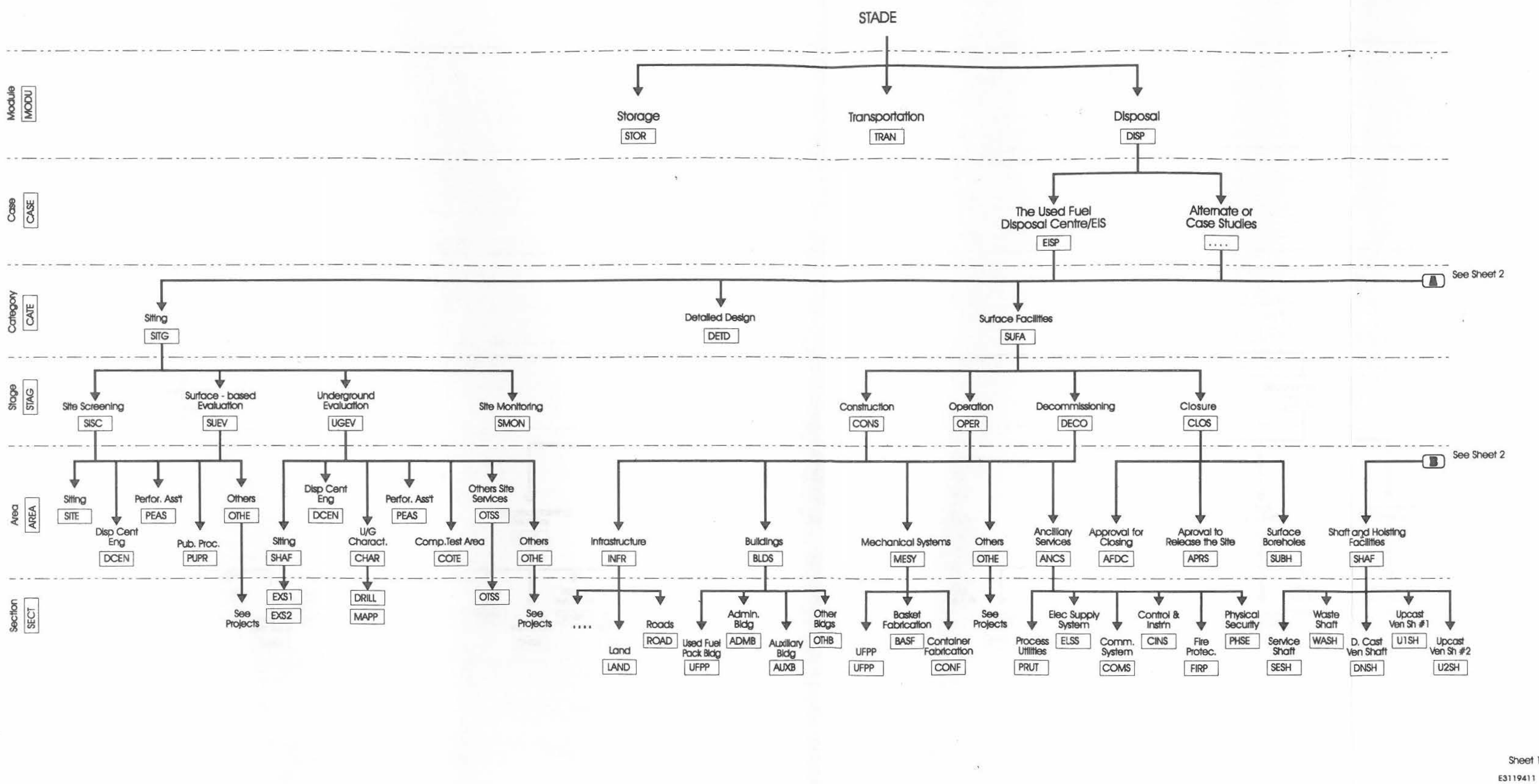

FIGURE 7a: Work Breakdown Structure from the Activity-Based Network System (Sheet 1 of 2).

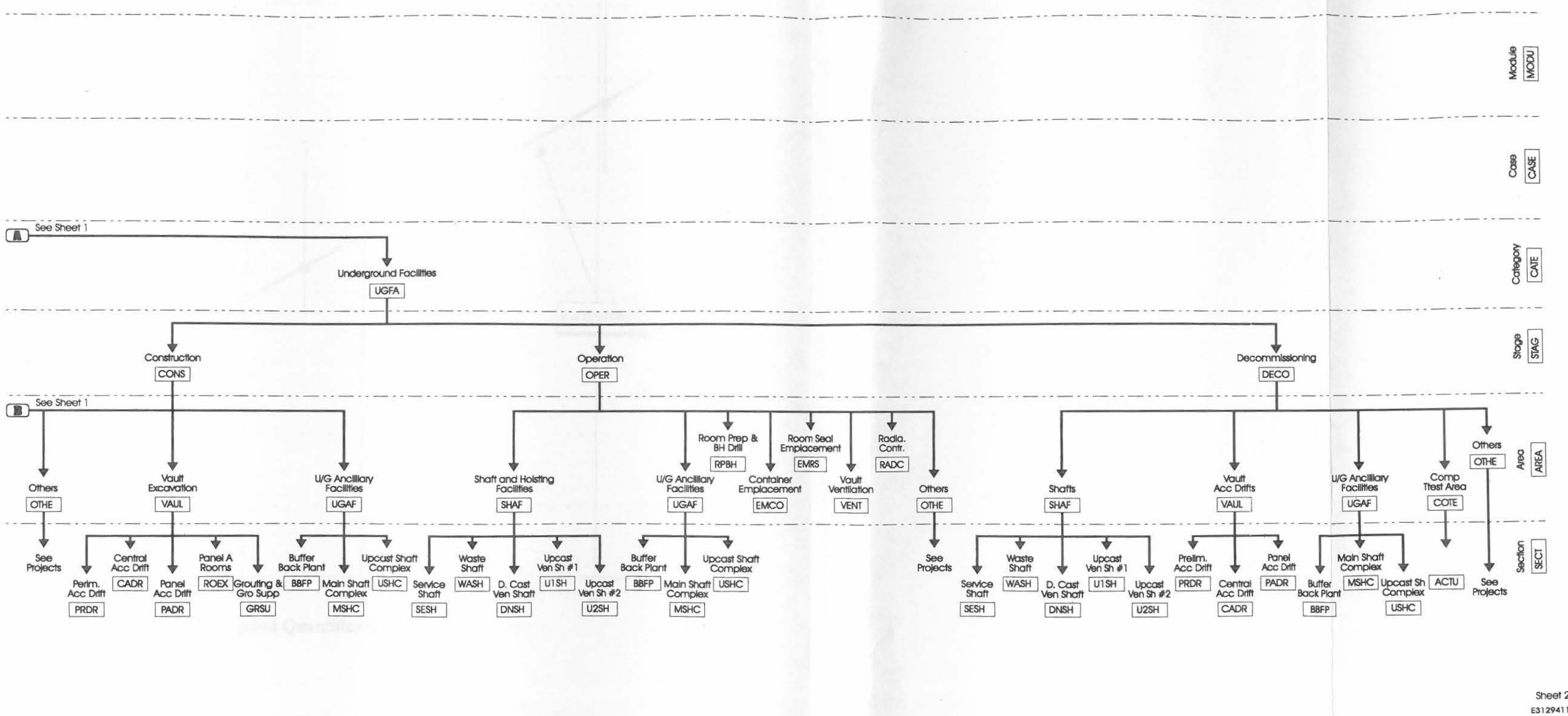

FIGURE 7b: Work Breakdown Structure from the Activity-Based Network System (sheet 2 of 2)

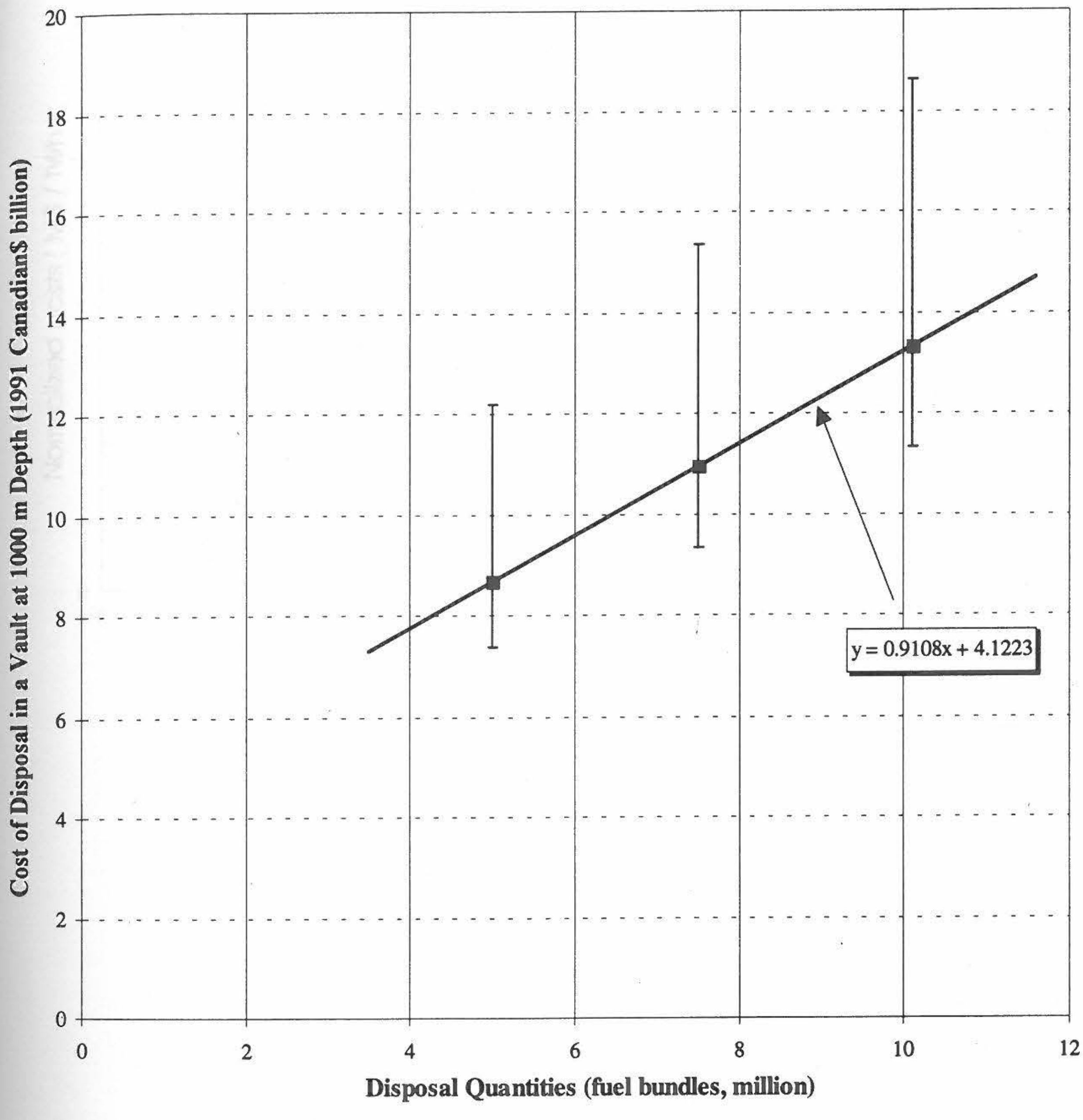

FIGURE 8: Comparison of Disposal Costs for Different Used-Fuel Quantities. The estimates for the 5.0, 7.5, and 10.1-million-fuel-bundle cases are plotted. The most detailed estimate is the 10.1-million-fuel-bundle case. The estimate for the 5.0- and 7.5-million fuel-bundle-cases are derived by scaling the relevant activities of the 10.1-million-fuel-bundle case.

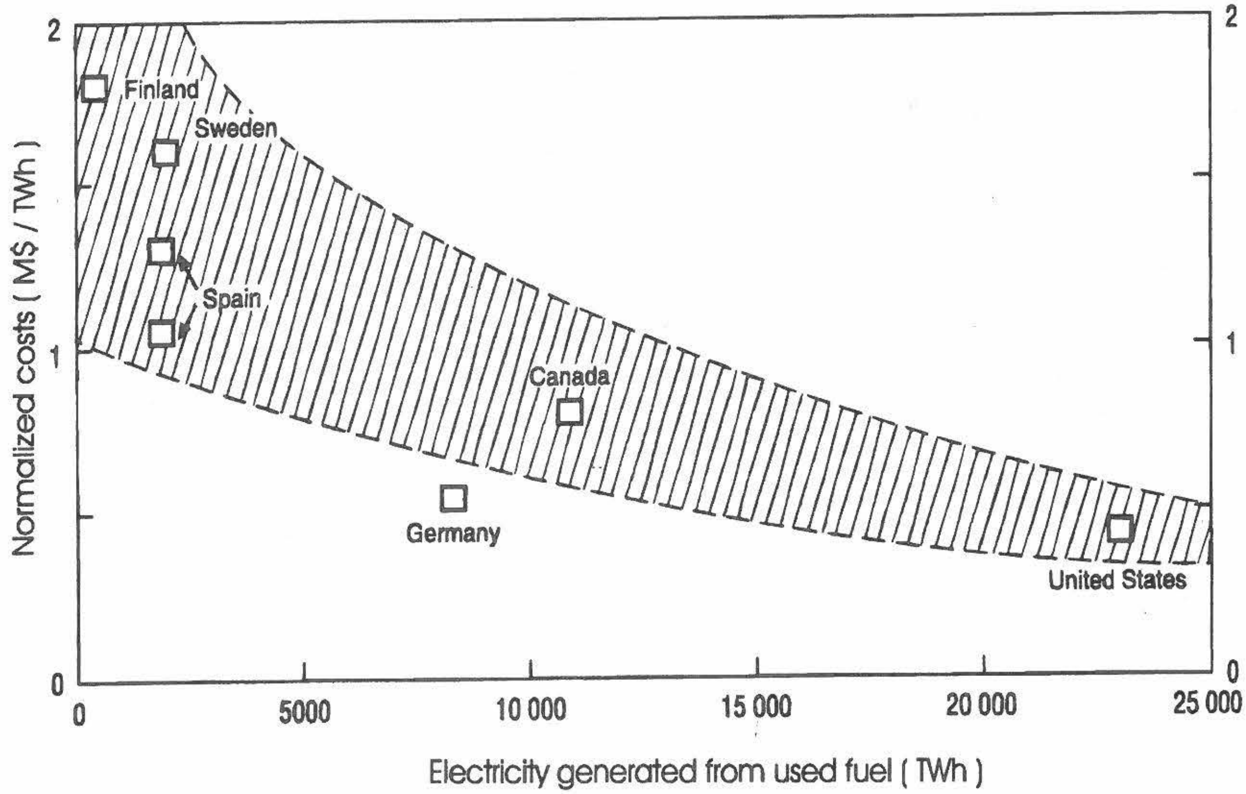

FIGURE 9: Comparison of Unit Disposal Costs with Some International Data (OECD/NEA 1993). The costs are in 1991 United States dollars. They include design, construction, operation, decommissioning and closure related costs, and exclude site screening, site selection and evaluation, and research costs.

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