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Consideration of early closure or continued operation of a nuclear power plant

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FOREWORD

This publication provides information to management and executives of electrical utilities responsible for the operation of nuclear power plants who are tasked with decision making related to early closures or continued operation. This information is based on the experiences of a number of countries in addressing a spectrum of issues broader than only the economics of the operation of the plant itself.

Any major decision involving changes in direction for a major investment such as a nuclear power plant has the potential to incur considerable additional costs for stakeholders. Major economic risks can be unexpectedly encountered when decisions based on a simplified economic understanding of energy options are successfully challenged on the grounds that choices and decisions have been made without accounting for some environmental, social or economic issues which are considered of prime significance to important stakeholders. Such risks include not only changes in project scope and delays in project implementation due to re-evaluations necessitated by such challenges, but risks related to the effectiveness, efficiency and safety of ongoing operations or shutdown maintenance of the nuclear power plant. Additional risks encountered at this stage are the adequacy of the decommissioning fund and the need to establish a process whereby the availability of adequate funds will be assured at the time of the final plant shutdown.

This publication provides information on several of these additional issues important to key stakeholders, and on methods that allow for their assessment and consideration when developing recommendations related to early closures or continued operations of a NPP.

This publication consists of two parts:

Part I: Includes a discussion of the main issues for consideration, with emphasis on issues important to stakeholders in addition to plant owners.

Part II: Provides an example of a basic analytical approach to the assessment of plant life cycle economic viability, demonstrating the potential impact of decisions on early closure or continued operation.

This publication was produced within the IAEA programme directed to increase the capability of Member States for improved planning and implementation of nuclear power programmes and for establishing and enhancing national nuclear power infrastructure.

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Part I

MANAGEMENT ISSUES RELATED TO EARLY CLOSURE OR CONTINUED OPERATION OF A NUCLEAR POWER PLANT

1. INTRODUCTION

1.1. Background

A wide range of factors have been seen, in different regions[1], as initiating a need for an assessment of available options for existing nuclear power plants (NPPs). These include public safety and environmental issues, changing social needs and expectations, economic issues such as sunken and stranded costs, credit rating, the availability of funding and costs of borrowing for other projects. Technical issues include plant and component ageing, projected remaining lifetime assessments of the specific plant versus economies of scale, needs of the local electricity market and availability, timeframe, capability and costs of alternative forms of generation.

Construction and operation of a nuclear power plant requires significant financial and human investment in design, construction and pre-operational training, the proportions of which are often of national significance. Stakeholders other than the plant owners have often quite significant investment in the overall infrastructure used to support plant operation. The loss of return on this major investment due to early closure can disproportionately affect local, regional and national social, economic and environmental factors. In contrast, extended operation might involve an opportunity of additional return on this major investment, provided that costs related to the extended operation can be assuredly recovered during the additional operational life that this allows.

Factors influencing decision making can cover a very wide range of technical, financial and social issues. In order to gain broad acceptance of decisions, appropriate weighting must be given to factors important to all stakeholders by those making or influencing decisions. International experience has shown that insufficient accounting of issues important to stakeholders can lead to re-examinations and re-evaluations resulting in implementation delays and even in reversals of decisions. There are two potentially significant adverse affects of such re-evaluations and delays. The first is a significant impact on the overall costs of the project and its alternatives. The second is the potential to significantly influence the safe operation and decommissioning of the NPP, by unintended or inappropriate influences on the morale, safety culture and resources available to NPP staff and managers.

Plant owners, managers and staff, the local, national or regional population, the customers for the electricity generated and those responsible for energy policy and the broader economic management can be expected to have different perceptions of the value of the NPP. The need for re-evaluations and any consequent project delays will depend on the perceived accountability of those making the decisions to the other stakeholders impacted by the decision, and the degree to which all relevant social, technical, environmental and economic factors are weighted in the decision making process.

Depending on the nature of the organization owning the NPP, the owner's primary responsibility and accountabilities may differ. In a private company, responsibilities may be limited to the safe operation of the NPP while it can generate revenue to provide profits. In a vertically integrated regional utility, responsibilities may extend to the provision of electricity needs to a given region, meaning that a replacement energy source must be provided for any

[1] In the context of this publication, regions may be either larger or smaller than nations and in either case may involve parts of more than one nation, depending on economic, cultural and electrical grid connectivity.

plant closed. In a government owned utility, those making the decisions may be responsible for the national integrated economic and social management. The different responsibilities of those making or influencing the decision can lead to different perceived weightings of factors such as the economic and social impacts of local employment versus out-of-region fuel purchases or long distance electricity transmission, whether there is a need to provide for alternative generation of electricity in the event of plant closure or on the capability, reliability and social, economic and environmental impacts of alternative forms of generation, be they local or distant.

There can be a significant regional economic impact amounting to tens of millions of dollars (or euros) if a NPP, with operating and maintenance (O&M) spending undertaken regionally and locally, is replaced by fossil fuelled electrical generation where these tens of millions of dollars are subsequently spent for fuels purchased outside of the region. For larger plants these differences run into hundreds of millions of dollars per year.

Many of the issues related to early closure or extended operation of a NPP are equally applicable to other types of plant outside the nuclear sector, (e.g. factories or mines) which are of a significant size in relationship to the economic environment in which they operate. All industrial facilities will reach an end to their operating life, following which it is appropriate to undertake a transition to decommissioning, dismantling, site cleanup and provision for the long term management of wastes produced during the operating life of the facility. Comprehensive planning and transition management should precede factory, plant and mine closures. This can prevent significant disruptive impact for the staff, customers and suppliers and for the local, regional and national economy. Planning for such closures should include provision for facility decommissioning and legacy waste management. Many plant closures outside the nuclear sector have had significant “shock” impact due to not only early closures, but inadequately planned and managed closures at the end of the predicted operational life.

There are differences in national and regional practices that apply to terminology related to early closure or continued operation. Three main areas have been identified during the development of this publication, which require attention from readers who are not familiar with some of these differences.

- Length of operating license — some regulatory bodies grant licenses for the anticipated operational lifetime of a facility, leading to continued operation being considered focused around "license renewal". Other regulatory bodies grant operating licenses for standard terms of five to ten years and "license renewal" is a normal practice unrelated to life extension.

- Structure of electricity supply system — in some cases NPPs are independently owned and operated in an open electricity market and owners are not responsible for provision of replacement power after the end of life of their facility. In other cases NPPs are part of vertically integrated and centrally managed utilities, which are responsible for electricity supply to meet customer demand. In the latter case decisions related to changes in plant operational life for a NPP are integrally coupled with decisions on alternative methods of meeting the electrical demand of customers.

- Spent fuel management and radioactive waste management — in some countries these are nationally or regionally managed by governments and in others they are the direct financial responsibility of NPP owners. In some countries spent fuel is subject to reprocessing and, potentially, recycling of the remaining fissile values in the fuel.

1.2. Objective

This publication provides information for both early closure and continued operation on the following topics:

Part I

- a broad spectrum of stakeholder issues, and
- the mitigation and management of liabilities and costs.

Part II

- an economic modeling for the decision on continued operation of a NPP versus early closure.

This information should assist in negotiations between various stakeholders on financial issues, regulatory, social and strategic planning issues and the changes required to a wide variety of arrangements and programmes related to the NPP.

1.3. Scope

Part I of this publication provides an overview of factors to be considered in assessing the technical needs and potential economic, social and environmental impact of a NPP early closure or continued operation project. It does not seek to provide a method to weigh each factor or to determine an adequate balance and reach a decision.

Part II of this publication offers a comprehensive perspective on the evaluation of the lifetime economic viability of a NPP in the context of an early closure or a continued operation decision.

1.4. Users

The target users are the executives, managers and owners of NPPs and their consultants and advisors. In particular this publication can be useful to managers and executives responsible for developing comprehensive recommendations to owners, boards of directors and government agencies on the future operations of existing NPPs.

This publication can also provide useful information to decision makers and advisors from government organizations, academic institutions, nuclear industry suppliers, major electricity customers and consumer organizations, environmental agencies and interested and concerned members of the public.

1.5. Terms used

Early closure

Stopping plant electrical production with the intent of removing the plant from service while there remains some positive economic value or safe and approved continuing production capability in the plant structures, systems and components.

This includes removal of a plant from electrical production where degradation of some plant structures, systems and components may have occurred which render the plant temporarily not serviceable, but where repair or replacement could be undertaken at costs which could be economically recovered during the subsequent operation of the NPP.

Continued operation

Continuation of operation beyond any administrative, regulatory or engineering fitness for service barriers that are specific to a nuclear power plant. This involves the undertaking of a comprehensive conditions assessment and additional investment where necessary for refurbishment of plant structures, systems and components, with the intention of extending the period of safe operation and economic production capability of a plant. In the context of this publication, continued operation implies going beyond the original design plant life for an additional and long operations period.

Stakeholders

Stakeholders are individuals or groups having an interest in the performance of an organization. Stakeholders typically include the following: customers; owners; operators; employees; suppliers; partners; trade unions; the regulated industry or professionals; scientific bodies; governmental agencies or regulators (local, regional and national) whose responsibilities may include nuclear energy; the media; the public (individuals, community groups and interest groups); and other States, especially neighboring States that have entered into agreements providing for an exchange of information concerning possible transboundary impacts, or States involved in the export or import of certain technologies or materials.

2. RISKS RELATED TO THE EVALUATION AND DECISION MAKING PROCESS

Section 2 discusses some issues of significance to important stakeholders besides the plant owners.

Factors influencing decision making can cover a very wide range of technical, financial and social issues. Serious misunderstandings, disagreements and lack of broad acceptance of decisions can result from stakeholder perceptions of inappropriate weighting given by decision makers to factors beyond basic plant economics. This can lead to interventions requiring project re-examinations and re-evaluations, with consequent delays in project implementation and even in reversals of decisions. There are two potentially significant adverse impacts of such re-evaluations and delays. The first is a significant effect on the overall costs of the project. The second is the potential to impact the safe operation and decommissioning of the NPP, by unintended or inappropriate influences on the morale, safety culture and resources available to NPP staff and managers.

IAEA has published guidance on managing change in nuclear utilities [1], and on lessons learned related to planning, managing and organizing the decommissioning of nuclear facilities [2].

Where there is potential uncertainty in the process or results of an evaluation of the potential future of a NPP, the opportunity exists to have an independent expert review the assessment process and results, as was undertaken for the New Brunswick Government as owner of the Point Lepreau NPP [3]. A lengthy evaluation and review process was undertaken in New Brunswick [4], leading to a decision in July 2005 by the Provincial Government, the plant owner, to proceed with the refurbishment of the Point Lepreau NPP [5].

2.1. Safety

Early closure

A major risk to safety due to early closure is the potential impact on the safety culture of the organization.

In most countries maintaining safe operation of a nuclear plant through the establishment of a good safety culture is recognized as also essential to good economic performance. Safety culture can be negatively impacted when the future of the NPP is subjected to significant uncertainty or extended durations of uncertainty and re-evaluation.

Safety culture can be expected to deteriorate if the stated objectives, purpose and values of the NPP management are seen to be changed or no longer supported by the plant owners, the local communities or the regional or national government. Prompt appropriate compensatory changes need to be established to support the well being of plant staff and the safety culture of the organization, during periods of uncertainty. Without clear compensatory measures, uncertainty regarding the future can reduce the clarity of objectives and priorities and a result in a reduction in resources available to effect change.

Safety culture problems due to early closure can become apparent in:

- reduced procedural adherence.
- reduction in the questioning attitude.
- resignation to the inability to effect change.
- increased use of work-around.
- reduction in formal problem identification.
- reduced attentiveness to training (including refresher training).
- less effective pre-job briefings.
- increased absenteeism.
- increased staff resignations or retirements.
- less interest in applications for internal promotions or job advancement.

Additional safety issues can arise due to reduced allocations or availability of resources as a result of planned early closure (including spare parts, trained and experienced staff, budget allocations etc). Such reductions can affect equipment maintenance or replacement activities and result in reduced availability of both safety related and production related equipment. From a budgetary perspective there might be reduced needs because of the upcoming extended operation project work or to the upcoming cessation of normal operations. However, plant staff may perceive such changes as a changed commitment by managers and owners to safety and quality and the previously upheld value system, which forms a core part of safety culture.

IAEA has published guidance on safety considerations in the transition from operation to decommissioning of nuclear facilities [6].

Continued operation

In the event of consideration of continued operation beyond the original design plant life, the adequacy of components, systems and structures for the extended life needs to be justified in order to demonstrate compliance with the safety regulations.

2.2. Economic

The removal of a NPP from service, or the undertaking of work to assure safe continued operation, is likely to have significant investment implications and resource requirements. A decision to initiate such a project must be based on accurate and complete evaluations of all appropriate factors to avoid resource difficulties and associated cost increases. Problems can be expected if there are extended delays in making decisions or apparent reversals or uncertainties in the sustainability of the decision after the project has been partially initiated.

If decisions are reversed or delayed due to re-evaluations, additional unplanned costs can arise due to the inability to follow normal project management practices. It may become very difficult to adhere to schedules and projections which had been optimized for cost and resource utilization effectiveness. In extreme cases key resources may no longer be available when required for the project, and delays may compound leading to cost increases which may appear greatly disproportionate to the originally projected costs. However, the costs of inappropriate decisions, made due to incomplete or inaccurate consideration of all of the issues, has the potential to be even greater.

A plant continued operation project undertaken without a thorough and accurate assessment of the condition and projected remaining lifetime of all of the plant components can result in significant additional work scope during or subsequent to the project, additional resource requirements and associated increased costs. These can be compounded by project delays while the additional resources are found and integrated with the project plan. Similarly the completion of a plant continued operation without appropriate consideration of the ongoing staffing and support resource requirements can result in a project that is unable to operate efficiently and recover its costs due to essential operational support being insufficient or unavailable when needed. Such conditions can occur if, due to project uncertainties, human resources come to see other opportunities as more attractive.

An early closure decision can have major negative economic impact if the decision is made without adequate consideration of the needs for the electrical output and the availability, costs and other impacts of the source of this replacement energy. The removal of a plant from operation and revenue generation eliminates its capability to repay its own construction and commissioning costs (existing debt retirement), or to provide any additional funds towards its own decommissioning or long term waste management. There will be continuing financial needs for the transition to and undertaking of decommissioning and the management of legacy wastes after cessation of revenue earning operations. Such needs include not only secure and adequate funding but appropriate staffing, security and records management to ensure safety and allow optimum undertaking of subsequent post operational stages.

2.3. Environmental

There are often significant environmental effects from decisions related to early closure or continued operation of NPPs. In many cases these environmental impacts are only partially evaluated and so cannot be fully factored into decision making. For example, in cases where environmental impact assessments are conducted prior to decisions being made, such assessments are often limited to the impact of the NPP in isolation rather than in the full context that the decision will embrace, which involves any replacement energy source or alternative power plant.

In exceptional circumstances decisions related to the removal from service of a power plant involve only that power plant in isolation. In such exceptional circumstances the demand for the power from that plant can be considered optional in that without the availability of that specific plant there is no corresponding demand for its product. A similar situation might exist where extensive demand side management has eliminated the market for the electricity generated by a specific power plant.

The reality in most cases is that the choice is between operation of the NPP and the operation of an alternative power plant. Correspondingly, the environmental impact of the decision is to replace the environmental impact of one plant by the environmental impact of the alternative.

In many current situations, whether the specific situation is a proposed refurbishment for extended operation such as at Bruce Power Units 1 and 2 in Canada, or early closure such as at Barsebäck in Sweden, the alternative to the operation of the NPP is coal fuelled generation, in a market that has not undergone demand side management to an extent sufficient to eliminate the need for alternative generation.

While some consideration has been given to replacement of specific NPPs with wind generation, from a practical perspective wind generators are currently available in individual capacities up to 1.3MW with development potential to 5MW. However three 1.3MW wind generators widely distributed on different windy locations are required to provide the availability to meet a 1.3MW continuous load given that wind is not continuous. This has the effect of requiring over 1500 wind generators of current capacity to substitute for a 650MW(e) NPP.

All forms of energy generation have an impact on the environment. However it is not common practice to assess, on a comprehensive basis, the relative environmental impacts of alternatives when decisions are made regarding the removal from service of one type of power plant and its replacement by another.

Where the impacts of both of the relevant types of power plant have already been assessed, are readily comparable and are well understood, new environmental assessments may not been needed. However, it appears to be common practice to either avoid environmental assessments altogether in cases where NPPs are being taken out of service (except for consideration of the environmental impacts of the subsequent decommissioning), or to treat the operation of the two power plant types entirely separately. In many cases the organization mandated with the responsibility to assess the environmental impact of the operation of a NPP does not consider it has a mandate to review the environmental impact of alternatives. Thus there is rarely a forum in which both options are considered on a common basis (from an environmental impact perspective) and the overall impacts of each factored in to the decision making. This perceived lack of comparison of the alternatives can be one of the more significant contributions to dissatisfaction of some stakeholders, lack of acceptance of decisions and calls for their re-assessment.

2.4. Social and cultural

The social and cultural impact of a NPP, in most cases, differs significantly from that of other types of power plant. The location of most non-NPPs is determined on the basis of proximity to the fuel supply (or other energy sources such as dams for hydraulic generation), to minimize transportation costs for the fuel, or on proximity to the load centre, to minimize costs and losses associated with transmission of the power after generation. In addition, the costs associated with power generation from a non-NPP are either primarily capital cost recovery (for example in the case of dams for hydraulic generation or wind turbines), or they are primarily dependent on fuel costs (as in the case of fossil fired power plants using coal, oil or natural gas). In most cases the operating staff of a non-NPP is relatively small and staff costs are not a major component of overall generation costs. The social and cultural impact on the surrounding region of the small staff numbers involved for a non-NPP is normally not very large.

Impacts on the surrounding region of non-NPPs are normally restricted to:

- the presence of the physical structures in the community.
- the actual and/or perceived health effects resulting from the environmental impact of the power plant.
- the impact on the immediate locality of the transportation of the fuel to the power plant (for example the impact of damming rivers and providing diversion channels to the power plant, including any local impacts on river navigation, or alternatively the impact of rail transport or pipeline transport of fossil fuels).

The physical infrastructure and operational environmental impacts of various types of power plant all have social and cultural impacts for the surrounding region. Each will have different levels of acceptance depending on the existing regional culture and the other uses of land and water in the region

A NPP has additional social and cultural impact due to the significant numbers of staff required for ongoing operational support. These staff requires or demand additional regional support services and facilities such as housing, schooling, transportation, health services including hospitals, emergency services such as police, fire and ambulance protection, and shopping and cultural facilities.

Such additional demands may have placed a strain on local infrastructure and capabilities at the time the NPP was initially constructed and commissioned. However, from a social and cultural perspective, when a decision is to be made on early closure or continued operation of a NPP, this means the withdrawal or the continuation of demands for services and infrastructure, and the corresponding spending power of the NPP workforce in the local communities and region. There can be a significant impact of this spending on the existing support services and facilities and related employment in the community and region. Depending on the nature of the economy of the surrounding communities or region, and the contributions of other industries or activities, the impact of the NPP may be relatively minor or may be predominant (or anywhere between the two extremes). However, with some notable exceptions, NPPs tend to be located in areas not adjacent to other major population centers.

For small and medium sized communities which are somewhat isolated from surrounding economies, there is potential for significant social and cultural impact from decisions on the future operation of NPPs. Although this impact may be significant, there is rarely a requirement for or an available methodology to comprehensively assess this impact (as opposed to stating an opinion on the significance of the impact without a comprehensive assessment). More importantly, there is often no available methodology for assigning a value to such impact in a manner which requires that it be factored into decision making (such as by the formal provision for a method of determining appropriate compensations to the impacted communities or incentives to the NPP operators). These issues are even more acute in countries of the Former Soviet Union and Eastern Europe where entire dedicated towns were built to house the staffs of large multi-unit nuclear power stations and their families.

As a result, it is common practice for the actual social and cultural impact of decisions related to continued operation of a NPP to neither be comprehensively assessed nor effectively factored in to the decision making process.

While the social and cultural impact of continued operation of an existing NPP may not be great, as the support infrastructure and services already exist, there may be a major impact of early closure on the well being of small and medium sized neighboring communities with the withdrawal of needs for facilities and services and the withdrawal of the spin off effects of the spending power generated by employment at the NPP.

Associated risks of inappropriate decision making relate mainly to early closure of a NPP and the potential for significant spin off effects from the collapse of local economies as a consequence of the loss of employment, reduction in spending power and potentially significant reduction in the needs or support for housing (impacting the value of housing), schooling, health and social support services and recreational and cultural centers.

3. VALUE OF THE EXISTING PLANT VERSUS ALTERNATIVES

Section 3 discusses, from the perspectives of a wide variety of stakeholders, the value of the existing plant versus alternatives that would need to be implemented, if a plant were not to continue to operate.

IAEA have provided information on cost drivers associated with assessments of life extensions for NPPs [7], [8].

Decisions to construct large, expensive facilities such as a major NPP, utilize finite resources, and often such facilities have an economic significance in their regions which is far greater that might be perceived without a comprehensive assessment. A full investment appraisal will help in determining the most appropriate solution.

Stakeholders other than the plant owners may perceive the plant to be of considerable cost or benefit to them. In order to be factored in to an analysis, any costs or benefits for stakeholders other than the owners may only be considered if local, regional or national authorities have acted on this perception and established a method by which the owners are required to account for these values by means of legislation, regulation, compensation, grants, incentives, subsidies, fee payments or taxation.

Decision analysis tools such as cost-benefit analysis (CBA) and multi attribute utility analysis (MUA) provide methodologies for assessing the potentially competing values and objectives of various stakeholders in comparable terms. MUA is particularly useful where values are initially expressed in different frameworks, including non-financial, intangible components, and the inclusion of various stakeholder issues needs to be undertaken in a collaborative process involving objectivity and transparency.

While MUA, in common with other decision analysis methods, involves value judgments which can give rise to disagreements, MUA has an advantage in that these judgments become open and explicit and stakeholders can apply sensitivity analysis to determine whether credible different judgments would alter overall conclusions.

When applying MUA to a new situation, such as an assessment of options for the future of a NPP, it is useful if the relative weighting of non-financial, intangible factors can be referenced to other topics for decision analysis with which stakeholders may be more familiar. This can be especially relevant if this places some stakeholders in different positions on some of the issues, as it assists in viewing issues on a broader and more socially comprehensive scale. Such other topics include decisions related to highway improvements, school and hospital closures, operations, expansion, or closures or introduction of new major employers in the involved communities, and new housing developments.

3.1. Value to plant owners

This section considers factors which relate specifically to the NPP being considered for closure or continued operation, including the plant staff, the plant structures, systems and components, the financing of initial construction, subsequent improvements, operations and normal maintenance and the funding of its decommissioning and long term waste management activities. In some cases the NPP may be owned and operated by a company, organization or government with wider assets and liabilities that the specific plant under consideration. In such cases this section limits consideration to the aspects specific to this NPP where they can be reasonably separated from the broader impact for the owner. The broader implications for the owner in such cases would be considered under Sub-sections 3.3 or 3.4.

Part II of this report addresses the basic economic decision making process and assumes that early closures or continued operations options are primarily selected on the basis of the derived economics. In order to allow for the development of the economic analysis in Part II of this report for various electricity markets, a number of specific assumptions were made. In particular the modeling for regulated utilities, obligated to provide electricity to a given region at prices which are subject to some form of regulation, is based on practices in the USA and may not be universally applicable. Nevertheless, the models should be applicable to most circumstances with some minor adjustments to local regulatory practices.

3.1.1. Full life cycle net present value (investment appraisal)

In order to perform a full investment appraisal of a NPP, taking into consideration potential early closure or continued operation, it is necessary to consider the full lifecycle of the plant.

1. Construction phase
    - Design
    - Construction
    - Commissioning
2. Operation phase
    - Initial operation
    - Safety upgrades and component replacement/refurbishment
    - Additional operation
3. Safety enclosure preparation phase
    - Defueling
    - Preparations for care and maintenance

4. Safety enclosure phase

   - Care and maintenance

5. Dismantling and disposable phase

   - Final demolition and remediation
   - Long term waste management
   - Long term spent fuel management

Figures 1.1 and 1.2 provide a basic representation of the impact of early closure or continued operation on the life cycle phases.

The duration of each of these phases will vary depending upon reactor type and national strategies for decommissioning, waste management and spent fuel management.

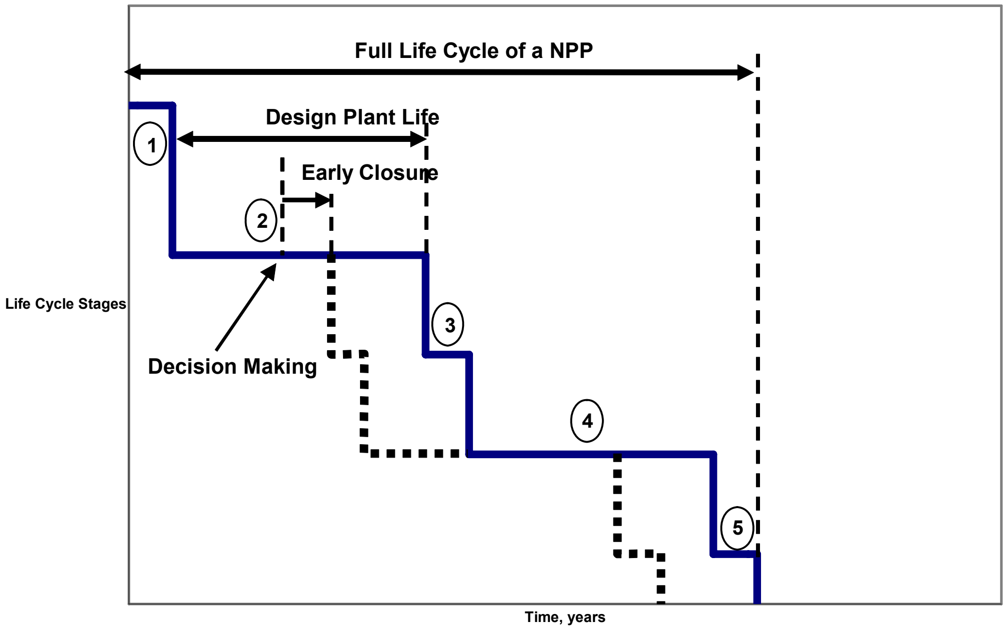

Fig. 1.1 Life cycles stages of a NPP showing impact of early closure

1. Construction Phase
2. Operation Phase
3. Safety Enclosure Preparation Phase
4. Safety Enclosure Phase
5. Dismantling and Disposal Phase

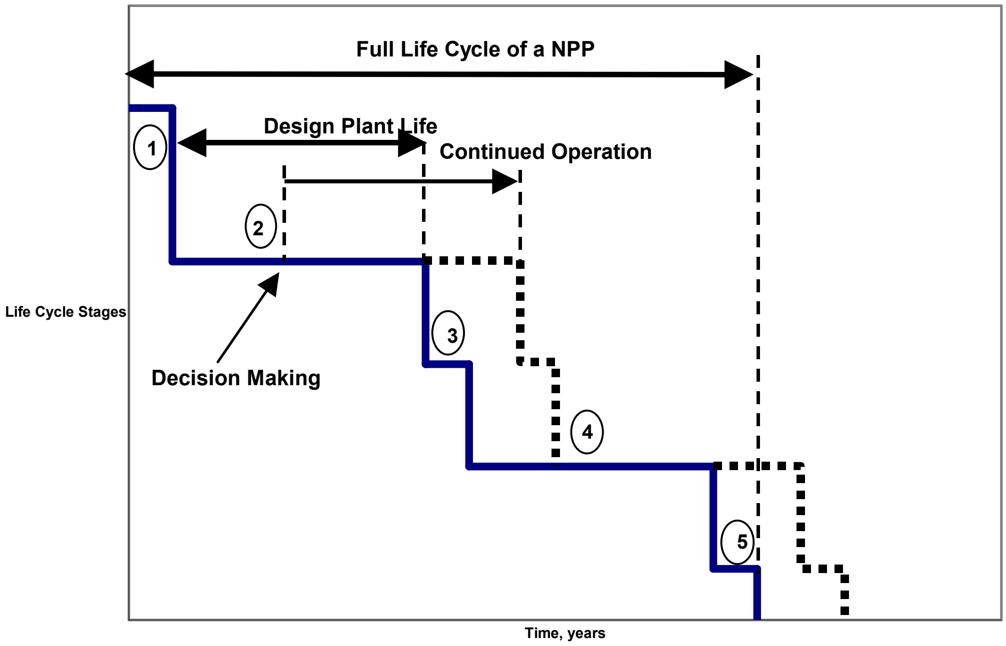

Fig. 1.2 Life cycle stages of a NPP showing impact of continued operation

For existing facilities, all phases, with the exception of operation, involve unavoidable costs. Operation includes avoidable costs and income generation, intended to provide a net benefit. It follows that for the investment to yield a positive result, income generated by the operation phase must as a minimum cover the unavoidable costs of all of the other phases. It also follows that any reduction in operation brought about by early closure or any increase in operation brought about by extended operation will impact on the total cost per unit of electricity generated by the NPP. While continued operation can reduce the overall cost per unit of electricity produced during the lifetime of the plant, early closure can bring an unexpected increase in real cost per unit produced, often after all reasonable means for normal recovery of such costs have been exhausted. In addition, an early closure may result in insufficient funding for decommissioning, long term waste management and spent fuel management costs. Funding programmes for these activities are normally developed on the basis of long term revenue earning from the NPP. This raises a potentially unanticipated need to subsidize or compensate for decommissioning costs, waste management and spent fuel management costs. In contrast, continued operation allows the opportunity to revise funding plans for these activities and to accumulate funds over a longer period of revenue generation. Further complications of early closures arise from plans for the recovery of costs of the original plant construction and subsequent safety upgrade costs. Given that such costs form a major portion of the overall costs of electricity production from a NPP, it is normal practice for the repayment of such costs to be arranged over a significant operational period of NPP. Early closure decisions can lead to the inability to generate revenue to repay these costs, leading to the need to devise other strategies such as subsidies or electricity price adjustments to recover these stranded costs. These issues are discussed in some detail in Part II of this publication.

3.1.2. Condition appraisal

A thorough condition assessment is needed to accurately judge the present value of the NPP and the maintenance needed to ensure that it can be assured to be fit for service for its intended operational lifetime. For both safety and economic reasons such thorough condition assessments should form part of the normal plant maintenance and inspection programmes. Scope should cover all systems, structures and components, in particular those important to safety. If these expected practices have been followed, information should be readily available to the plant owners to form the basis for an investment appraisal, and the plant owners may choose to derive and periodically maintain such an investment appraisal as part of their regular business practices. The IAEA has a number of Safety Series and TECDOCs available which can assist Member States in development and implementation of programmes for the assessment and management of ageing of major NPP components important to safety, references [9] to [21].

The existence of such comprehensive condition assessments is particularly important when preparing for decision making related to early closures or extended operations (see Sub-section 3.2). They form the basis for assessing the scope of refurbishment and component replacement work to support continued operation, or the basis for valuation of salvageable components and the approach to decommissioning in the event of an early closure.

Primary refurbishment work giving rise to the need for a major maintenance outage has often been related to deterioration in steam generator (boiler) condition. In other cases, such as Canadian pressure tube reactors, refurbishment has been required due to deterioration of pressure tubes and their feeder pipe work. Replacement of such components can incur significant costs and outage time, and to be able to finance such work it is normally necessary to reliably demonstrate that:

- The full costs of the work are known and readily manageable.
- The costs can be assuredly recovered against future revenues.
- The condition of other components and systems is assured to allow subsequent operation for an extended period necessary to recover the refurbishment costs.
- Any other systems and components likely to need replacement or extensive repair to allow a subsequent period of extended operation are also clearly identified and included in the overall refurbishment costs.
- Any technology or safety upgrades or retrofits needed for or beneficial to post refurbishment extended operation are clearly identified and their costs are included in the refurbishment project.

Steam generators replacement for light water reactors – a process with significant industrial experience worldwide – now requires two to four months to complete. Less experience has been accumulated with CANDU reactor re-tubing. This process is currently expected to require one to two years to complete, though this performance period might be shortened as additional plant experience is accumulated.

In addition, the following issues should be considered and appropriate strategies should be developed, prior to decision making on early closure or continued operation of a NPP:

- Recovery of construction costs
- Recovery of earlier safety upgrade costs
- Funding of decommissioning
- Funding of spent fuel management
- Funding of waste management

Figures 2.1 and 2.2 show an overview of the impacts upon the cumulative cash flows, where

1. Construction phase
2. Operation phase
3. Safety enclosure preparation phase
4. Safety enclosure phase
5. Dismantling and disposal phase
   A – Early closure option
   B – Extended operation option

For simplicity, Figures 2.1 and 2.1 indicate the differences in the cumulative cash flow between early closure and continued operation. The absolute values and relative values are only schematic and do not consider the capital outlay necessary to justify continued operation.

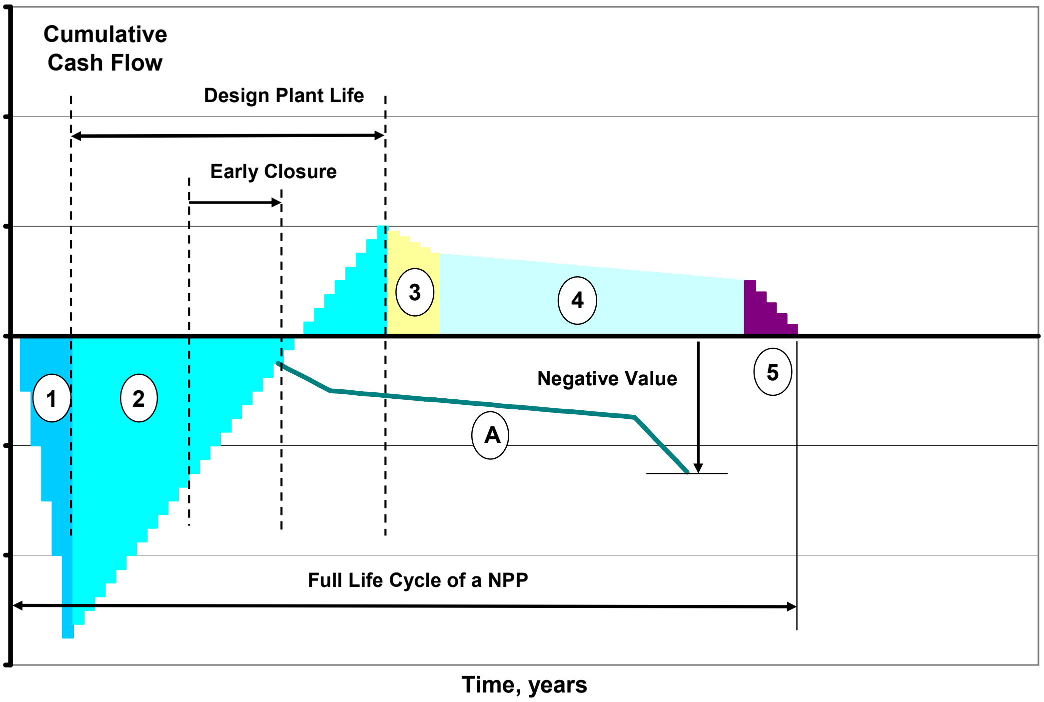

Fig. 2.1 Cumulative cash flow during the full life cycle of a NPP, showing the impact of early closure

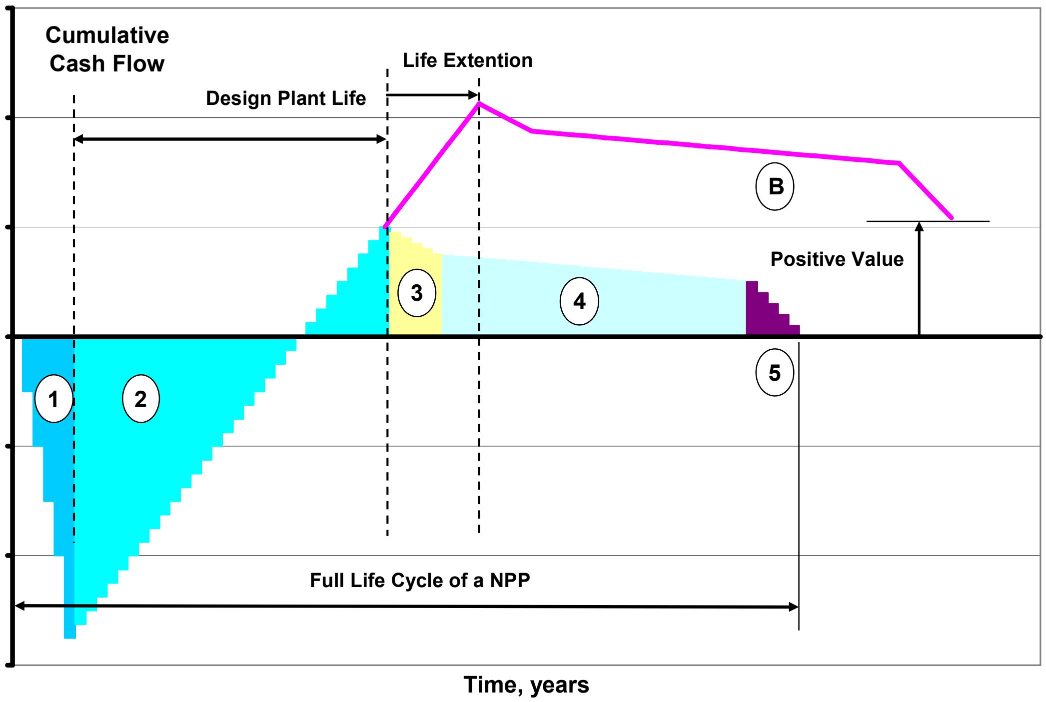

Fig. 2.2 Cumulative Cash flow during the full life cycle of a NPP, showing the impact of continued operation

3.1.3. Employee issues

IAEA has provided guidance for use by Member States in the areas of safety [22, [23] and human resources [24], [25], which form a useful background for issues discussed in this section related with ensuring sufficient committed workforce.

3.1.3.1. Safety

Safe operation requires professionals with high academic backgrounds, suitably trained and experienced and properly motivated. While it is assumed that the availability of a sufficient and committed workforce has been assured for the normal operation of the NPP, significant changes are introduced and diligent management becomes required as soon as the potential for early closure or continued operation is recognized.

Employee cooperation could be expected to be readily available to support extended operations, as this would guarantee continuity of employment. This concept may be tempered for an aging workforce, due to the employee's plans and intentions for retirement from the workforce. It may also be tempered by the availability of more certain employment in other locations or industries, particularly if there is a period of significant uncertainty prior to decisions being finalized on continued operations. It should be recognized, though, that in most operating nuclear plants a decision on continued operation based solely on economics is relatively straightforward and requires a relatively short time period to reach, provided the condition and life expectancy of plant systems is adequately known.

There are two areas of continued operation of an older plant where the impact upon a previously good safety culture can become of concern. The first area, when an unexpected or poorly substantiated decision is announced to close the plant, especially where this is not immediately complemented by the introduction of a credible programme aimed at the welfare and continued employment prospects for the plant workers. The second area is when there is significant protracted uncertainty on plant closure, again when not promptly accompanied by a credible programme aimed at the welfare and continued employment prospects of the plant workers. Such situations are aggravated when, during a protracted uncertainty, plant executives, managers or other key personnel, who might be perceived to have insider knowledge of the future prospects of the plant, announce their retirement or departure for employment elsewhere.

If a positive safety culture is to be maintained through either scenario, then management should ensure that a specific and credible human resources programme is devised and implemented, to avoid career uncertainties becoming a major distraction for the workforce. The plant workforce can be expected to lose confidence in their management, plant owners and politicians whose priorities now lie elsewhere than with secure long term operation of the plant.

A credible human resources programme is needed so that the plant workforce can continue to believe that they are valued by the plant owners and managers, that they have future career prospects and credible choices about their own future and that they are not being misled, misinformed and exploited by plant managers and owners.

Employee reaction to what they perceive to be an inappropriate early closure, or to protracted uncertainty on the future and possible closure of the plant, can manifest itself in a number of ways:

- Increase in absenteeism leading to inefficiency.
- Reduction in a previously good safety culture leading to increased industrial accidents and precursors to nuclear incidents.
- Conflict and industrial action by trade unions.
- Sabotage and civil unrest in the most extreme cases.

Addressing the human resource issues of NPP closure is important to ensure that individual workers receive adequate support in the change process and to avoid potentially dysfunctional human resource consequences, such as industrial unrest. Equally, safety, operational and support programmeme requirements are potentially imperiled if an effective human resource strategy is not in place. This then puts wider social consequences initiatives at risk; for example if potential alternative industries and investors are deterred by a negative perspective on the local labor force or community.

Employees need to understand and accept the announced reasons for closure. These reasons are difficult to explain if continued operation is perceived as a viable but unselected option. Any decisions for early closure may prove very difficult to be accepted by the total workforce.

The reactions in the workforce can be expected to be somewhat specific to the local culture and to the local economic and political situations. Each of these can vary with time for any given plant location, and the actual experience will also be compounded by the age of the workforce, given that different groups in the workforce may have been culturally and economically shaped by different situations and experiences during their careers. Workers who perceive their careers developing in a dynamic environment, where an individual stays in a particular job for only a few years before moving on, can be expected to react to a plant closure announcement or uncertainty in a manner that is completely different from workers who had perceived the plant or company to have expected a lifetime commitment from them.

The worst-case scenario can be considered to be that of an early closure decision based on purely political decisions imposed by external political entity at the regional or state level.

Methods to overcome the potential “alienation” of the workforce and the subsequent potential for industrial unrest and conflict should be considered by management. These methods normally involve employee representatives participating in the decision making process. Workforce alienation can be significantly aggravated by the appearance that managers are being offered transfers by the plant owners or related organizations to other locations while no similar programme is being made available to other levels of plant staff.

Involving the plant workforce in consultation and communication during and subsequent to major decisions, can provide a mechanism for constructive engagement of the workforce and avoid alienation and its negative consequences. Outcomes are much more likely to meet local needs and conditions as they have been discussed and agreed by both parties.

A more detailed explanation for early closure implications are presented in IAEA Safety Reports Series No. 31 Managing the Early Termination of Operation of NPPs [26].

3.1.3.2. Staff numbers and age profile

Decisions for early closure or continued operation will have an effect on staff numbers required and also the age profile at closure. This is particularly significant in cases where the initial construction or operation of a plant involved a relatively young workforce, a significant number of whom subsequently remained with the plant for most of its operating life and whose normal or intended retirement age closely matches the closure date originally anticipated for the NPP. For such cases, early closure brings the prospects that workers with highly specialized work skills and a long history of a single employer and work location will face a prospect of changes that they had never contemplated. For such workers there would be a significant barrier to relocation and finding another career late in their working lifetime. This makes their personal situation very difficult and the envisaged changes may envelope a considerable portion of their attention and thinking time and prove a significant distraction to normal activities. In contrast, continued operations without adequate human resource planning can lead to a need to recruit, train and transfer knowledge to a new workforce, leading to unexpected pressures to delay planned retirements. Lack of clear advanced decision announcements and human resource planning can thus lead to significant labor relations and staffing issues. This situation might be partially ameliorated if the owner utility operates similar nuclear plants elsewhere, and could transfer qualified personnel from those plants on a temporary or permanent basis.

The following issues should be considered for continued operations:

- Staffing needs and projected age profile following any refurbishment project, particularly with respect to an aging workforce, their probable retirement plans and needs for knowledge transfer.
- Retirement programme adjustments may be useful to allow retirements to align with project milestones rather than being fixed by calendar date.
- Additional staff recruited and trained during a refurbishment programme may have limited opportunities for knowledge transfer, as the plant configuration would be different from the operational state.

- Procedural changes related to plant modifications may require careful introduction as they may be initially implemented by a relatively inexperienced new workforce.
- Availability of necessary skill sets may be a limiting issue without adequate planning, and opportunities to recover from such situations may be limited.

The following issues should be considered for early closures:

- Compensation payments to mitigate shock impact of closure announcement, particularly for an aging workforce
- Staff retention plan for key staff where critical numbers leaving could disrupt plans for safe operation or preparation for decommissioning.
- Career guidance and outplacement services, particularly for workers approaching retirement age who are not ready to retire.
- A workforce plan to identify staff reductions at key transition stages.
- A workforce plan to identify new skills required at key transition stages.

3.1.3.3. Staff training and skills

Many of the skills necessary to operate a NPP differ from the skills needed to decommission the plant and in particular clean up the site.

There is a need for all staff to recognize the phase of the lifecycle which they are entering and the changed work environment and business culture in which they will be working. This requires constant communication, briefing and regular training. The following issues need to be considered:

- Organizational change to manage a decommissioning nuclear site requiring different management skills from those for an operational NPP.
    - Staff numbers and skill sets required
    - Target organizational structure for decommissioning
    - Transition plan from current to target state
    - Lead time required to prepare and train staff
    - Expectations of external stakeholders
- A competitive decommissioning and site clean up market exists in some parts of the world and staff needs to be capable of exploiting international possibilities for services which should be contracted out.
- Many clean up activities require project management and contract management skills and this type of experience takes time to accumulate.

For continued operation, consideration needs to be given to the adequacy and comprehensiveness of training programme, skills transfer and information and knowledge transfer between different generations of plant staff. Particular focus needs to be given to the potential for larger than normal staff turnover rates just prior to or following completion of a refurbishment project. There is a need to consider not only the time related profile of the numbers of staff needed during such periods but also the skill and experience levels of staff in all key groups including those who undertake both classroom and on the job training and mentoring. Unexpected turnover of staff in any area supporting the operation of the NPP can lead to ineffective or inefficient support, with potential for unplanned and extended downtime and outages, if not proactively managed.

3.1.4. Plant income in regulated and de-regulated utilities

Electricity prices are not fixed for the full lifetime of a NPP and the projected income from future electrical generation can be a factor not only of competitive power generation types but also of the nature of the local electricity market and the extent of a regulated versus deregulated market for electricity and other energy sources and fuels.

It is often more difficult to assess the long term future income from a NPP than it is to estimate operating and maintenance costs for estimating the future net value to the utility of the electrical power that can be produced. This difficulty most often depends on whether the utility operates in a regulated or de-regulated market and whether or not it is part of a large utility with multiple power plants and shared contracts, or whether the power plant operates as a single entity. For example, in some cases of a regulated environment in a large utility, plant income has traditionally been managed in the form of an assigned budget for operations and maintenance with perhaps an additional capital budget amount for safety upgrades and other plant improvements with longer term payback. The actual income from electricity generation that might be commercially assigned to such a plant is often not determined as a normal practice. Assignment of an income would be potentially clouded by a variety of issues related to internal practices on overhead costs and procurement of goods and services. Large centrally administered companies often do not apportion costs and revenues in a manner suitable for allowing an understanding of the commercial viability of individual plants, nor do they always manage them in a manner similar to those applied to individual independently owned and operated plants. In a regulated environment income is generally based on the cost of production plus capital cost recovery, with in some cases a negotiated profit margin and in other cases (such as non profit government operated utilities) only a small contingency amount in excess of production costs.

In the case of a single power plant operating independently in a de-regulated environment the income would be based on sales. The actual income generated would depend not only on the amount available for the power plant to sell, but on the nature of the contracts that had been arranged. Additional complications arise when a portion of the plant output is assigned in a contract basis where income is based on an unpredictable hour-by-hour value assigned by the local distribution network. Between the two extremes there are many situations in which a larger utility has multiple contracts for the supply of power and could apportion only an average value to potential electrical output produced by various plants. How this income might be differently assigned between base load units and peak load units is often a matter of historic internal practices which are not necessarily tightly linked to current overall operating costs except perhaps in relation to the fuel cost component. In a regulated environment electricity price is normally fixed for a pre-determined period, but an obligation exists to supply whatever amount of power is demanded at any given time during that period. In a deregulated environment a utility can in some cases choose the basis for how much it will supply, to whom and at what price. However the deregulated case may be complicated by contracts involving penalties for not providing power when needed, for example during unplanned outages, giving rise to additional difficulties in estimating the net income to be derived from plant output over long periods of time. Such uncertainties can significantly affect the terms, conditions and costs of financing that would need to be arranged to fund a refurbishment project. The impact of incoming revenues from electricity sales on the computation of plant lifetime economics is discussed in detail in Part II of this publication.

Common difficulties for both regulated and de-regulated markets would be in predicting the impact of the costs of competitive forms of generation such as from coal, natural gas and oil. Added to these are the difficulties in predicting the nature and timing of any potential penalties or premiums that might become assignable to specific generation types. For example, while carbon dioxide emission trading is in trial use in some countries, the potential costs and timing of their implementation is not known in other regions. In some regions there are penalties or costs assigned to other forms of pollution emitted by or produced by power plants of various types. In other regions, the actual price of electricity that consumers are willing to pay depends on the source of that electricity, with premiums being paid by some consumers for electricity produced from wind power and other renewable sources. In general, in de-regulated energy markets the hourly price of electricity sold on the main "Day Ahead" energy market depends on the cost of operating the marginal unit (the last plant on the 'order of merit' called upon to serve), including all imposed pollutant emissions penalties.

3.2. Value to local and regional economy

Sub-section 3.2 discusses the value of the plant from the perspective of stakeholders in the surrounding communities. An example of the impact of a large NPP on the regional economy is the Kashiwazaki-Kariwa NPP in Niigata Prefecture, Japan, discussed in the Annex to this publication.

There can be significant impact on the local and regional economy of unexpected changes imposed by plans for early closure or continued operation compared to the impact that would have occurred following the normal closure of the NPP. The value of the presence of an operating NPP to the local and regional economy can be derived once the scope and extent of these impacts is understood.

If at the time a decision is made related to early closure or extended operation, there has not been any comprehensive planning for normal closure, then any assessment of the overall impact of the decision might include factors which more properly relate to planning for the normal end of operations. As such, these issues would need to be addressed at some point in the future and the only real impact is the timing of the event. In many cases no such planning for eventual closure has been undertaken and initial perceptions of impact are judged on the basis of assumptions that are likely to prove invalid. Generally this is attributable to either time pressures or the lack of easy access to relevant guidance or the experiences of others in similar circumstances. This section provides guidance on a wide range of factors which are relevant to the change in projected operation lifetime of the NPP. Section 4 provides guidance on factors which would need to be addressed whatever decision were made regarding the finite future of an operating NPP.

3.2.1. Environmental impact

A review of environmental issues should be undertaken whenever there is a major change in direction and intent with regard to the operation of any major industrial facility, including electricity-generating plants. Such a review should ensure that existing formal environmental assessments encompass the issues that are relevant to the proposed course of action.

In exceptional circumstances, where no previous formal environmental assessments have been undertaken related to the impact of operation of the NPP or to the impact of its closure, it may be appropriate to initiate a specific formal assessment to provide input to the decision making process and how expected environmental impacts might be mitigated.

The costs of any mitigating actions or strategies to reduce the environmental impact of proposed actions need to be assessed and a means made available to factor these in to the decision making process. This is not always a simple matter as responsibility for the costs of appropriate mitigation measures may lie with organizations which are different from those initiating the need for the mitigating measure and neither of these may be the plant owner, especially when they relate to the provision of alternative energy supplies.

Both early closure and continued operation are included in the concept of such major changes, as each can have a significant impact on the environment, not primarily in their own right, but more in relation to consequential changes they require in other parts of the economic and social environment. Such consequential changes include alternative electricity generation facilities, energy imports and transmission or fuel transportation, and consequential changes to support infrastructures and in other industrial facilities which are major customers of the NPP. The overall environmental impact of a decision on early closure or continued operation of a NPP would be restricted to the impact of the NPP itself only in exceptional circumstances in which the demand for the plant's electrical output ceased to exist once the plant no longer operated.

The environmental impact of a NPP is highly dependent on the nature of the plant environment and presence or absence of neighboring economic activities in terms of residential density, industries, transportation routes and agriculture/aquaculture activities. Also included under this heading are community values.

3.2.1.1. Some environmental issues

- Ongoing environmental impact of normal operation.
- Environmental impact of waste produced by additional operation.
- Environmental impact of project work related to refurbishment.
- Environmental impact of alternative generation (and location of alternative generation project — in same or different community/ region).

3.2.1.2. Community values

- Valued eco-system components (as judged by local communities who are well informed about their environment and NPP operations).
- Community workshops should be held to establish what the community currently values most about its environment.
- The outcome may show significant differences from community values when the NPP project first started a few decades previously.

3.2.1.3. Environmental assessment process

The environmental assessment process needs to demonstrate:

- A thorough understanding of the local environment.
- A thorough understanding of the energy sector impact on the environment.
- Means to minimize the impact of the energy sector on the environment.
- Means of assuring that the actual impact is not different from that intended.

3.2.2. Employment issues

Sub-section 3.2.2 discusses employment issues from the perspective of social and economic impact on the communities in which plant employees live and from which they demand goods and services.

The following factors should be considered:

3.2.2.1. Employment losses (including the multiplier effect on local economy

In considering employment losses incurred due to closure it will be necessary to assess:

- Direct employment losses (managers, specialists, employees and other workers from the plant).
- Indirect employment losses (in suppliers due to lost orders).
- Relative value of employment (high added value or low added value for local spending and taxation purposes).
- Consequential changes in demands for services provided by local and regional governments.

It will also be necessary to assess losses that are likely to occur and the cost of the aid programmes designed to soften the impact

The normal expected lifetime of an NPP can be very similar to the working lifetime of a senior specialist or manager who has based their career in the nuclear industry. In these instances it is likely that normal retirement plans for the employee could be in harmony with normal plant closure. In such instances early closure would impact and possibly terminate employment. Similarly continued operation could bring an unanticipated need to recruit and train replacement employees and transfer key skills and plant specific knowledge.

Impacts can vary depending on the value of any net job losses to the local economy, depending on the relative incomes of those losing their jobs to the local or regional average and past spending practices with respect to this income. Impacts would be significantly different for example if past practices had been that most spending occurred locally compared to situations where spending had traditionally been outside the of the region for goods and services not locally available.

Other considerations relate to the expected location of those losing employment, once the closure has occurred. There are significant differences for the local community and region if people stay in the area and remain unemployed, than if they obtain employment elsewhere and leave. These differences impact both the level of demand for local goods and services and social, educational and health care services, and the capability to support these from taxation or service fees.

3.2.2.2. Change in regional spending power

Much of the normal operating and maintenance budget of a NPP is spent in the surrounding area. Operation of the plant supports the economy in a number of ways, through the supply of goods and services to the employees who live in the surrounding areas, and through the supply of goods and services directly to the plant itself to support ongoing plant operation and maintenance.

The magnitude of the changes experienced by the region will depend on the significance of the NPP operating and maintenance and capital additions budgets for the local and regional economy. In some regions this may be a dominant factor and in others it may play a minor role, with a full spectrum of possibilities between these two extremes.

Potentially significant changes can be expected in both the overall amounts of spending and the profile or types of goods and services supported, not only following an early closure but relatively promptly following the initiation of any uncertainty regarding the future of the plant. Both plant employees and the plant itself can be expected to react to the introduction of uncertainty by changing their spending patterns. Normal reactions would see people attempt to conserve their resources to deal with an uncertain future and to avoid large expenditures which would increase their commitment to the local region, for example the purchase or construction of new houses or major consumer items. Additional uncertainties of future employment following an early closure announcement can be expected to further aggravate such situations. The region may experience significant issues related to elimination of the demand for some types of goods and services, significant reductions in others, and the potential to find a portion of the population still requiring social services but unable to fund these due to increased unemployment.

The specific situation will be highly dependent on a variety of factors:

- the significance of the NPP operation for the local economy.
- the age and skill spectrum of those who become unemployed.
- the proportion of these former employees who are willing and able to relocate to find employment elsewhere.

NPP continued operation can also cause challenges for local and regional economies if a significant project is required to refurbish the plant for the extended period. The project may impose unanticipated increases in demands for accommodations, social and other services and goods as contractors and other temporary workers are brought into the region to undertake the plant project work. The nature of the challenges will depend on the extent and timing of the temporary increase in the workforce supporting the plant and the ability of the local region to adapt and support the needs of this temporary workforce.

3.2.2.3. Staff mobility – age of workforce

Staff mobility and the relationship with the age of the workforce can have significantly different impact in different regional economies.

In economies where there is a strong demand for or shortage of the skills and training of the workforce that would be released on early closure of a plant, there may be a positive overall impact. The opposite may be true in the event that there is no continuing demand for the existing skills and training of that workforce in the same region. There is a range of situations between these extremes.

One issue can be the level of compatibility of the staff skills and training with the general level of the local community. There may be no significant issue if the staff had originally been recruited and trained from the local communities and region and can find other employment there easily, at a similar level of income. There may be significant issues if the staff have skills, training and income levels which are not compatible with the rest of the local economy, or if the staff had been recruited from other regions which have any significant cultural or linguistic differences from the local community or region. Skilled nuclear specialists have often been recruited from other regions or countries and do have cultural or linguistic differences which may have been accommodated during the plant operational life but would not necessarily be similarly accommodated in the different economic circumstances following a plant closure.

The age of the workforce may also have significant impact. The working lifetime of the staff may be well matched to the originally expected operational life of the NPP. In such cases, many staff may expect to spend the remainder of their working life and retire from that specific NPP. An early closure may disrupt this expectation and require staff to find employment of a significantly different nature for several years relatively late in their careers. This may be an issue amenable to the retraining and redeployment of these human resources. Where plant lifetime and workforce age profile had been well matched, a continued operation project may bring a sudden demand for training of additional staff to continue the work into the extended NPP lifetime. This may introduce a peak need at the time of a refurbishment project to employ an increased number of staff while new recruits are trained to replace staff who intend to retire following the project.

3.2.2.4. Housing market

The impact on the housing market of extended operation or early closure can have considerable impact on the mobility of the staff employed at the NPP. There are significant differences between local situations in which housing has been provided on a rental basis, where individual staff have no long term investment in their homes near the NPP, and those situations where staff have built or own their home. Again there are significant differences between local economies which have a significant dependence on the NPP and those which have a more varied economic base in which housing is in significant demand for a much broader range of people than those working at the NPP. Where staffs predominantly own their own homes and where the NPP is the predominant employer then there can be a significant impact on the housing market and hence the mobility of staff either away from the NPP at the time of early closure, or to the NPP to support a significant refurbishment project for extended operation.

Early closure can mean that staffs need to sell their home in order to be mobile and take new employment in a different region. Early closure can mean that this has to be done when there is no demand for the housing that needs to be sold with significant competition from fellow workers also wanting to sell. Where the staffs have a significant personal financial investment in their own home there may be no practical opportunity to sell the home to move this major investment to a new community in another region. This may have an impact which is significantly different from the original intent of the staff regarding their own retirement.

Similarly a continued operation project may bring a demand for housing where little surplus exists, and this can have a significant, if temporary impact on the price for local housing and pressure to construct additional homes and related infrastructure. Different communities can have significantly different reactions to an unexpected demand for additional housing accommodation, particularly if this demand is of a temporary nature.

3.2.2.5. Social services and amenities including schools and hospitals

In many cases the staff community associated with a large NPP is sufficiently large to induce a requirement for significant local social amenities and services, including schools, clinics and hospitals which are beyond what would be provided for the local community had the NPP not been present. In some cases the need for and support for such amenities and services would disappear should the power plant be closed.

3.2.2.6. Local and regional tax revenue

A NPP, its staff and support community, as well as related spin off jobs normally significantly increase the overall economic activity in the locality and region in which they are situated and contribute both directly and indirectly to local and regional tax revenues.

In many countries, different forms of social services and amenities are funded from different types of tax revenue, some from local taxation by a local town or district, some regionally and some nationally.

In many cases the economic activity supported by a large NPP contributes more to tax revenue streams than it takes while the NPP is operating. Thus there is a net benefit or hidden subsidy to other citizens in the community from operation of the power plant. Early closure can withdraw a significant amount of tax revenue from all levels of government income while not removing a proportionate requirement for government expenditures to support these local or regional social amenities and services.

Withdrawal of the economic activity associated with any large employer can thus have unanticipated requirements to re-align social services and amenities to the new situation, sometimes requiring increases in local and regional tax rates to the remaining local community for an actual reduction in the level of social amenities and services, including but not limited to closures of schools, clinics and hospitals formerly serving both the NPP staff and the local community.

The reverse can be true of a continued operation project where additional demand can be created for all forms of social services and amenities without necessarily increasing the demand to the extent that additional physical social facilities are required (perhaps due to an increased requirement only for a short timeframe of a few years). This effect can lead to unexpected over-crowding of facilities and other factors related to high demand pressures, impacting not only the staff and support community for the NPP but the entire surrounding local and regional population.

Such impacts, both of continued operation and of early closure can be magnified if cultural or linguistic differences exist between a significant proportion of the plant staff and the local community.

3.2.2.7. New economic opportunities from re-allocation of scarce resources

The significance of the operation of a NPP to its local and regional economy can be quite different for different regions and economies depending on the nature and extent of other activities, industries, employment opportunities and social circumstances. All of these can affect the relative costs and benefits of an early closure or extended operation for a specific NPP.

In some cases the early closure of a NPP could provide a significant benefit primarily due to the ability to re-allocate scarce resources tied up with the operation of the NPP to other more effective and economically productive and beneficial activities.

This benefit might be internal to the NPP industry where it is extremely difficult or impractical to recruit and train sufficient skilled and experienced staff to meet the continued needs in a specific region. The industry itself may undertake the removal from service or early closure of some older or less productive plants to allow re-allocation of the skilled workforce to support the operation of more reliable or more productive NPPs. Such action was taken in Ontario, Canada in the late 1990s where older operating reactors at Pickering A and Bruce A were taken out of service to allow re-allocation of operating and support staff to twelve newer units at Pickering B, Bruce B and Darlington [27]. Such action does not necessarily preclude the return to service of such reactors when circumstances have changed to increase the numbers of skilled operations and support staff. It must be noted, however, that experience shows that projects to undertake the removal from service and the return to service of large NPPs can incur major costs not only for the owners of the plants but also for local and regional economies. Such actions result in significant economic cycles due to the reduction and subsequent increases in demands of the workers on the supply of local and regional goods and services, including housing and other social services such as schools and hospitals.

In other cases the early closure of a NPP may be beneficial to the regional electrical distribution system if the scarce resource which can be re-allocated is electrical transmission capability. In many regions it has become difficult to add additional electrical transmission line routes between generation centers and load centers, either due to physical limitations of the geography or due to lack of social acceptance of such additional routes [28]. It may be practical to more effectively use existing transmission routes by undertaking early closure of specific older generating facilities and replacing them with generating facilities which are more efficient or potentially of higher capacity if existing routes can be upgraded. Better utilization of existing transmission capability by new reactors from the Bruce NPP was given as one of the primary reasons for the closure of the smaller and older Douglas Point NPP in Ontario, Canada in 1984 after only 17 years of operation.

3.3. Value to electricity customers (impact on the electrical supply system)

The organizations responsible for dealing with the impact on the regional electrical supply system of a NPP early closure or continued operation can be significantly different depending on the nature of the regional electrical industry structure.

In some cases a single vertically integrated electrical utility is responsible both for management of the NPP and for management of the overall electrical capacity in the region to meet projected electrical demands.

In other cases private or public companies are responsible for management of the issues related to early closure or continued operation of the NPP and management of the consequential impact on energy supply and demand rests with an entirely independent organization or government department.

The economic viability and competitiveness of industries and other major customers of electricity can be affected not only by the availability and reliability of electrical energy but in the certainty of electrical prices. An assessment of future needs should include an understanding of the consequences of any projected changes in availability, reliability and pricing on the viability and competitiveness of major customers as this may have a direct consequential impact on future electrical demand, resulting in more widespread economic and social changes than might be initially apparent.

In all cases there is an impact which has associated policy and cost implications which warrant consideration from one or more of the affected organizations or government departments.

3.3.1. Replacement needs

The need for replacement of the electrical generation capacity of a NPP which is subject to early closure, or the viability of continued operation will depend on the:

- current over-supply or under-capacity situation, both in relation to growth in electricity demand.
- grid stability and transmission capability (related to the location of generating facilities with respect to major load canters) and consequential mitigation measures required to maintain overall system reliability.
- reliability and capacity factors of different types of electricity generation.
- security of supply (related to potential for assured fuel supply at costs levels that can be recovered within the electrical price structure).
- impact on future demand of any projected changes in electricity prices, availability or reliability.

The requirements for replacement of electrical generation can be significantly dependent on the local, regional and national situation of the NPP under consideration. In some cases there may be an over-supply of generating capability, as compared with local or regional demand, which would allow closure of a power plant with no significant impact on the electrical supply system. In other cases there may be a general shortage of electrical generating capability which requires careful consideration and coordination of the availability of replacement capacity before an existing NPP can be taken out of service if a significant negative impact on the regional economy is to be avoided. In yet other cases, while the overall supply situation may appear adequate, there may be local transmission capacity issues, grid or line stability and reliability issues that can result in local requirements for generating capability in order to leverage more distant generation capability over long distances. The overall supply and demand situation for electrical generation needs to be carefully assessed to ensure continuing security of supply. Thus the replacement needs are related not only to generating capacity but to reliability of that generating capacity and the location of that capacity with respect to its impact on the stability and overall reliability of the electrical grid or supply system.

3.4. Value to energy policy and the environment

If a need for replacement generation is identified, consideration needs to be given to how this need will be met. Factors to be considered include:

- Import or export of electricity.
- Import or domestic supply of alternative energy sources.
- Reliability of supply of alternative fuel or generation supply.
- Environmental impact of alternative generation.

Many regions have developed and periodically review their energy policy to assist in decision making regarding options for energy supply and energy use. A typical example is the New Brunswick Energy Policy White Paper, which provided background information for a decision on closure or life extension of the Point Lepreau NPP [29]. Each of the ten North

American (Both the USA and Canada) Electric Reliability Councils produces annually an updated ten years look-ahead generation and transmission resources planning publication.

3.4.1. Import or export of electricity

Depending on the capacity and reliability of international electrical grid connections, it may be practical to consider the direct import of electricity to replace the capacity of the NPP under consideration. In other cases there may be long term electrical supply contracts available or in place and a capable electrical grid infrastructure which imply replacement generation should be undertaken at the same location as the existing NPP. Electrical generation at this location may be optimal not only to meet local system stability and reliability needs, but also to meet longer term obligations to neighboring countries and regions which do not have a local electrical infrastructure readily adaptable to meeting their own needs.

Revenue from electrical exports and the industries and services supplied by or supporting the existing NPP may be of regional significance and the impact of these consequential changes may also need to be considered.

3.4.2. Import or domestic supply of alternative fuel

There can be a significant local, regional and even national economic impact of a change between NPPs, for which most ongoing operational costs are in the form of local labor costs, and fossil fuel power plant where most of the ongoing operational costs are in the form of fuel costs. In the case of a NPP, much of the associated spending power going directly into the local economy. Unless there is a good local supply of fossil fuel, most of the associated spending is directed to another region which supplies the fuel and does not flow back as spending power to help sustain the local economy. The construction of a new NPP is more capital and labor intensive than the comparable sized coal fired plant. Thus even during the construction phase a nuclear plant will contribute more to the local economy.

There are also significant differences in economic impact from the choice of other generation types, depending on whether the cost of power plant construction or refurbishment is predominantly spent locally, regionally within the same country or whether most of the equipment and construction costs are for goods and services imported from a third party, with little flow back to sustain the domestic economy.

3.4.3. Reliability and security of supply of alternative fuel or generation supply

Consideration needs to be given to the reliability of supply of the fuel type for alternative generation and to the physical reliability and availability for continuous generation from that alternative. Among these considerations should be the national or regional strategy towards diversity of supply, and hence the priority on avoidance of dependence on one type of fuel supply or energy source.

Security of fuel supply is an issue in terms of both availability and cost. Availability of fuel supply can be a factor in terms of both exhaustion of supply, as when natural gas or oil wells or coal mines are exhausted and alternative supply locations need to be sought, and in terms of fuel cost fluctuations over the lifetime of the alternative generation. In some cases these market fluctuations can be tempered by long term supply contract arrangements which will be honored by the fuel supplier.

Long term fuel supply availability can also be significantly impacted by foreign political changes. Examples include the vulnerability of long supply chains to hostile actions between third parties, but also include significant changes in political direction in fuel supply countries following changes in government.

Other actual and potential foreign political changes that need to be considered include changes in energy demands and energy policies and supply strategies in other countries. These can have individual and cumulative impacts on both the price and availability of fuels impacted by changes in demands and policies.

Technical reliability of the proposed alternative form of generation needs also to be considered compared to the type being replaced (base load in the nuclear case). For example, replacement of a NPP with a hydraulic generating plant will require careful consideration of the seasonal and long term variations in the flow of the water supply. Many hydraulic generating facilities have historically been constructed to take advantage of high seasonal or periodic flows and such facilities have not always been intended for long term base electrical load contribution. Similar considerations are required for specific plant designs for some gas powered facilities which are intended for occasional peak demand situations rather than continuous base load supply. The design requirements and the initial construction costs of facilities for occasional peak load operation, for taking advantage of seasonal or occasional river water flow or periodic wind flow situations and the requirements for continuous long term base electrical load generation are quite different.

3.4.4. Environmental impact of alternative generation

All forms of electrical generation have an environmental impact, the significance of which depends both on the type of generation and on the plant location in relation to significant population centers, significant eco systems and migration routes and areas of significant natural value (for example national parks). For example, the location of a large number of wind powered generators in a coastal location which is a migratory route for several rare or endangered bird species may have a potential impact which could preclude the use of an otherwise advantageous location by this generation type.

Careful consideration needs to be given to the overall environmental impact of the proposed alternative form of replacement generation, using similar factors and methodology to assess the overall impact of the NPP, so that an effective comparison can be made. Environmental impacts consider not only the nature and significance of the impact of effluents and wastes rejected to the atmosphere, rivers, lakes and seas, but also the impact on local and regional ecology, where the overall size of facilities of comparable capacity and reliability also becomes a factor. For example the overall area impacted by a hydraulic power plant will depend significantly on the available elevation difference and on the nature of the country surrounding the head-pond and on the extent of the river supply system for that head-pond. Similarly the area impacted by wind generation with units of 800kw and 1.3MW capacity will be significantly different from that impacted by units of 4MW capacity when large arrays of either type are being considered.

The impact of additional fossil fired fuel exhausts needs also to be considered not only in terms of local environmental impact but on a global scale, including in terms of obligations to meet limits set in the Kyoto protocol or other international agreements.

Broad scale actions, such as those required to meet the Kyoto protocol, are difficult to factor into decision making unless a regional or national authority has enacted measures which can effectively transfer these obligations to those responsible for decision making at the plant and utility level. Such measures can include regulations, taxation, incentives or subsidies designed to encourage activities which would meet the obligations and penalize activities which would detract from the obligations being met. Measures can be broadly effective only when they are accepted as being reasonable, certain, appropriate and sufficient to ensure the obligations are likely to be met.

3.5. Value to the broader economic management of the region

Decisions related to continued operation of a NPP can have a significant impact on the electricity market and the availability, stability and pricing of electricity. Such changes can have consequent impacts on the viability and economics of other industries, in addition to the impact on residential, commercial and institutional electricity customers.

Major changes to electricity pricing and availability can lead to relocation of major industries which are heavily dependent on their energy costs. Such changes can thus have much broader implications for the economic management of a region. The overall economic, social and environmental impacts of such direct consequential changes in related major customers should therefore also be considered as part of the overall assessment process.

As an example, the overall increase in electricity prices in the Pacific Northwest region of USA during 2000–2001 resulted in local generating plants revoking their contracts to supply low cost electricity to the regional aluminum smelters. It was much more profitable to transmit the generated power to the more distant and higher value California energy markets, despite the transmission losses over the more than 1,000 km distance. This resulted in the demise and shutdown of most of the region's aluminum refining industry, and its relocation to the more hospitable Caribbean islands.

3.5.1. Compensation, aid or incentive packages or programmes

Compensation and aid packages can be made available to mitigate the effects of early closure and to partially fund plant refurbishment projects (particularly those involving pioneering technology or issues related to the quality of initial component supply or fabrication) including:

- Technical related projects.
- Social consequences related projects.
- Economic regeneration projects.
- Training and re training projects.
- Plant investment related projects.
- Environmental related projects.
- Partnership related projects .

Such sources of funding assistance should be considered as a factor in any decision making process and utilized where appropriate.

Potential sources include:

- National Governments.
- Local Governments.
- Industry organizations.

- Regional aid agencies.
- National aid agencies.

Instances of early closure are particularly attractive to aid programmes but it is also necessary to review and assess the extent to which such aid programmes successfully meet their objectives.

4. ISSUES THAT SHOULD BE EXCLUDED

Section 4 discusses some of issues that have the potential to be introduced into reviews of options on the future of NPP operations which are in most cases inappropriate and could bias decisions in directions which would not stand close scrutiny, and as such would subsequently be open to challenge and reversal. Such issues generally fall into the realm of issues which would need to be addressed no matter which option is selected as well as legacy issues which should have been addressed but were not.

The apparent attractiveness of alternatives can be significantly influenced by the inclusion or exclusion of various high value items. In some cases, such high value items may be inadvertently added to some options, even though the costs would have to be undertaken no matter which alternative were chosen. This has the potential to lead decisions that can be successfully challenged by some stakeholders as being inappropriate.

Adequate operational lifetime management and end of life planning are required to mitigate anticipatable safety risks and financial liabilities. The following issues relate to normal life cycle management and should not be included as factors specific to early closures or continued operations programme.

1. Pre-planning and transition management for the closure of the NPP at the end of its normal operational life.
2. Financial provision for funding of decommissioning and of long term management of spent fuel and radioactive waste.
3. Sufficient periodic inspections and condition assessments of all structures, systems and components important to safety and to the operational reliability of the NPP.
4. Pre-planning and transition management of changes in organizational structure, de-integration and privatization of vertically integrated utilities and movements to open market situations.
5. Contingency generating capacity provisions in national or regional strategies for energy supply, such that energy supply situations would become critical if any major source of supply was discontinued for any reason.

However, the differences in timing, brought about by an early closure or by continued operation, can have costs which need to be taken into account.

It is assumed that technical, economic and social infrastructure to support ongoing operation is already in place and that the environmental impacts of normal operation have been defined, reviewed and accepted. As such no additional costs related to these factors should be included unless they are changes required by the change in expected operational life and would not be undertaken if there were no change in operational lifetime.

4.1. Costs which are common no matter which decision is made

It is important to exclude from the costs assigned to an early closure or continued operation project any costs which would need to be undertaken, no matter what choice were made.

Such costs would include normal costs for decommissioning, for the establishment of programme and facilities for long term radioactive waste management, for the management of any other wastes produced by the NPP and for management of spent fuel.

It is expected practice to set aside funds from normal operation of a NPP to retire capital debt related to initial construction (and subsequent improvements), and to establish funds to cover the anticipated future liabilities for decommissioning and for the long term management of operational wastes and of spent fuel. It is normal practice to ensure that such debts are paid down and such liability funds are established at sufficient rates that there is an assurance that the full debt will be retired and liabilities fully funded prior to the planned end of the operating lifetime of the plant, accounting for reasonable contingencies. These issues are modeled in section 10. Such practices take into account that any potential for more rapid debt retirement and liability fund accumulation towards the end of operating life is often offset by lower overall capacity factor experienced by most industrial facilities towards the end of their operating lifetime.

Other costs, which must be excluded from assignment to the project costs for decision making purposes, include the costs of:

- replacement energy for the plant customers during the project.
- staff re-training.
- staff compensation or layoffs during the project.

4.1.1. Replacement electricity costs

Arguments have been made, for accounting purposes, that if an owner must provide electricity from other sources (for example by generation at a more expensive power plant or by purchase from a third party) during a period when a power plant is unavailable, that the costs of this replacement electricity should be assigned to the unavailable power plant. As discussed in Sub-section 14.3, this practice may be appropriate if there are specific contracts in place for that power plant to provide electricity during the period of unavailability and it is normal practice to assign such costs to all power plants in such circumstances. However, it would not normally be considered prudent practice for a plant to engage in contracts to supply electricity during periods when it would be either scheduled for a refurbishment outage or taken out of service having reached the end of life of some of its key components. While some regulated utilities may be obliged to provide replacement power in such circumstances, these are utility costs, not costs that should be assigned to the power plant requiring refurbishment or removal from service. Such assignments should only be made during period of operation from the initial in-service declaration to the end of capable operation of the power plant.

Once a power plant reaches a point in its operating lifetime when the condition of any structure, system or component renders the plant no longer serviceable and this cannot be rectified in a normal maintenance outage, then decisions on future operation following an optional refurbishment need to be considered. The options should not be clouded with the assignment of the costs of replacement energy for the period required to undertake the refurbishment. While such replacement energy may be a cost to the utility, such replacement energy would need to be provided for that period whether the decision made were to refurbish or to close and decommission the power plant.

4.1.2. Decommissioning and waste management issues related to original NPP operation

Decommissioning and waste management issues must be managed whatever the operating lifetime of the NPP.

The IAEA is developing guidance to review issues and factors affecting decommissioning and to assist in the selection of decommissioning strategies [30].

Costs assignable to an early closure or to a continued operation relate only to the differences in costs due to the change in closure date from that initially intended. As described in [30], this change in closure date may impact the decommissioning strategy selected.

Such changes in costs include the changes in deficit in funding of established decommissioning, waste management and spent fuel management funds due to the reduction in the operating period below that originally intended. There may also be differences in actual decommissioning costs due to the lack of available technology or experience that had been anticipated to be available by the originally intended decommissioning date. However, these costs should not include any deficit in funding that would be attributable to failure to establish or adequately manage such funds or failure to set aside contributions to such funds on an ongoing basis during the plant operational life.

Any surplus in funds accumulated for decommissioning or waste management should be managed in accordance with local rules for the management of such surpluses.

4.1.3. Stranded debt that would have existed at end of original design plant life

It is normal practice to set aside funds from normal operation of a NPP to retire the capital debt related to initial construction and any subsequent capital improvements to the plant. Stranded debt is the remaining amount of this capital debt that has not been paid down at the time of an early closure. However, the only portion of this debt that should be assigned to costs related to the early closure, is that portion which would have been paid down should operation have continued for the normally expected operating period, i.e. changes in stranded debt. Stranded debt that would have remained due to insufficient pay down rate of the overall capital debt during the initial period of operation should not be attributed to the early closure. This discussion equally relates to changes in equity that would be paid to the shareholders once the debt holders have got their money back.

4.1.4. Social, economic and environmental impacts of closure at end of original design plant life

There are a number of potential additional liabilities and costs related to closure of a major industrial facility. These vary considerably in different regions due to regional strategies for human resource management, labor relations and regional strategies on social economic and environmental impact management. They will also depend on the nature of the NPP operation and its relationship to neighboring facilities and communities.

As with other costs and liabilities, care must be taken to assign to the cost of an early closure (or continued operation) only those costs which relate to the consequential change in closure date, not those costs which would have been incurred at the time of a normal closure of the NPP.

Any plant closure can result in spin-off costs to suppliers and service providers. Such costs include stranded debt or inadequately funded liabilities of any facility or service for which the NPP was a major customer or supplier. Affected facilities or services could include a broad range of related industries and services, including local and regional municipalities, and housing, educational, transportation, infrastructure, health, social and recreational services for the plant workers.
Few if any of these costs would normally be the responsibility of the NPP, as many are normally attributable to other agencies and authorities or to commercial risk assumed by companies related to normal business practices. However, where a NPP is a major employer and has a major economic influence and impact in a locality or region, special circumstances apply. This is especially true when early closures are the result of regional or national changes in energy policy. Stakeholders will need to negotiate a balance in assuming responsibility for associated stranded debts and inadequately funded liabilities related to significant changes in closure date for NPPs imposed by such policy changes.

4.2. Costs that relate to inadequate adjustment to predictable business circumstances

Other costs that should not be attributed to either an early closure or to an continued operation project are those related to any failure to adjust to predictable or anticipatable changes in business circumstances which are announced well in advance of implementation.

It is expected that adjustments to the funding of capital debt retirement or to the rate of accumulation of funds to cover decommissioning, waste management, spent fuel management (or other end of life related costs) would be undertaken at a reasonable frequency based on a comprehensive review of current and future business circumstances.

Examples of such changes in business circumstances include any of the following:

- Changes in codes, standards and regulatory or legislated requirements which impose additional or different requirements on NPPs for operation after a defined future date.
- Changes in the future availability of essential support facilities or services for the NPP (such as fuel supply, fuel fabrication, spent fuel reprocessing or long term waste management facilities).

The period for which sufficient lead time may be judged adequate would be specific to a particular change in circumstances and specific to the anticipated period between the announcement of the change and the end of the period at which the debt would be retired or the liability fully funded. Sufficient advanced notice excludes any period subsequent to an announcement during which significant uncertainty remains as to whether or not such conditions will actually be implemented for the NPP in question. In most circumstances, announced lead times of 15 to 25 years should be sufficient to allow adjustment of business and accounting practices to accommodate even the most significant changes.

5. COSTS OF IMPLEMENTING EARLY CLOSURE OR A CONTINUED OPERATION PROJECT

Section 5 discusses some of the major areas of estimation of the costs of technical issues which need to be appropriately considered and addressed when reviewing options on future plant operation, to ensure that cost estimates for various options, and subsequent decisions, are well founded.

Some of the costs associated with future activities will be necessary irrespective of the choice between early closure or continued operation. Other major capital investment costs are quite specific and would only be incurred in the event of continued operation.

In general the technical costs associated with early closure would mainly be costs that would be incurred at a later date in the event of a normal closure, however there are issues that could lead to some costs being higher due to earlier closure and these are identified in Section 5.1 below.

Specific costs associated with the justification for continued operation are identified in Section 5.2.

Early closure

Early closure involves removing a plant from service before the end of its original design life, before its license to operate expires and while there is remaining value in the structures, systems and components. Comprehensive and accurate condition assessments are appropriate in relation to early closure decisions in order to:

- Produce a realistic estimate of the lost value for electricity production, i.e. an accurate assessment of the remaining lifetime of the systems, structures and components based upon their current conditions in order to determine the realistic present value of the NPP. This is required for comparison with current accounting "book" value of the plant and the remaining operational lifetime which was assumed from the original design specifications and projections from past operating experience. This comparison will help to validate or challenge the accounting practices that had been employed to retire debt related to past capital expenditures (original construction plus subsequent upgrades). The net cost of an early closure needs to consider the value of the electricity that could have been produced from the plant without the imposition of early closure, and compare this with the operating and maintenance costs that would need to be incurred to generate that electricity. This assessment needs to be based on knowledge of the "book" value of the plant at the time when a decision is to be made on early closure, and the actual plant condition at that time.
- Determine the extent of any shortfall (or surplus) in decommissioning funds. A thorough current condition assessment is needed to determine the nature and extent of preliminary work required to prepare the plant for decommissioning subsequent to an early closure. The nature, extent and timing of implementation of this work may be different from that anticipated in the original decommissioning plans and adequate funding may not have been set aside for such purposes at the time that an early closure decision is made.
- Determine the potential re-sale value of those components for which there may be a commercial market. The actual value of many components would depend on current condition and the nature and extent of work required to make them fit for alternative

service (which may include decontamination of some components subjected to exposure to radioactive substances.) There may be potential re-sale value in excess of scrap value for components which were designed for a long service life but which will now be withdrawn from service significantly before that service life is achieved. This can only be determined if the condition of these components is assessed in a manner meaningful to prospective purchasers.

Continued operation

When a project is considering extending the operating life of a NPP beyond both its original design life and its current operating license a comprehensive condition assessment of all of the plant structures systems and components should be undertaken. This is to ensure that the full scope and cost is determined for all of the work required to ensure the plant can meet its revised operational life and that the costs of the full project can be recovered against future operation. This work may involve some major component replacement work or significant safety upgrades and additional systems or equipment might be needed. This assessment might identify that more work than was initially apparent would be needed, however it is often more economical to be aware of and undertake such additional work in parallel with the major component replacement or safety upgrade work than to subsequently undertake additional extended outages.

5.1. Costs associated with early closure

5.1.1. Significant changes in closure date

Sub-section 5.4 discusses some of the major areas, other than accountancy discounting, in which cost can change due to significant changes in plant closure date brought about by decisions on early closure.

When determining costs related to work required following an early closure, there needs to be consideration given to the fact that there would in many cases be similar issues and costs that would need to be incurred in the event of a normal closure. These could be funded from established decommissioning funds. Costs specifically associated with early closure are those related to the timing of the closure, not due to the concept of closure. There are potentially quite a number of costs which are specific to the timing of the closure date, due to changes in the availability of key resources or services. Normal closure may have anticipated the availability of an extensive competitive market for preparatory work and for decommissioning work, yet an early closure may force activities to be undertaken in a market where no such competition is available, and experienced resources are scarce and unexpectedly expensive compared to previous plans.

5.1.2. Early closure of plants of an imported design

Additional issues may be particularly evident if the NPP is of an imported design and early closure takes the plant out of service significantly before similar plants are taken out of service in the country of origin. In such cases normal end-of-life and decommissioning plans might have reasonably anticipated the existence of standard end of life and decommissioning processes developed by the original supplier by the time the specific plant needed them. Without benefit of this experience, early closure may require the plant to now develop and implement such plans in isolation and by pioneering such activities, at much greater cost than had been previously anticipated.

5.1.3. Early closure prior to availability of national waste repository

Additional early closure costs may be incurred where normal closure plans had anticipated the availability of national or regional facilities for the long term management of radioactive wastes and of spent fuel. In some regions there have been significant delays in the establishment of a national strategy or national or regional repositories related to long term management of radioactive wastes and spent fuel. In some cases government policies at the time of initial construction and operation of the NPP had stated that a government would accept responsibility for long term spent fuel management. But several subsequent governments have reversed such policies, or delayed implementation of them, such that no facilities or national strategy exists at the time of an early closure. Unanticipated additional costs may thus be incurred to develop and construct interim radioactive waste storage facilities and additional interim spent fuel storage facilities to accommodate storage of decommissioned systems and components which had previously been assumed to be sent to a national repository.

5.1.4. Long term waste management and spent fuel management liabilities

If the costs associated with long term management of radioactive wastes (both operational wastes and waste from subsequent decommissioning) are (by national strategy) the responsibility of the owner of the NPP, then it is normal practice to set aside funds for this purpose from the revenue generated during the operational lifetime of the NPP. It is reasonable to expect that such funds would be set aside in a protected manner such that they would be available for the intended purpose no matter what other anticipatable economic conditions occurred for the owner of the plant. It is also reasonable to expect that adequate contingency is built into such funding arrangements that changes in operating duration and capacity factor which can be anticipated will not adversely affect the funding of such future needs. If, however, this normally anticipated lifetime is unexpectedly shortened by an early closure, then the remaining period for revenue generation may be insufficient to allow accumulation of such funding in addition to the recovery of normal operating costs. In such cases the owners or other responsible authorities or stakeholders will need to make alternative arrangements for the funding and future management of the operational wastes generated by the NPP, wastes generated during the subsequent decommissioning and for the long term management of its spent fuel. These issues are modeled in detail in the decommissioning sections of Part II of this publication.

5.1.5. Retiring debt from initial construction and subsequent improvements

The initial construction cost of a NPP is a major component of the overall lifetime costs and is significantly larger that the initial construction costs of a fossil fuel power plant (normally fuel costs form a much more significant component of the overall lifetime costs for a fossil fired power plant). Added to these initial construction costs would be the capital costs of any major improvements undertaken during the operating lifetime of the plant. These costs may be covered by a loan or bond issue from financial institutions of financial markets. Owners would normally make financial provision for the repayment of these loans or bonds as a portion of the anticipated revenue generated by the NPP over a significant portion of its operating lifetime. Such provisions would normally include contingencies for anticipatable changes in capacity factor and period of operation. See Part II of this publication for details.

However, in the event of an early closure of the NPP the income necessary to repay this debt would not be available. The remaining debt related to the initial construction and subsequent capital improvements to the NPP may thus become stranded and the owner may be unable to repay this stranded debt. Either the owner or other responsible stakeholders would need to make other arrangements to address this stranded debt. This debt would be in addition to any unfounded liabilities related to decommissioning of the NPP or the long term management of its radioactive waste and spent fuel.

5.1.6. Decommissioning of the NPP

It is normal practice for NPP owners to be required to undertake planning for decommissioning well in advance of decommissioning, and to derive reasonable estimates for associated costs. Measures are then put in place to establish a decommissioning fund and to assign contributions to this fund from the revenue generated from operation of the NPP. These decommissioning plans are normally periodically updated with associated changes and adjustments to anticipated costs and to the accumulation of the necessary funds. Early closure removes the ability to generate revenue from which decommissioning fund contributions can be made. In addition an early closure can significantly alter the timing or even the nature of the decommissioning activities such that they no longer fall fully within the scope anticipated in the original decommissioning plans. The plant owners or other responsible stakeholders would need to make alternative arrangements for the adjustment of decommissioning plans and for contributions to the decommissioning fund following an early closure of the NPP.

5.1.7. Condition assessment and major financial impact

Condition assessments would normally be part of the existing system health monitoring and plant life management programmes and are aimed at understanding and managing ageing mechanisms of all structures, systems and components important to safety, plus those important to reliable economic operation of the NPP. Such programmes are normally focused on assuring that component maintenance or replacement will be scheduled to take place before fitness for service limits are reached. These programmes are significantly different from inspection programmes whose primary objectives are to detect and correct component problems after they have fallen below fitness for service limits.

In most cases a mature operating plant has reached a balance between predictive and preventative maintenance for priority systems important to safety or production, and reactive or breakdown maintenance for systems which have lesser importance to production where breakdown can be tolerated with minimal impact on overall plant operation. A more comprehensive programme may be required to reach the level of assuredness and understanding of overall system condition given the financial implications of early closure or major component replacement greater than those related to risks of forced outages.

It is also of critical importance to accurately assess conditions for an early closure, as there is significant potential to impact decommissioning costs and there could be an impact on compensation for perceived liabilities. The issue on compensation relates to the demonstration that the plant would have been serviceable for the period claimed in negotiations and to validate the operating and maintenance costs to be defrayed against the value of electricity that could have been produced.

Steam generator condition seems to have been a significant factor in the decision by Ontario Power Generation (OPG), announced in August 2005, to not undertake a return to service of units 2 and 3 at Pickering [31], despite the earlier return to service of units 1 and 4. Significant cost over-runs were experienced during the returns to service of units 1 and 4 [27]. This project, however, was initiated without an expressed intent of extending the service life of the units, but rather of returning the units to service for the remainder of their originally projected operational life. While some lessons may be learned from the OPG experience at Pickering, it must be kept in mind that there would not have been only the original projected lifetime rather than an expected extended period of revenue generation from which additional return to service costs would have been projected to be recovered.

Similarly, if a decision to close and decommission a plant were taken based on an inaccurate assessment of poor steam generator condition or inaccurate assessment of the nature of work required to assure fitness for continued service, then a major financial penalty may be incurred to the owners and other stakeholders as a plant is removed from service unnecessarily. Such situation has occurred in the early shutdown of Zion NPP in USA during the mid-1990s. Steam generators replacement costs have coupled with a period of low demand growth, existing excess generating capacity and low incoming revenues. Under such conditions it was decided that the replacement option was not a viable one and a decision made to shut the plant down. By the mid 2000s demand and revenue conditions changed and the average cost of electricity markedly increased. It is not clear at this point if the early decision can be reversed given the cost and difficulty of re-licensing a shut down plant.

Condition assessments which are inaccurate or insufficient, in either scope or extent, can result in project-critical additional unanticipated costs, whether the project is refurbishment for continued operation or lay-up, or preparatory decommissioning work subsequent to an early closure.

5.2. Costs associated with continued operation

5.2.1. Delay in plant closure date

While there may be some relief from the costs of accumulating funds for ultimate decommissioning of the NPP and for funding long term waste management, there can be expected to be additional costs. Items resulting in additional costs include interim management of radioactive wastes and spent fuel related to the refurbishment activities and to the period of subsequent extended operation. Refurbishment and component replacement work can be expected to generate additional radioactive wastes.

The costs for management of the additional volumes may be proportional to the originally intended volumes but they might also be higher or lower due to strategies related to volume discounts or volume penalties applied. Such non proportional costs might occur for example due to the change in volume being either well within the capacity of existing interim or long term waste management facilities, and hence per unit costs might be significantly lower. On the other hand, originally tightly managed facilities for interim or long term storage may mean that the additional waste cannot be accommodated in the same location and a new waste management site has now to be constructed to handle the additional volume. In such cases there may be a significant increase in unit costs.

5.2.2. Condition assessment and major equipment refurbishment

It is of critical importance to accurately assess the condition of plant structures, systems and components and to accurately assess the nature and extent of replacement or refurbishment work required to meet the projected service life over which costs are to be recovered.

It is noted that discovery of a significant unanticipated condition of a major structure, system or component after a project for continued operation has been initiated could result in a change in direction of the overall project even though proper planning could have accommodated that condition had it been understood before the project were initiated.

An example of such an extreme might be steam generator condition in a project primarily involving other major components. If a refurbishment project in preparation for continued operation were initiated based on an inaccurate judgment that steam generators would remain serviceable for a further twenty years, and part way through a refurbishment project this were determined to not be the case, then the resultant projected cost over-runs and return-to-service delays might result in cancellation of the entire refurbishment project and massive financial penalties for the owners. In such an extreme, factoring in steam generator replacement or refurbishment to the initial project scope, based on an accurate condition assessment might still have resulted in a viable project and a positive decision to continued operation of that NPP.

5.2.3. Improvements to meet modern or developed safety standards

To continue operation beyond the original design life and the current licensed operation, it may be necessary to carry out some modifications, or improvements to existing systems, in order to demonstrate compliance with revised safety standards. The costs of these modifications or improvements needs to be assessed, and included in the cost associated with a project to continue the operation of a plant.

It is also to be expected that a revision to the existing safety substantiation will be necessary for any operation beyond the existing approved license duration. The costs of developing this additional safety substantiation should also be included in the assessment.

5.3. Accuracy of costing and schedule for projected work

Once an accurate scope of work based on a comprehensive and accurate condition assessment has been developed, fundamental project management requirements become predominant either for the work necessary to support an early closure, or to justify and support continued operation. Accurate determination and subsequent management of the costs and schedule for implementing the required work scope become critical to success.

There is a potential for major cost over runs, major delay in project completion or even in extreme cases risks of abandonment of the project, if the project scope, costs and schedule are not managed appropriately. While this may appear to be a difficult challenge in cases where the project involves work that is novel, innovative and for which no precedents exist, it is a challenge that if not successful met can undermine agreements with stakeholders on project funding and acceptance of liabilities. Such liabilities are often accepted only in exchange for perceived future benefits related to the project.

5.3.1. Availability and cost of funding and other key resources

Some additional factors for consideration in management of the project after a decision is made include the availability and cost of funding and other key resources necessary for successful project implementation. These are particularly important when the project involves a work scope that is novel, innovative or for which little regional precedent exists. It is likely that project management needs assurance that funding will be available when required to pay for necessary labor and material resources which are delivered. The timing of funding availability and the cost of providing these funds become important items in success or potential for delay in project implementation. A further key component for project success or potential critical delay is the timing and availability of key components, material, services and labor resources to coincide with project needs.

Project management practices could be expected to account for such issues. However, there is potential on major projects of this nature for an extended time delay between the initial planning, scheduling and costing of the project and decisions or approvals to proceed. Implicit (or even explicit) conditions on the timing, costs and availability of funding, and of key components, materials and services or labor resource skills may become invalid before an approval to proceed is given.

These issues are further complicated by subsequent situations in which projects are temporarily stopped, deferred or decisions re-examined or reversed. Often, implicit assumptions on availability and timing of funding and resources are found to be invalid. Incomplete communication between all parties in relation to possible contract work to be put out to tender may be an inherent feature of a competitive market for such contracts in some regions. This is of particular concern when funding and any of the key components, materials, services or labor resources are scarce and or in high demand regionally for other important projects.

In the event of an early closure, a review should be undertaken of the available decommissioning funds and the basis on which the amount of the funds was assessed. Liabilities arising from an early closure can be funded from the decommissioning fund to the extent that they cover an issue for which decommissioning funds were set aside. Additional liabilities should only be funded from this source if there is determined to be a surplus in funds needed to cover other primary components of the decommissioning that will need to be undertaken. Such surpluses may arise if original estimates of funds needed were conservative and currently available technology and experience has demonstrated the work can be successfully undertaken at lower costs.

5.3.2. Overall costs and viability

The following questions need to be carefully considered before reaching conclusions on the overall costs and viability of a proposed project:

Availability of funding

- Has funding been set aside for the entire project and been made available to the project for payments as contracts are fulfilled or is financing based on commitments to provide funding?
- Are there any implicit or explicit conditions related to the actual provision of committed funding that might not be met to the satisfaction of those committing the funds?
- Are there any other perceived actual difficulties in providing committed funds?
- Is there sufficient funded contingency built into the project to allow for delays in the provision of committed funds or has borrowing been arranged to span any potential gaps in provision of committed funds?

Cost of funding

- Is the cost of funding, including any anticipated borrowing, firm and accounted for in overall management plans?

Availability of key resources

- Are sufficient workers with the necessary skills and training available for the projected project stages and time periods for which they are needed?
- Is reliance being placed on older more experienced workers who may reach retirement age and who may withdraw from the labor market if there are significant delays to the project?
- Are there other important or attractive projects or job prospects for key workers or skills that may attract key staff away from the project during its execution or in the event of any project delays? Are these jobs within the utility itself or are they external to the utility on a local or regional basis?
- Are there sufficient resources to provide the necessary training and skills to the workers undertaking the project at the time that such training and skills are needed?
- What is the level of assurance of availability of key material resources required for the project given competition from other needs or projects in the region?
- Are there any key services required that may not be available as and when required for the project in the event of actual or rumored delays in commitment to the project (e.g.: factory space for the production of replacement steam generators)?

5.4. Costs associated with significant changes in closure date

Sub-section 5.4 discusses some of the major areas, other than accountancy discounting, in which cost can change due to significant changes in plant closure date brought about by decisions on early closure or continued operation.

When determining costs related to work required following an early closure, there needs to be consideration given to the fact that there would in many cases be similar issues and costs that would need to be incurred in the event of a normal closure. These could be funded from established decommissioning funds. Costs specifically associated with early closure are those related to the timing of the closure, not due to the concept of closure, even for plants which can undertake continued operation. There are potentially quite a number of costs which are specific to the timing of the closure date, due to changes in the availability of key resources or services. Normal closure may have anticipated the availability of an extensive competitive market for preparatory work and for decommissioning work, yet an early closure may force activities to be undertaken in a market where no such competition is available, and experienced resources are scarce and unexpectedly expensive compared to previous plans.

5.4.1. Early closure of plants of an imported design

Additional issues may be particularly evident if the NPP is of an imported design and early closure takes the plant out of service significantly before similar plants are taken out of service in the country of origin. In such cases normal end-of-life and decommissioning plans might have reasonably anticipated the existence of standard end of life and decommissioning processes developed by the original supplier by the time the specific plant needed them. Without benefit of this experience, early closure may require the plant to now develop and implement such plans in isolation and by pioneering such activities, at much greater cost than had been previously anticipated.

5.4.2. Early closure prior to availability of national waste repository

Additional early closure costs may be incurred where normal closure plans had anticipated the availability of national or regional facilities for the long term management of radioactive wastes and of spent fuel. In some regions there have been significant delays in the establishment of a national strategy or national or regional repositories related to long term management of radioactive wastes and spent fuel. In some cases government policies at the time of initial construction and operation of the NPP had stated that a government would accept responsibility for long term spent fuel management. But several subsequent governments have reversed such policies, or delayed implementation of them, such that no facilities or national strategy exists at the time of an early closure. Unanticipated additional costs may thus be incurred to develop and construct interim radioactive waste storage facilities and additional interim spent fuel storage facilities to accommodate storage of decommissioned systems and components which had previously been assumed to be sent to a national repository.

5.4.3. Long term waste management and spent fuel management liabilities

If the costs associated with long term management of radioactive wastes (both operational wastes and waste from subsequent decommissioning) are (by national strategy) the responsibility of the owner of the NPP, then it is normal practice to set aside funds for this purpose from the revenue generated during the operational lifetime of the NPP. It is reasonable to expect that such funds would be set aside in a protected manner such that they would be available for the intended purpose no matter what other anticipatable economic conditions occurred for the owner of the plant. It is also reasonable to expect that adequate contingency is built into such funding arrangements that changes in operating duration and capacity factor which can be anticipated will not adversely affect the funding of such future needs. If, however, this normally anticipated lifetime is unexpectedly shortened by an early closure, then the remaining period for revenue generation may be insufficient to allow accumulation of such funding in addition to the recovery of normal operating costs. In such cases the owners or other responsible authorities or stakeholders will need to make alternative arrangements for the funding and future management of the operational wastes generated by the NPP, wastes generated during the subsequent decommissioning and for the long term management of its spent fuel. These issues are modeled in detail in the decommissioning sections of Part II of this publication.

5.4.4. Retiring debt from initial construction and subsequent improvements

The initial construction cost of a NPP is a major component of the overall lifetime costs and is significantly larger that the initial construction costs of a fossil fuel power plant (normally fuel costs form a much more significant component of the overall lifetime costs for a fossil fired power plant). Added to these initial construction costs would be the capital costs of any major improvements undertaken during the operating lifetime of the plant. These costs may be covered by a loan or bond issue from financial institutions of financial markets. Owners would normally make financial provision for the repayment of these loans or bonds as a portion of the anticipated revenue generated by the NPP over a significant portion of its operating lifetime. Such provisions would normally include contingencies for anticipatable changes in capacity factor and period of operation. See Part II of this publication for details.

However, in the event of an early closure of the NPP the income necessary to repay this debt would not be available. The remaining debt related to the initial construction and subsequent capital improvements to the NPP may thus become stranded and the owner may be unable to repay this stranded debt. Either the owner or other responsible stakeholders would need to make other arrangements to address this stranded debt. This debt would be in addition to any unfounded liabilities related to decommissioning of the NPP or the long term management of its radioactive waste and spent fuel.

5.4.5. Costs related to the decommissioning of the NPP

It is normal practice for NPP owners to be required to undertake planning for decommissioning well in advance of decommissioning, and to derive reasonable estimates for associated costs. Measures are then put in place to establish a decommissioning fund and to assign contributions to this fund from the revenue generated from operation of the NPP. These decommissioning plans are normally periodically updated with associated changes and adjustments to anticipated costs and to the accumulation of the necessary funds. Early closure removes the ability to generate revenue from which decommissioning fund contributions can be made. In addition an early closure can significantly alter the timing or even the nature of the decommissioning activities such that they no longer fall fully within the scope anticipated in the original decommissioning plans. The plant owners or other responsible stakeholders would need to make alternative arrangements for the adjustment of decommissioning plans and for contributions to the decommissioning fund following an early closure of the NPP.

5.4.6. Costs related to continued operation and delay in plant closure date

While there may be some relief from the costs of accumulating funds for ultimate decommissioning of the NPP and for funding long term waste management, there can be expected to be additional costs. Items resulting in additional costs include interim management of radioactive wastes and spent fuel related to the refurbishment activities and to the period of subsequent extended operation. Refurbishment and component replacement work can be expected to generate additional radioactive wastes.

The costs for management of the additional volumes may be proportional to the originally intended volumes but they might also be higher or lower due to strategies related to volume discounts or volume penalties applied. Such non proportional costs might occur for example due to the change in volume being either well within the capacity of existing interim or long term waste management facilities, and hence per unit costs might be significantly lower. On the other hand, originally tightly managed facilities for interim or long term storage may mean that the additional waste cannot be accommodated in the same location and a new waste management site has now to be constructed to handle the additional volume. In such cases there may be a significant increase in unit costs.

6. OPPORTUNITIES FOR REDUCTION OF COSTS AND LIABILITIES

Section 6 discusses some opportunities for reduction of costs and liabilities which may be useful to consider when reviewing options and which should again be reviewed once a decision on project direction has been finalized.

Several opportunities for the reduction of costs and liabilities following a decision on early closure or continued operation have been mentioned in earlier sections of this publication. These will be included again here for completeness.

6.1. Reduction of costs and liabilities related to early closures

6.1.1. Maximizing value of remaining electrical output

Depending on the nature of the requirement for early closure, opportunities may exist for maximizing the value of the remaining electrical output capability of the NPP. This depends to a considerable extent on whether the projected early closure date is fixed in calendar time or is related to remaining number of operational service hours at power, or amount of electricity generated.

If an upcoming early closure date is fixed in calendar time, then minimal opportunities exist to maximize the remaining value of the electrical output other than by careful management of planned outages and by optimizing plant state to minimize the risk of unanticipated plant outages. During planned outages, in particular any work which would be of benefit in the long term can be avoided.

Any unanticipated outage close to the final calendar date could result in an advancement of that closure date and avoidance of costs related to a late return to service. Such late term unanticipated outages may thus lead to a magnified loss of electrical output as there may be little overall benefit from a late term restart. There is thus some added benefit in reducing the risk of unanticipated outages close to the closure date.

For situations where the remaining operational life of the plant is related to operational hours at power, rather than relating to a fixed calendar date, then different opportunities exist to maximize the value of the electrical output. For example it may be advantageous to change the operational strategy from base load supply towards seasonal peak load supply. This would involve matching local market conditions by adjusting remaining operation to periods of high demand and high value or prices and avoiding operation in period of low seasonal prices. Such optimization will depend both on local electrical value or price fluctuations, availability of other generating plants in the region and the specific operational costs for the NPP during periods, close to end of life, in which it would not be operating due to low electrical demand. Considerations of the repayment of the remaining plant debt will also become important at this point. If the plant has to return a fixed amount of money derived from a smaller amount of generation, then the unit costs of generation might climb to new and potentially uncompetitive levels.

6.1.2. Re-optimizing maintenance and component replacement strategy

Opportunities exist towards the end of life of a NPP to re-optimize proactive and preventative maintenance programmes and component replacement programmes (including refueling strategy) to optimize for the remaining available plant lifetime instead of for continuous long term operation of the plant. Such re-optimization must be undertaken without compromising plant safety for the remaining operational period. IAEA have provided guidance for optimizing NPP maintenance programmes [32].

Examples of such a strategy would include avoidance of a late term refueling outage and instead operating for the remaining plant lifetime at a reduced overall plant output. This strategy would marginally reduce volume related spent fuel management costs in addition to saving the lost electrical output costs for the term of the refueling outage, provided of course no parallel necessary maintenance activities could have taken place in parallel with this refueling outage.

Other examples might be changes in component replacement strategies related to ensuring long term serviceability of structures, systems and components where long term serviceability is no longer a foreseen requirement. Normal operational maintenance practices may involve undertaking component replacements in an area because other maintenance work allows access to such an area at a specific time. Previous strategies might have involved changing components which are nevertheless fit for service for the remaining much shorter service interval now required of them.

6.1.3. Maximizing the value of used components

An early closure is likely to mean that many plant components will no longer see a service life of the length originally projected and thus at the end of their current duty they may have remaining value for sale as used parts in another application.

The value of these components may be significant but in most cases values realized at any subsequent sale will depend on an accurate and verifiable assessment of the current condition and serviceability of the component, and the availability to prospective buyers of maintenance records and design and operational documentation. In some cases the owner utility might choose to utilize the components made available in other nuclear plants of similar design it might own.

An understanding of the cost and benefits of any necessary maintenance and decontamination of such components prior to their availability for resale for use outside of a NPP may be necessary. This would need to be balanced against the costs of disposal of the components in accordance with local or regional radioactive or non-radioactive waste management practices.

6.1.4. Developing alternative career opportunities for plant workers

Permanent staff who support the operation of a NPP are usually full time, long term employees. Their career length expectations might exceed the remaining projected lifetime of a NPP subjected to an early closure decision.

In the event of an early closure announcement which is not promptly accompanied by an appropriate human resources management programme, there can be serious and costly consequences for the remaining operational lifetime of the NPP. Such costs range from the negative impact on safety culture of a poorly managed or poorly communicated change in operational strategy, and its career impacts for the workers, to uncontrolled and unanticipated loss of critical numbers of key workers leaving for career opportunities elsewhere while they are still needed to support remaining operation or preparations for decommissioning.

Costs for meeting the requirements of local labor laws, regulations and labor contracts may result in additional obligations and liabilities for the plant owners. These will need to be integrated with the plant safety culture and operational and post operational needs, in developing and promptly communicating an appropriate and acceptable human resources strategy to the workers.

Plant workers can be expected to suffer from significant increases in personal and family stress levels and perhaps overall community stress levels following an early closure announcement and such stress levels, whether apparent or not, will increase with the duration for which they remain undressed to the satisfaction of the individuals involved. Stress levels can manifest themselves in a number of ways most of which are likely to be detrimental to the efficient and safe operation of the plant for its remaining lifetime. An unmanaged human resources situation of this nature can lead to significant unanticipated costs for the plant owners.

Workers who manage such stress best are those who remove the cause of the stress and uncertainty in their future career paths by creating and taking early opportunities to leave for other employment. From the plant owner's perspective, those most likely to do this are potentially among the most necessary for continued safe and reliable operation or preparations for decommissioning. If this is not the case then other costly manifestations could result from deterioration of safety culture, absenteeism and significant negative impacts on inter work group relations at the plant, resulting in overall losses of effectiveness and efficiency and worsening of overall communications between workers and work groups.

The costs and liabilities associated with such issues can be minimized by the prompt implementation of a human resources management plan considered adequate and appropriate by the impacted workers. Such a plan is likely to involve the development with individual workers of satisfactory alternative career opportunities and compensating the workers for any delays to the implementation of such alternatives which would benefit the necessary remaining operations support for the NPP.

6.1.5. Developing alternative productive uses for former plant facilities

Developing alternative productive uses for all or parts of the former plant site, structures, systems and components might assist in minimizing overall costs and liabilities for many of the stakeholders involved in operation or support for a NPP. The IAEA is developing specific guidance on post decommissioning redevelopment of various types of nuclear facilities, including NPPs [33]. This guidance may be useful in both gaining acceptance of stakeholders for proposed courses of action, and in minimizing some components of decommissioning costs if projected decommissioning scenarios without considering redevelopment had envisaged returning the site to a “green field” state.

Where a very high value is attributed by stakeholders to redevelopment of the site such that it continues to support a workforce of similar size and skill requirements, then it would likely minimize the overall costs and liabilities for the owners to cooperate in a joint project with other local and regional stakeholders with this objective.

In many cases the value of used components is optimized if they can be adapted for alternative purposes in the same location. Alternative uses with the highest value are usually those closest to the original purpose of the plant as they require the least adaptation. It would thus be appropriate to first examine the feasibility of using the existing NPP site, facilities, support infrastructure and electrical transmission lines for a new electrical power plant. If this does not prove to be appropriate for the local and regional circumstances, then utilization of the site and facilities for other heavy or light industrial purposes may be the next most effective. In some cases with very high local land values, the additional costs of expeditious decommissioning, site clearance and release of the site for unrestricted use may be warranted.

6.2. Reduction of costs and liabilities related to continued operation

Most of the opportunities for the reduction of costs and liabilities related to extended operation are good business and project management practices for any large project.

For a project requiring plant component refurbishment prior to extended operation, costs can be minimized by understanding well in advance of the project start the full scope of work needed to be undertaken, so that the unanticipated scope additions are minimized. Once the full scope is known then costs related to loss of revenue can be minimized by selecting the optimum time for implementation of the work, taking into account future demand and availability of alternatives for supply.

Such timing would need to consider which other regional electrical generating plants were potentially undergoing long maintenance outages, which other plants were being withdrawn from service, and which new plants might be available for service. Timing of the availability of such other plants and their respective operational costs would affect the future value of the output of the plant undergoing refurbishment and it may be of value to the owners of the NPP to adjust the timing of the refurbishment work to optimize the value of their future electrical output to match the predicted regional market conditions.

Other cost factors relate to potential time variations in the cost of the supply of materials and major components for the project. For example if steam generators were to be replaced, then the cost of replacement steam generators may vary significantly depending on the delivery date for which they were needed. Maximum early flexibility in setting the date for the refurbishment work would in such cases allow such factors to be blended in to an overall project cost optimization. Another key factor to be accounted for in these considerations is the availability and cost of key labor resources and services. Here timing may again be key to the costs involved, particularly where any of the required key resources are scarce and in demand for several similar projects in the same timeframe. In extreme cases work may not be able to be undertaken with the required effectiveness and efficiency during certain timeframes due to key labor resources being contracted for other work. Included in such considerations are the required accommodations and services to support the workers undertaking the project. In some regions the variability of the project work force may be readily accommodated within the local economy with little adverse impact. In other cases special arrangements may be needed to supply the accommodation and other services for the project workers and their families, depending on the extent and timing of the work, numbers of workers involved and the ability of the local economy to support them at the required time.

Another important factor in minimizing costs and liabilities related to the project is adherence to announced project directions and timing. Costs can be optimized for major projects where timing and resourcing have been arranged in accordance with best management practices. Subsequent actual or perceived variances in commitment to the project and its schedule, particularly on behalf of the plant owners, can result in other stakeholders making perhaps unanticipated changes to their own commitment to the project, resulting in delays to or inabilities to complete certain segments of the project with the resources initially intended. Key resources may no longer be available when needed and the resultant impact on the overall project schedule may have severe overall cost implications. Worst case situations may occur when key systems, structures or components for the plant reach the end of their service life prior to the actual commencement of a delayed project. Under such circumstances the project may be subjected to an extended loss of revenue while unavailable for service prior to the commencement of the project and may lose the ability to optimize costs related to market conditions for its output, costs and availability of major replacement components, materials, services and labor resources.

A further opportunity for reduction of costs and liabilities relates to the management of operational wastes and spent fuel for the period of extended operation. How this can be best managed will depend on local and regional options and strategies. It may for example be practical to re use waste management structures from the initial period of operation by re-sorting, reclassifying or compacting early operational wastes based on improved technology and reduction in activity levels due to radioactive decay since the original contamination. In such cases it may not be necessary to construct additional interim waste management to the same extent as had been original practice. Depending on national strategies and available technologies, it may be possible to relocate some of the original spent fuel from early operation (for example to concrete canisters not necessarily immediately adjacent to the reactor), such that there is not a need to construct additional facilities for pool cooling of fuel from the extended period of operation.

7. OPPORTUNITIES FOR MEETING REMAINING COSTS AND LIABILITIES

Section 7 briefly reviews some of the available options for meeting remaining costs and liabilities once a project implementation direction has been decided.

7.1. Meeting costs and liabilities for early closures

Costs and liabilities related to early closure include the following components discussed in Sub-section 5.4:

- cost increases related to the non-availability, at the time of closure, of services and resources that were assumed would be available by the time of a normal closure (including costs related to implementation of the human resources management programme discussed in Sub-section 6.1.4).
- cost shortfalls related to insufficient duration of overall plant operation to allow planned accumulation of funding for capital debt retirement, decommissioning and long term management of radioactive wastes and of spent fuel.

Given that the revenues from electricity generation are no longer available following an early closure, alternative means of funding the additional costs mentioned above and funding shortfalls will need to be found. In all cases these costs will need to be transferred to stakeholders other than the business unit of the specific NPP which is being subjected to early closure.

Options for covering these additional costs or transferring the associated liabilities will be different for different regions or countries depending on their strategies for waste management, labor relations legislation and strategies for incentives, subsidies and compensation for compliance with national or regional policy decisions.

A mixture of strategies for the recovery of the additional costs and transfer of liabilities may be appropriate. In many regions there is a bias towards the transfer of costs to those perceived to benefit from an action such as an early plant closure. In such cases there will likely be case specific issues related to who is perceived to benefit from the early closure. If the closure is due to a change in regional energy policy, then it may be perceived that those most likely to benefit are those who would supply the electrical or other energy required to replace that from the NPP.

Such options include:

- Transfer of costs to electricity customers — by assigning rate surcharges to electricity prices.
- Assumption of waste management and spent fuel management costs by regional or national authorities.
- Assumption of decommissioning costs by regional or national authorities.

- Compensation payments provided by those perceiving a benefit from the early closure implementation.
- Fees or surcharges applied to organizations seeking approval to import energy or to construct replacement electricity generation facilities to provide replacement power for the plant being subjected to early closure.
- Special additional taxation on the profits of competitive energy suppliers who may benefit from market condition changes resulting from the reduced supply side competition subsequent to an early closure.

7.2. Meeting costs and liabilities for continued operation

While it may appear that the costs and liabilities of continued operation should be recoverable against future revenues generated by the extended operation period, there are cases this may not be a clear and obvious option due to regional energy policies and practices.

Past practice in many regions has been that electricity pricing has been controlled to less than free market values based on a regulated environment allowing margins over fundamental costs of generation. In such cases electricity prices may reflect historic construction costs and historic fuel costs rather than being appropriate to current costs. An extended operation project may involve significant new expenditures for refurbishment or safety upgrade work leading to a new debt line. There may therefore be a need to ensure that expected rate or price adjustments subsequent to the project will be allowed to ensure that the full costs of the project could indeed be recovered in the future market situation. This may be difficult if there are parallel proposals to change the future market from a regulated to an open market, especially if there are inadequate provisions to deal with any historic under-funded components of initial construction debt or provisions for decommissioning or waste management funds.

An additional complication is evident in circumstances where pollution mitigation costs are assigned to newer or refurbished generating facilities but not to older generating facilities. In these circumstances, overall costs are higher for new and refurbished units competing in the electrical market, whether this represents a free or regulated market situation. It may be necessary to adjust regional energy policies to more evenly assign liabilities for mitigating environmental impacts of generating facilities of all types in order to ensure that new or refurbished units can compete on an even basis without skewing market conditions to favor the construction of low capital cost facilities for which current fuel prices are temporarily low. Such measures may include the implementation of a variety of pollution control requirements applied equally to all generating facilities, including the imposition of penalties related to CO_2 emissions for all fossil fuelled generating facilities. In order to implement such measures it may be necessary to adjust energy and environmental regulation frameworks so that all sectors are governed by similar rules and requirements.

Part II

ECONOMIC MODELING AND IMPLICATIONS OF THE DECISION ON EARLY CLOSURE VERSUS CONTINUED OPERATION

8. GENERAL

Part II includes an economic modeling the decision on continued operation (beyond original design plant life) of a power plant versus early plant closure. The economic modeling principles described in detail below are equally applicable to all types of large utility power plants including NPPs, fossil-fired plants or renewable plants. It is only in the choice of the detailed components of each equation and the relative magnitude of the cost components that one can indicate to what type of plant is the economic analysis applied. We have chosen here, per the topic of this publication, to apply the generalized analytic approach to a NPP continued operation or early closure decision. However the general part of the analysis and the top level equations equally apply to all types of power plants. In the discussion below we indicate where we depart from the general model and apply it specifically to NPP issues. Part I of this publication addresses many of the important though less quantifiable issues relevant to the decision on early closure vs. continued operation decision such as plant staff morale deterioration, disruption of social services to the local community, etc. Part II of this publication addresses the basic economic decision making process which is based on straight plant economics. It may be possible to incorporate some of the topics reviewed in Part I in the economic modeling discussion of Part II. If such straightforward inclusion is not feasible, then utility decision makers are urged to find the most appropriate way, given their particular circumstances, to incorporate topics similar to those addressed in Part I in their economic analysis, which employs analytic approach similar to Part II. Only by responding to issues similar to those addressed in Part I and in Part II of this publication can a utility assemble a comprehensive decision making analytic package that can be presented to top management and to external reviewers. The results of the analysis based on the economic model of Part II could be used as one input to a multi-attribute utility analysis as discussed in Section 3 of Part I of this publication.

The economic analysis presented below is based on deriving the equations for the discounted cumulative net cash flow during the original design plant life span, including the construction and operation periods, and the post-shutdown decommissioning period. The equations derived for the original design plant life are then modified to cover the continued operation or the early closure options. In each case we comment on how the analytical approach would be modified if the plant was operated by a non-regulated or restructured versus regulated utility. We use the terms non-regulated and restructured utility here interchangeably. We do realize that there are many types of electric utility restructuring which results in various degrees of 'non-regulated' utility operations. Discussion of these issues is beyond the scope of this publication. We simply indicate that some utilities are still regulated by the current regulatory system, and some have shifted to a restructured operating mode which is less regulatory-prescriptive. We further discuss costs attributed directly to the plant, and costs born by the owner utility, in all of the cases reviewed here. We apply this methodology to a NPP as becomes evident in the choice of the detailed components of the top-level equations. A choice of slightly different components would be appropriate as we apply the methodology to other plant types.

The analytical approach below is conducted on a constant currency basis with no inflationary impacts. All cost computations are discounted to the start of commercial operation of the power plant, which is defined here as the zero time point of the computations. The equations derived here are based on a year-by-year recursive computation of the remaining plant investment to be depreciated, and on the computation of the annual and discounted cumulative net cash flows during the plant lifetime, and post-shutdown decommissioning period. Taxes paid on net taxable income are not considered here as their inclusion will make the various equations that much more cumbersome. The extra rigor introduced by the inclusion of tax considerations, and the resulting more complicated equations might detract from understanding the basic logic of the analysis.

9. BASIC EQUATIONS

The basic equation used throughout the computations is that of the plant's net annual cash flow.

$$NCF(t) = REV(t) – OM(t) – FL(t) - DD(t) – RET_{Debt}(t) – RET_{Eq}(t) \quad (1)$$

Where

$NCF(t)$ – Net annual cash flow in year t, [M$/year]

$REV(t)$ – Annual revenues obtained from sale of electricity in year t, [M$/year]

$OM(t)$ – Annual operations and maintenance (O&M) expenditures in year t, excluding capital additions [M$/year]

$FL(t)$ – Annual fuel costs including waste management charge in year t, [M$/year]

$DD(t)$ – Decommissioning fund outlay in year t, [M$/year]

$RET_{Debt}(t)$ – Annual payments for the return of and on the remaining plant debt in year t, [M$/year]

$RET_{Eq}(t)$ – Annual payments for the return of and on the remaining equity in the plant in year t, [M$/year]

Equation (1) denotes that the plant's net annual cash flow in year t is equal to the revenues coming in from the sale of electricity to the grid minus all the costs incurred during plant operations, and minus expenses paid to provide a return on and of the remaining plant investment.

All costs incurred in year t are discounted to the start of commercial operation of the power plant using the discount rate, or the average cost of money r [%/year], based of the following standard equation

$$r = d \times i_d + (1-d) \times i_e \quad (2)$$

Where

r – Annual discount rate or the average cost of money (assumed here to be the same) [%/year]

i_d – interest rate on plant debt [%/year]

i_e – Return on equity invested in the plant [%/year]

d – Debt fraction of total plant investment

1-d – Equity fraction of total plant investment

We assume that all investments made in the plant include combinations of debt and equity only. We further assume that the debt/equity investments ratios are kept constant throughout the entire plant life span and equally apply to both the initial investment and all annual capital additions expenditures treated as investments.

It is now possible to derive the basic equation for the discounted cumulative net cash flow in the year t during the plant operations period, as

$$CUMCF(t) = - I(t=0) + \sum_{k=1}^{t} \{NCF(k) \times (1+r)^{-K}\} \tag{3}$$

Where

CUMCF(t) – Discounted cumulative net cash flow by year t, [M$]

I(t) – Remaining un-depreciated investment, yet to be recovered by the year t, [M$]

k – Running index from first plant operation year to the year t

By definition, CUMCF(t = 0) = - I(t = 0), implying that the initial value of the discounted cumulative net cash flow at the beginning of plant operations period is the transition discounted cumulative cash flow from the end of the previous construction period representing a negative-value accumulated construction investment of – I(t = 0).

– I(t = 0) represents the un-depreciated investment in the plant at the commercial operation start point – sum cumulative of all plant investments during the construction period, including base construction cost, contingency, owners costs and accumulated interest during construction (IDC). At the end of the construction period the net cash flow is negative, since only construction related e×penditures have occurred, with no offsetting revenues received. Hence the minus sign in front of the I(t=0) term. This negative cash flow is being offset during the operations period by the accumulation of discounted annual net cash flows from the start point of commercial operation until the year t. Not all annual cash flows might turn out positive, and some might add to the large negative cash flow overhang accumulated during the construction period. Yet, year-by-year, assuming mostly positive net annual cash flows, the large initial negative cash overhang is being reduced, and in most cases, after fifteen to twenty five years depending on the specific plant cost data, the cumulative cash flow turns positive and the plant provides increasing larger net positive cash flows (profits). The issue of extended operation versus early shutdown relates to the question of has the discounted cumulative net cash flow at the decision point turned positive or not. This issue is covered in more detail later.

It is now possible to introduce the recursive element into the basic equations, as it relates to the net remaining un-depreciated plant investment

$$I(t) = I(t-1) \times \{1 - (N-t+1)^{-1}\} + CAPADD(t) \tag{4}$$

Where

I(t-1) – Remaining un-depreciated plant investment in year (t-1) [M$]

CAPADD(t) –Annual capital additions to the plant treated as investment [M$/year]

N – Nominal expected plant lifetime (original design plant life) [years]

Equation (4) denotes the change in remaining un-depreciated plant investment between the year (t-1) and the year t. A portion of the existing investment at the end of the (t-1) period is depreciated, assuming a straight-line depreciation procedure. The remaining lifetime over which the investment I(t-1) can be straight-line depreciated is N – (t-1) or N – t + 1 [Years] . The portion of the investment I(t-1) depreciated during year t is then $I(t-1) \times (N - t + 1)^{-1}$. Thus the remaining un-depreciated investment carried over from period (t-1) to the end of period t, is then $\{I(t-1) - I(t-1) \times (N - t + 1)^{-1}\}$, which upon rearrangement, yields the first term on the right hand side of equation (4).

The complete equation (4) indicates that two plant investment-related processes happen in year t:

1. A portion of the remaining investment from the previous period is straight-line-depreciated, and
2. A new annual capital addition, if it has occurred and if it has been recognized by the regulatory agencies as an investment increment, is capitalized and added to the books, rather than being treated as an O&M cost item and expensed in the year it occurs.

Thus the remaining investment at the end of period t, is the remaining investment from the previous period after deducting depreciation during period t, plus the capital additions investment increment which might have incurred during the year t. This process is depicted graphically in Figure 3. We should mention here that in some years during the plant operations period no capital additions might have occurred, or those that have occurred might be relatively small and are directly expensed rather than capitalized. Capital additions that qualify as investments in a NPP case could include large projects that can not be expensed in one year, such as the construction of a dry cask spent fuel storage facility on site, the construction (and equipment) of a new computer building, a new training center and simulator addition, steam generator replacement, plant primary pumps replacements and up-rates programmes, up-rating the turbine generator for higher plant output, core shroud replacement in a BWR, or CANDU reactor re-tubing. In all cases the decision on whether to treat capital addition expenditure as an investment or as an annual O&M expense will depend on the tax treatment for either option afforded by the regulatory agencies in that year. Annual capital additions not treated as investments will be considered here as a part of the fixed O&M annual expenditure in that year, as discussed later.

Equation (4) can be rearranged to yield

$$I(t) = I(t-1) \times \{(N-t) / (N-t+1)\} + CAPADD(t) \qquad (5)$$

Equation (5) is the basic recursive equation of this analysis, and it is graphically presented in Figure 3. As indicated above this treatment equally applies to all types of power plants.

It is now possible to simplify equation (1) based on elements of the above discussion, by re-defining the last two components of that equation. Thus

$$RET_{Debt}(t) = I(t-1) \times d \times (N - t + 1)^{-1} + I(t-1) \times d \times i_d$$

$$RET_{Eq}(t) = I(t-1) \times (1-d) \times (N - t + 1)^{-1} + I(t-1) \times (1-d) \times i_e$$

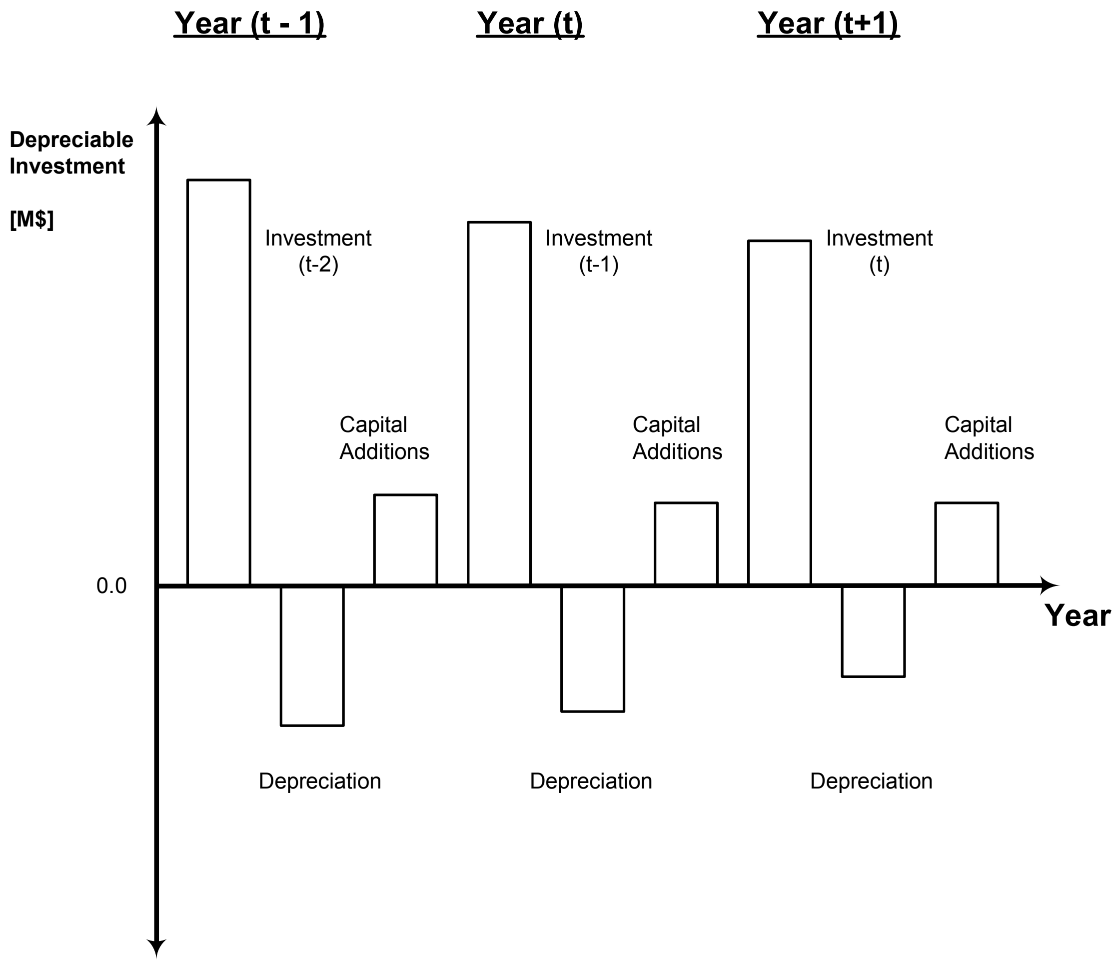

*Fig. 3 Annual change in plant depreciable investment**

* Axes and bars not drawn to scale

The annual return in the year t on and of the debt fraction of the total investment, and the annual return on and of the equity fraction can each be expressed in a two terms equation. The first term represents the amount straight-line-depreciated in the year t, as discussed above, i.e. the return of the investment expended on the plant. The second term represents the annual interest payment on the plant debt and the return on plant investment (ROI) during the year t on the yet un-depreciated plant investment. The second term thus represents the overall return on the investment in the plant, including both its debt and equity fractions. The above two equations can be re-arranged as follows:

$$RET_{Debt}\,(t) = I(t\text{-}1) \times \{d \times (N - t + 1)\ \text{-}1 + d \times i_d\}$$

$$RET_{Eq}\,(t) = I(t\text{-}1) \times \{(1\text{-}d) \times (N - t + 1)\ \text{-}1 + (1\text{-}d) \times i_e\}$$

Combining the above two equations and rearranging we get

$$RET_{Debt}(t) + RET_{Eq}(t) = I(t\text{-}1) \times (N - t + 1)^{-1} \times \{d + (1\text{-}d)\} + I(t\text{-}1) \times \{\, d \times i_d + (1\text{-}d) \times i_e\} \quad (6)$$

The bracket in the second term on the right hand side of the above equation is however the average cost of money r, as defined in Equation (2). Thus upon further rearrangement, we get

$$RET_{Debt}\,(t) + RET_{Eq}\,(t) = I(t\text{-}1) \times \{(N - t + 1)^{-1} + r\} \quad (7)$$

And substituting back into Equation (1) we get

$$NCF(t) = REV(t) - OM(t) - FL(t) - DD(t) - I(t-1) \times \{(N - t + 1)^{-1} + r\} \quad (8)$$

Equations (8), (3), and (5), are the basic equations of the recursive process, used throughout this analysis. A graphic representation of equation (8) is shown in Figure 4.

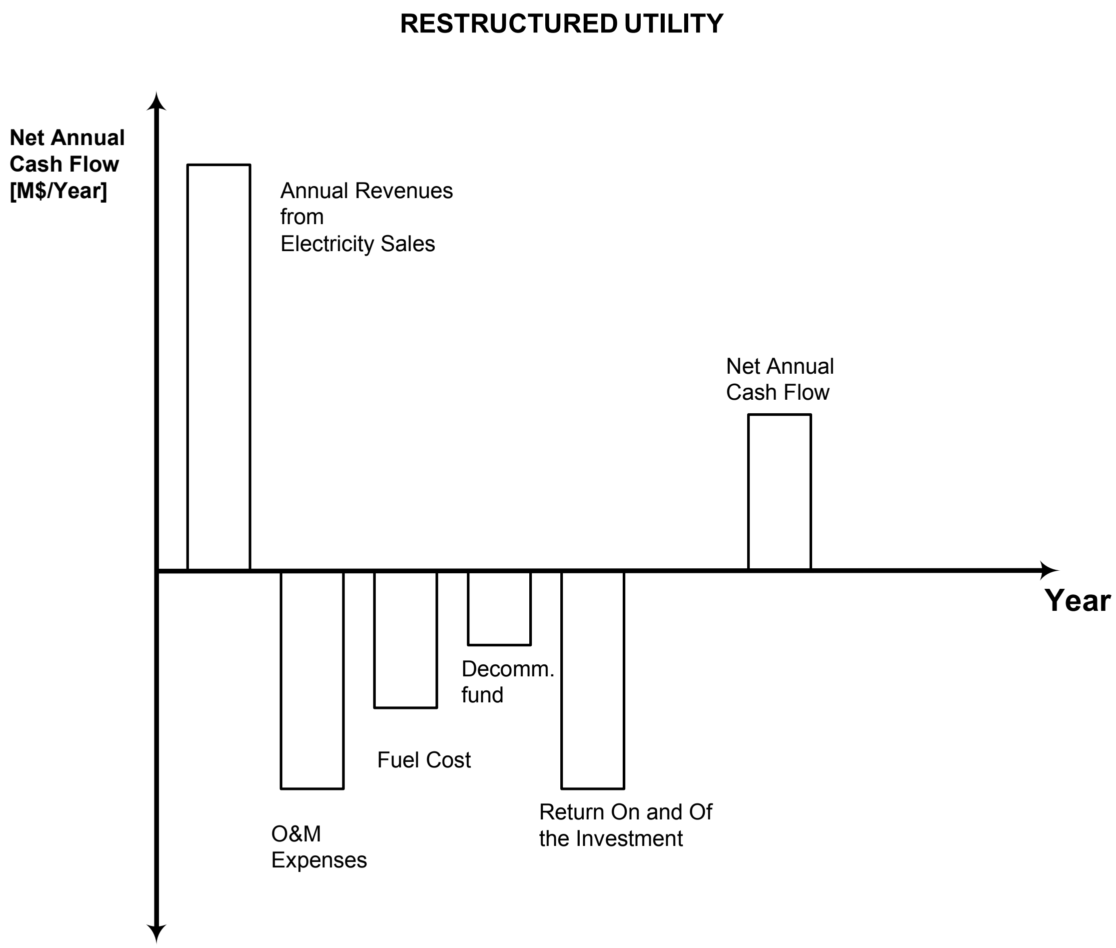

*Fig. 4 Components of plant net annual cash flow**

- Axes and bars not drawn to scale

10. EQUATIONS FOR ORIGINAL DESIGN PLANT LIFE OPERATION

It is now possible to provide a more detailed set of cost equations related to the original design plant life span case, covering the three periods of the plant life considered in this economic modeling, and based on the above discussion. All the cash flow equations derived above and elaborated upon later relate to a restructured or 'non-regulated' utility, whose power plants sell electricity into the electric power grid. Each plant of such restructured utility acts as both a profit and a cost center. We will deal with the case of the regulated utility in section 11 below. Three distinct periods within the plant life span are considered here: the construction period, the operations period and the decommissioning period. The computational process developed here involves three separate summations one for each of these three periods, using period specific time indices. In all three summations discounting is performed to the zero point of the entire computational process which is the start of the plant's commercial operation. Boundary conditions for the transition from one period to the other are specified.

10.1. Construction period

During the construction period no revenues are available and only construction related expenditures, electric utilities' owner's discretionary costs, and interest costs on monies borrowed to finance construction, accrue. Here we compute the costs accrued and accumulated during the construction period using a (negative) time index, starting from our zero time point which is the point of commercial operations start, t = 0, and proceeding in a negative direction for a time period of N_{Con} (i.e. till $-N_{Con}$), which represents the total duration of the construction period. We employing a negative time scale j = -1, -2, -3, ……..,$-N_{Con}$, such that (j = 0) = (t = 0), and while during the operations period t proceeds in the positive direction, during the construction period j proceeds in the negative direction, away from the zero point which is the commercial operation start. The basic cost accrual equation during the construction period is then

$$NCF_{Con}(j) = \{S(j) \times BCC + S_{own}(j) \times OWNC\} \times (1 + Cont) \times (1 + i_{IIDC})^{-j-1} \quad (9)$$

Where

$NCF_{Con}(j)$ – Net annual cash flow by year j during the construction period [M$/year]

BCC– Plant total base construction costs during the construction period [M$]

OWNC – Plant total owners costs during the construction period [M$}

S(j) – Fraction of total base construction cost expended during year j [1/year]

$S_{own}(j)$ – Fraction of total owners cost expended during year j [1/year]

Cont – Contingency allowance fraction

i_{IIDC} – Interest during construction fraction [%/year]

N_{Con} – construction period [years]

We chose to separate out in equation (9) the total base construction cost BCC over the entire construction period, from the total utility owner's discretionary cost OWNC during construction. We provided this explicit separation since:

1. Each of these two cost categories is accounted for in different places. BCC is related to plant expenses. OWNC is related to utility owner's expenses. Since later in the discussion, particularly when discussing utility versus plant-specific cost issues this distinction is important, we thought it preferable to allow this separate accounting option even during the construction period.
2. BCC and OWNC are annually distributed differently during the construction period; whereas BCC is annually distributed in a (skewed) bell shape curve (skewed normal distribution), OWNC is annually distributed in a logistic curve form (S-Curve) heavily skewed towards the end of construction. It is for this reason that we have two separate annual distribution patterns for the base construction cost – S(j) and for the owner's

cost — S_{own} (j). We assume here that contingency expenses, expressed as a fraction, apply equally to the base construction cost (BCC) and to the owner's cost (OWNC).

We further assume that interest during construction (IDC), expressed as a fraction, equally apply to each annual portion of the BCC and the OWNC, and is accumulated from that year to the end of the construction period. Note that in the negative time index used here the end of construction occurs when j = 0 whereas construction start occurs at j = $-N_{Con}$. Thus for each annual BCC and OWNC cost increment during the year j, IDC accumulates from that year towards the end of construction j = 0. Thus we are by this representation accumulating costs from the end of construction to construction start. This is dictated by the choice of the start of operations period as the zero point in this analysis. Interest during construction represents interest payment on a non-performing asset, and thus could be regarded as a more risky interest rate than the average cost of money - r, as defined in Equation (1).

The discounted cumulative cash flow during construction accumulated from j = 0 (construction completion) till j = $-N_{Con}$ (Construction start) is expressed as

$$CUMCF_{Con}(j) = \sum_{j=-1}^{-j} NCF_{Con}(j) \times (1 + r)^{-j-1} \quad (10)$$

Where

$CUMCF_{Con}(j)$ – Discounted cumulative net cash flow year j during construction period [M$]

Note that due to the choice of the time axis and the zero time point we are integrating backwards from construction completion to project start. Note also that with the index j having negative values, the discounting factor $(1 + r)^{-j-1}$ actually assumes positive values, indicating that expenditures before the zero time point have higher value determined by the discount rate.

Since during the construction period all costs represent negative cash flows from the plant's perspective, we can now define the discounted sum total of construction related expenditures at the end of the construction period, or the beginning of the operations period (year t =0), that need to be recovered as

$$I(0) = \{CUMFC_{Con}(j = -N_{Con}) + \text{First Core Cost}\} \text{ and } CUMCF(t = 0) = - I(0) \quad (11)$$

The two parts of equation (11) represent the boundary conditions between the construction period and the operations period. This equation implies that at the end of the construction period we are left with a large, negative, investment-related cash flow, discounted back to the zero time point. This discounted negative cash flow at t = 0 should be recovered from revenues obtain from sale of electricity generated by the plant during its operations period. The recovery process starts at the beginning of commercial operations, when all (negative) cash flows incurred during construction are consolidated and converted into a new operations investment. This investment is financed by a utility mix of debt and equity (Debt fraction d, equity fraction (1 – d)), recovered at an average cost of money r, as specified in equation (2) above.

Until this point the discussion has not been plant specific. Equation (11) introduces a nuclear-specific issue by referring to first core cost (or the cost of the initial reactor nuclear fuel inventory). First core costs include the cost of purchasing the first nuclear fuel core loaded into the reactor before startup. Some utilities may choose to purchase the first core plus few annual reloads in one package. First core costs could be accounted for in the utility owner's cost, could be accounted for as a separate line item, or could be spread over the lifetime levelized nuclear fuel cycle cost. We include this cost item explicitly here for completion. Note that on-line refueling reactors such as CANDU or RBMK NPPs require smaller inventories of fresh fuel assemblies or elements to be kept on hand, as more fresh fuel could be obtained at each operations year. In a CANDU type NPPs we have to consider the reactor's initial inventory of heavy water which usually is included in the owner's cost component. In a coal-fired power plant the analogy to the first core cost would be the cost of the initial coal pile. Likewise in the cases of gas-fired plants the analogue term would be the cost of the initial gas supply to the plant.

10.2. Operations period

The cost equations applicable during the operations period are similar to the basic cost equations derived in section 9 above, except that we need to be more explicit about the definition of each cost component. To recapitulate, the basic annual net cash flow equation is:

$$NCF(t) = REV(t) - OM(t) - FL(t) - DD(t) - I(t-1) \times \{(N - t + 1)^{-1} + r\} \qquad (12)$$

This is similar to equation (8) and to its graphic representation in Figure 4 above, with the specific cost item defined following equation (1). The remaining investment in year t during the operations period to be recovered and to provide a return on is defined as

$$I(t) = I(t-1) \times \{(N-t) / (N-t+1)\} + CAPADD(t) \qquad (13)$$

This is identical to equation (5) above, and cost item definitions as given following Equation (4). The representation of equation (5) is shown in Figure 3. Note that in equation (13) when we set t = 1 we get I (0) which represents the discounted cumulative NPP Investment carried over from the end of the construction period to the start of the operations period. The numerical value of I(0) is given by the first (left) part of equation (11).

Finally, the discounted cumulative net cash flow, which accounts for all the negative cash flow incurred during the construction period (discounted), and the repayment of that negative cash flow overhang by year t from incoming revenues (minus operations costs), is given by the following:

$$CUMCF(t) = CUMCF(t = 0) + \sum_{k=1}^{t}\{NCF(k) \times (1+r)^{-K} = - I(t=0) + \sum_{k=1}^{t}\{NCF(k) \times (1+r)-K\} \qquad (14)$$

This is similar to equation (3) above, with definitions following discussions related to equations (3) and equation (11) above.

Having defined the basic equations governing plant economics during its nominal operations period, we will now provide more explicit definitions for the various terms in the above equations. The more detailed equations eventually introduce NPP-specific elements into the hitherto generalized discussion, as seen below. The incoming revenues in equation (12) can be defined as

$$REV(t) = ELCPRC(t) \times CAP \times 8.76 \times 10^{-3} \times CF(t) \qquad (15)$$

Where

REV(t) – Annual incoming revenues obtained from sale of electricity in year t, [M$/year]

ELECPR(t) – Unit electricity sales price in year t, [$/MWh]

CAP – Plant Capacity [MWe]

CF(t) – NPP Annual capacity factor in year t, [%]

This revenue stream is the only source from which the operating costs can be repaid, and the negative investment overhang can be depreciated. Annual schedules of expected electricity prices and plant capacity factors should be provided in order to compute the value of the incoming revenue stream by year t. In general, over the operations lifetime of the plant's unit electricity prices are expected to increase with the general rise of the Producers' Price Index above inflation. Plant capacity factors are expected to rise above early-in-life low values, achieve a high plateau value and maintain it throughout most of the operations life, and possibly decline a bit prior to the scheduled end of life.

The plant's annual O&M expenditures could be defined as

$$OM(t) = NSTAF(t) \times SALAV(t) \times 10^{-3} + FOM(t) \times CAP \times 10^{-3} + VOM(t) \times CAP \times 8.76 \times 10^{-3} \times CF(t) \quad (16)$$

Where

OM(t) – Annual O&M expenditures in year t, excluding capitalized capital addition costs [M$/year]

NSTAF(t) – Number of plant staff in year t, [persons]

SALAV(t) – Average loaded salary for the mix of plant employees defined by NSTAF(t), in year t, [K$/year]

FOM(t) – Annual fixed O&M costs in year t, excluding personnel costs, and including small capital addition costs and interim replacement costs which are expensed in the year they accrue [$/KWe –year]

VOM(t) – Annual variable O&M costs in year t, [$/MWh]

In this analysis we break the total annual O&M costs into four components: personnel salaries and benefits costs, fixed O&M costs excluding salaries and including expensed capital additions, variable O&M costs which include mostly plant consumables determined by the plant's power generation rate, and large capitalized capital addition costs CAPADD(t), discussed in section 9 above. We find it useful to break out personnel costs separately, since both the staffs mix and the average salaries will change during the transition from the operations to the decommissioning phases. Thus, an explicit schedule of plant staffing mix and the average salary levels of those mixes are useful ways of capturing changes in this important O&M cost category which, specifically in the NPP case, contributes 50 – 70 percent of overall annual O&M expenses. We further break out the remaining fixed O&M costs from the variable operations costs, again, bearing in mind that variable O&M costs disappear during the plant decommissioning phase. In the nuclear-specific case, with NPP O&M costs comprising about two thirds of all annual operations costs, this is an important cost category, and the more we can break it into time-related or fixed components, data permitting, the better we can describe it during the analysis.

In likewise fashion we can define annual fuel costs, specific to a NPP, as

$$FL(t) = FFL(t) \times CAP \times 10^{-3} + \{VFL(t) + WMC(t)\} \times CAP \times 8.76 \times 10^{-3} \times CF(t) \quad (17)$$

Where

FL(t) – Annual fuel costs including waste management charge in year t, [M$/year]

FFL(t) – Fixed portion of fuel cycle costs in year t, including first core costs payable in year t (if any), or inventory charges on fresh fuel supplies held in storage for more than a year in year t, [M$/year]

VFL(t) – Variable portion of annual fuel cycle cost in year t, representing mostly costs incurred in the front end of the fuel cycle [M$/year]

WMC(t) – Annual payment towards the ultimate spent fuel disposal by the appropriate agency during the NPP Shutdown phase [M$/year]

In general, the annual costs of storing spent fuel in the pool at the NPP fuel storage building are accounted by the FOM(t) cost defined above. Construction of an on-site spent fuel dry cask storage facility is accounted for as a CAPADD(t) cost item. The annual spent fuel control and monitoring expenses during the post shutdown phase could be included in the $FOM_{DD}(t)$ term during the decommissioning period as discussed in Sub-section 10.3. The WMC(t) term represents the annual cost in paid year t of the operations period, for the ultimate disposal of the NPP's spent fuel, during the post shutdown phase. We included here a time dependency in the waste management charge WMC(t), to account for the possibility that this annual charge might be changed, sometime during the NPP operations period.

The FFL(t) term – the NPP fixed fuel cost component is relatively small and is included here for completion only. Typical cost numbers are 3–5 [$/MWh] for VFL(t), 1 [$/MWh] for WMC(t), and a fraction of [$/MWh] for FFL(t). This breakdown would be different for other power plant types.

We can now define the last term in equation (12), not yet discussed – the decommissioning cost. Decommissioning cost and the significant attention paid to their estimation and collection are unique features of a nuclear plant operation. While fossil-fired plants now start incorporating some (yet small value) decommissioning cost items in their cost evaluations, the discussions here, and its later implications, are NPP-specific.

$$DD(t) = C_{DD} \times SFF_{DD} = C_{DD} \times \{i_{DD} \times [(1 + i_{DD})^{N} - 1]^{-1}\} \quad (18)$$

Where

DD(t) – Annual decommissioning fund outlay in Year t, [M$/year]

C_{DD} – Final value of the decommissioning fund at the end the operations phase, expressed in today's constant currency value [M$]

SFF_{DD} – Sinking fund factor – the fraction of the final decommissioning fund value that needs to be set aside annually and deposited into an interest bearing fund that will accumulate to the desired value after N years [1/year]

i_{DD} – The interest rate on the sinking fund accumulating annual decommissioning outlays [%/year]

Thus, if we would like to accumulate 400 [M$] in constant dollars of today at the end of the NPP nominal operations period of 30 years, and we deposit annual decommissioning outlays into a sinking fund invested in Government bonds bearing 4 [%/year] interest, the sinking fund factor computed for that outlay will be 0.04/ (1.04^{30} -1) or 0.0178 [1/year], and the annual decommissioning outlay will be 7.13 [M$/year].

Getting back to the more generalized plant economics discussion we must first define end of operations period cost factors, before discussing issues related to the decommissioning period. Two important changes occur at the point of end of the original design plant life. Firstly, all initial investments in the plant have been completely depreciated, since depreciation payments were set to be completed during an operations period of N years. Most of the capitalized annual capital additions costs have also been depreciated in like manner save for the last one.

Thus

$$I(t = N) = CAPADD(t = N) \quad (19)$$

We have assumed for simplicity sake that the book life period over which depreciation occurs is identical to the nominal plant operations period. If we assume shorter book life than operations life, then the modified investment recovery equations will become more complicated having to address two different time intervals, however the principle embodied in equations (13) and (19) would still be valid and equation (19) would remain unchanged. Assuming that the initial investment overhang except for equation (19) above has been depreciated, this implies that the investment related recursive process that has driven the net cash flow equations during the operations period is no longer necessary during the decommissioning period.

The second change occurring at the end of the plant operations period is that the decommissioning fund has been fully accumulated, and it becomes available to the plant to pay for decommissioning period expenses. Thus CDD is added to the cumulative discounted net cash flow at the end of life, and these two sources of funds are available to pay all decommissioning period costs. Once we get into a discussion of a large decommissioning fund and its disposition, we do however imply that we address a NPP-specific situation. Thus Sub-section 10.3 below represents a nuclear-specific section.

10.3. Decommissioning period

The equations derived above for the operating period, which were general in nature until we got into the components breakdown of the fuel and decommissioning costs, need now be further modified to account for changes occurring during the decommissioning period. We continue here, as before, our basic practice of discounting all future expenses to the plant initial commercial operations date, thus keeping in mind that we now address a NPP specific case. It is convenient at this point to define new running time indices. The complete decommissioning period over which all activities occur, and at the end of which the former NPP site is released to new industrial or general use is NDD years, starting at the plant shutdown date. We thus have $k = 0, 1, 2, 3, \ldots\ldots, N_{DD}$, and

$$j = N + k = N + 1, N + 2, N + 3, \ldots\ldots, N + N_{DD}$$

as our running time indices during the decommissioning period. The time index j is the extension of the time index t, employed during the operations period.

To be consistent with our decision to employ separate summation over each time period we will use the decommissioning period time specific index k though it is possible to use the joint operations-decommissioning time index j. The value of keeping separate summation for each phase of the plant's life span will become apparent during the discussion on extended life operation in section 12.

Based on the end of discussion in the previous Section, we can now define

$$CUMCF_{DD}\ (k = 0) = CUMCF(t = N) + C_{DD} \times (1 + r)^{-N} - CAPADD(t = N) \times (1 + r)^{-N} \qquad (20)$$

Where

CUMCFDD(k = 0) – The discounted cumulative net cash flow at the beginning of the decommissioning period [M$]

Equation (20) and Equation (19) above represent the boundary conditions for the transition from the operations period to the decommissioning period. Equation (20) implies that the net total cash flow available to fund decommissioning activities is the sum of the net cumulative cash flow generated by the end of the operations period, as computed by equation (14) above, and the decommissioning fund CDD released at that point to the NPP, minus the capital additions costs incurred during the last operations year – all discounted to the zero time point. The value of $CUMCF_{DD}(k = 0)$ represents the largest value of the discounted cumulative net cash flow over the entire life span of the plant (in this case the NPP), and is the initial cash flow value at the start of the decommissioning period. From now on there will be no more in-flows of annual incoming revenues, as discussed below, and the NPP will only experience annual cash outflows to pay for decommissioning expenses.

The necessary financial condition for initiating the decommissioning process is that the total net cash flow available at the start of this phase is equal to or exceeds the expected cost of the decommissioning operations. In more exact definition,

$$CUMCF_{DD}(k = 0) \geq \{\text{Expected discounted cumulative decommissioning cost}\}.$$

To anticipate the discussion that follows we can state that $CUMCF_{DD}(k = 0)$ should be equal to, or exceed, the summation term in the right hand side of Equation (25) below, when carried out from $k = 1$ to $k = N_{DD}$.

Since during the decommissioning period the NPP does not generate electricity any more, no revenues from the sale of electricity are available during this period. Thus

$$REV_{DD}(k) = 0 \qquad (21)$$

For all k values from $K = 1$ to $k = N_{DD}$, which correspond to j values from $j = N + 1$ to $j = N + N_{DD}$

It is possible that some revenues could be obtained during the decommissioning period from the salvage value of some equipment or commodities left over from the operations period. Additional credits might apply from the use of balance of plant equipment or facilities with a replacement power plant or other industrial facility installed on site, or transferred to other plants operated by the owner utility. Given the uncertain nature of these possible revenue sources (if they materialize), we prefer to treat them here as negative capital addition costs in the year they accrue, rather than treating them explicitly as distinct revenue items.

Capital addition costs $CAPADD_{DD}(k)$ might be incurred during the decommissioning period, e.g. for new facilities related to spent fuel storage on site, however the distinction made between small capital items expensed in the year they accrue or large capital items added to investment and then depreciated, is no longer necessary. All capital expenditures are now expensed as they accrue. Very limited interim replacement costs are incurred during the decommissioning period, to account for replacement parts for some NPP systems kept operational such as the decay heat removal system from the spent fuel pool.

Another change that occurs in the cost equations is that the fuel cost component and the variable O&M cost component are now zeroed out. No nuclear fuel is burned in the reactor any more and all O&M expenses related to generation do not accrue. Thus

$$FL_{DD}(k) = VOM_{DD}(k) = 0 \tag{22}$$

For all k values from $k = 1$ to $k= N_{DD}$

We can now define the net annual cash flow equation applicable during the decommissioning period as

$$NCF_{DD}(k) = - \{CAPADD_{DD}(k) + OM_{DD}(k)\} \tag{23}$$

For all k values from $k = 1$ to $k= N_{DD}$

Equation (23) implies that all new cash flows that occur during the decommissioning period represent expenditures on decommissioning activities without offsetting new revenue sources (save for possible salvage values), hence the negative sign in front of the right hand side of equation (23). These expenditures are recovered from funds becoming available at the end of the operations period, or the start of the decommissioning period, as specified in equation (20). We now need to define O&M costs during the decommissioning period.

$$OM_{DD}(k) = NSTAF_{DD}(k) \times SALAV_{DD}(k) \times 10^{-3} + FOM_{DD}(k) \times CAP \times 10^{-3} + FSC_{DD}(k) \times CAP \times 10^{-3} \tag{24}$$

For all k values from $k = 1$ to $k= N_{DD}$

Where

$OM_{DD}(k)$ – Annual O&M costs in year j during the decommissioning period [M$/year]

$NSTAF_{DD}(k)$ – Number of NPP remaining staff in year j, during the decommissioning period [persons]

$SALAV_{DD}(k)$ – Average loaded salary for the mix of plant employees defined by NSTAF(j), remaining in the plant in year j during the decommissioning period [K$/year]

$FOM_{DD}(k)$ – Annual fixed O&M costs in year j, during the decommissioning period, excluding personnel costs [$/KWe – year]

$FSC_{DD}(k)$ – Spent fuel storage costs in year j during the decommissioning period [$/KWe – year]

As seen in equation (24) we break the decommissioning period O&M costs into three distinct components –distinct from each other and from parallel activities during the operations period. These are the remaining staff salaries and benefits, other fixed O&M costs and spent fuel storage costs. The staff size and mix during the decommissioning period $NSTAF_{DD}(k)$ are different than those during the operations period NSTAF (t) since the NPP does not need plant operators and as much operations department personnel. The sizes of the training staff security staff, and most other plant departments are reduced and different mix of talents are required. This results in a different average salary value for the remaining plant personnel, as compared with the operations period. We have decided to break spent fuel storage costs into a distinct cost category since spent fuel might have to be stored on site long after all other O&M costs have stopped.

We can now define the discounted cumulative cash flow equation during the decommissioning period as follows

$$CUMCF_{DD}(k) = CUMCF_{DD}(k = 0) - \sum_{k=1}^{k} \{CAPADD_{DD}(k) + OM_{DD}(k)\} \times (1+r)^{-(N+k)} \qquad (25)$$

Equation (25) is the main equation governing the discounted cumulative cash flow during the decommissioning period. This equation though general is applicable mostly to NPP situations and represents the evaluation of the economics of a NPP decommissioning process. The final numerical value computed from equation (25) for $k = N_{DD}$ is the final numerical result of the entire computational procedure developed here, and covering expenses and revenues –all cash flows attributed to the NPP — during its construction, operations and decommissioning life phases. The annual and the cumulative net cash flows over the nominal life span of a non-regulated NPP are shown graphically in Figure 5a, and Figure 6a, respectively.

If $CUMCF_{DD}(k = N_{DD}) = CUMCF_{DD}(j = N + N_{DD}) \geq 0$

The NPP represented a positive profit centre for its parent utility over its entire life span – starting with a clean power plant site and ending up with (hopefully) a clean plant site again.

If $CUMCF_{DD}(k = N_{DD}) = CUMCF_{DD}(j = N + N_{DD}) \leq 0$

The NPP has ended its total life span with a loss that should be covered by its parent utility or by an external source of public funding.

11. PLANT OPERATION IN RESTRUCTURED VERSUS REGULATED UTILITY

In this section we discuss the differences in the treatment and the equations developed for plant operation in a restructured utility as described in section 10, when applied to a plant operated within a regulated utility. The discussion here applies to the original design plant life span case. All the basic approaches and assumptions used above apply here also.

11.1. Equations for plant operations in a restructured utility

As mentioned above, the equations developed in sections 9 and 10 relate to a plant (and later specifically a NPP) operated within a non-regulated or restructured utility. Such plant is regarded as both a profit center and a cost center. It is allowed to sell its generated electricity in the energy markets and retain the incoming revenues. These revenues are then used to pay all operating expenses, depreciate all outstanding capital investments, pay the relevant taxes (ignored here), accumulate adequate decommissioning funds, and earn a profit. The annual and cumulative cash flows in this case are shown in Figures 5a and 6a, respectively. If the plant is found profitable before the end of its nominal operation period, and if the costs of continued operation, refurbishment and decommissioning are estimated to be within the range of the accumulated profit by the end of the extended operations, then life extension may be recommended. If the plant is found to operate at a loss it might try to gain recourse to the general funds of its owner utility to remain in operation. The utility might be willing to support an un-profitable NPP considering that the costs of constructing and operating new alternative power plants might be higher. More general considerations such as the potentially high social cost of the shutdown the utility might have to bear, the pollution avoidance credits the NPP provides, or the creation of instability in the utility transmission network due to the loss of a particularly located generation node, are all evaluated in analyzing the prospects for life extension. These issues are discussed in detail in Part I of this Publication and in section 14 below. If the utility is not willing or cannot bail out a money losing NPP, that plant might have to resort to early closure.

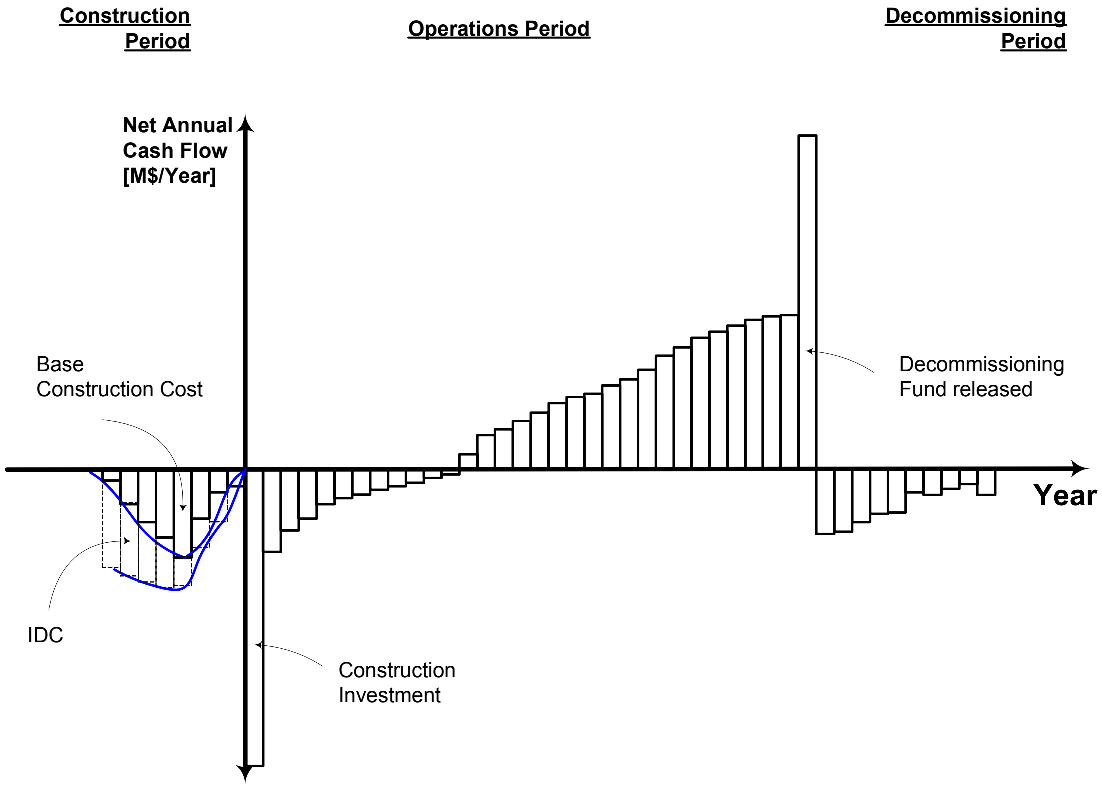

*Fig. 5a Plant net annual cash flow over original design plant life**
– Plant operated by non-regulated utility

*Axes and figures not drawn to scale

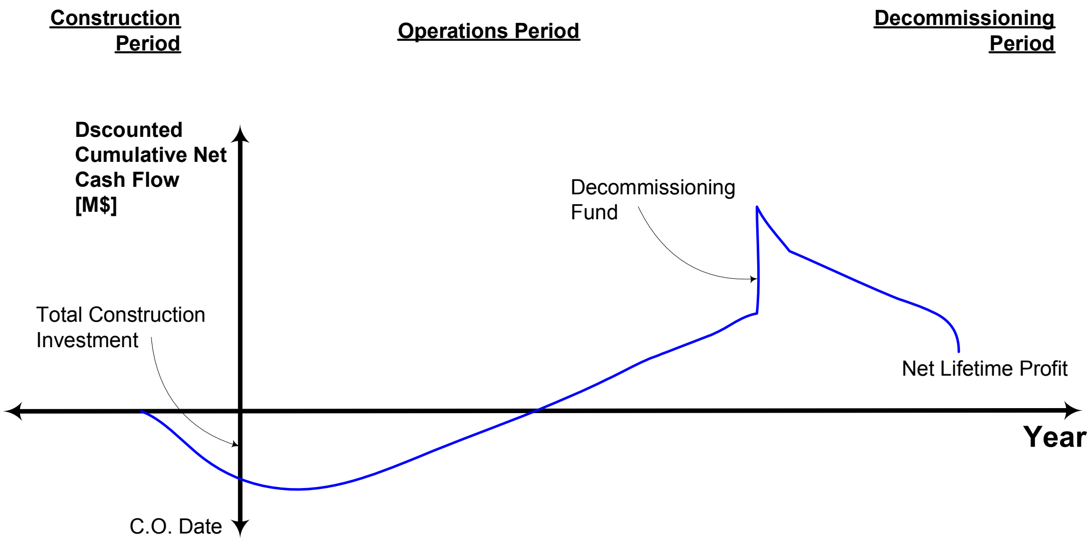

*Fig. 6a Plant cumulative net cash flow – original design plant life**
– Plant operated by non-regulated utility

*Axes and figures not drawn to scale

11.2. Equations for plant operations in a regulated utility

A plant (or more specifically a NPP) operating within a regulated utility is subjected to a different set of rules than a plant operated within a restructured utility. The regulated utility owned plant operates as a cost center only, incurring capital-related and operating costs. Both sets of costs, if allowed by the regulatory agencies, are returned to the utility through the sale of electricity at regulated prices, as discussed below. All incoming regulated revenues go to the owner utility, not to the plant itself. The utility is also responsible, using its overall revenues pool to pay for all plant costs not approved by the regulators to be passed-through to the ratepayers. While this system, depending on how it is applied, allows the utility to recover all its 'prudently accrued' costs (as defined by the regulators), it does allow very limited and regulated profits and provides limited incentives to improve operating efficiencies so as to increase profits. On the other hand, the utility is guaranteed adequate returns to cover all prudent costs, so theoretically it could not incur major financial losses. We now discuss the impact of the regulatory process on the cost equations related to the construction, operations and decommissioning periods, assuming an original design plant life span.

11.2.1. Plant construction period — regulated utility

Periodically during the construction period the regulatory agencies review all plant construction related costs reported by the utility and determine which costs were prudently incurred and which costs were imprudently spent. The regulatory agencies allow only prudently incurred costs to be included in the 'Rate Base'. The rate base is defined as the cumulative, un-depreciated, prudently incurred investment on which a regulatory determined return is collected from the utility ratepayers. In the restructured or non-regulated utility system, the sum of all un-depreciated investments in the plant is referred to as the 'Book Value'. The issue of investment prudence is not considered in the non-regulated utility, since power plant investment decisions and the risks thereof are not reviewed by the local state or regional regulatory agencies and are considered the sole responsibility of the utility. Thus we can, in general, say that if all plant investments were included in the rate base – the rate base would be identical to the book value. Conversely stated, the rate base represents the “prudently incurred’ book value. We thus define for each period j during the construction period a fraction of allowed costs P_{ALOW} (j) as determined by the regulators. It follows that during each period a fraction of (1 - P_{ALOW} (j)) represents the portion of the costs incurred which are disallowed by the regulators from the rate base and must be born by the utility stockholders rather than its ratepayers. We can thus modify Equation (9) above for the plant operated by a regulated utility as

$$REGNCF_{Con}(j) = \{S(j) \times BCC + S_{own}(j) \times OWNC\} \times P_{ALOW}(j) \times (1 + Cont) \times (1 + i_{IDC})^{-j-1} \quad (26)$$

Where

$REGNCF_{Con}(j)$ – Net annual regulatory-allowed cash flow by year j during the construction period [M$/year]

$P_{ALOW}(j)$ – the fraction of construction costs in year j considered by the regulators as prudently incurred and allowed into the rate base

All other cost definitions are similar to those reported for equation (9).

We can sum up all annual prudently incurred construction cost increments in similar way to Equation (10) above, to define the allowed rate base at the end of the construction period and the start of the operations period as

$$REGI(t = 0) = - \{REGCUMFC(j = - N_{Con}) + \text{First Core Cost}\} \quad (27)$$

where

REGI(t = 0) – The regulatory approved Rate Base (or the allowed discounted cumulative net cash flow) at the end of the construction period [M$]

$REGCUMFC(j = - N_{Con})$ – The cumulative discounted prudently incurred plant construction costs at the end of construction [M$]

Equation (27) is equivalent to equation (11) for the non-regulated case. As mentioned above using the term (1 - P_{ALOW} (j)) in equations (26) and (27) will allow us to compute the amount of construction-related investments incurred which are not allowed by the regulators and will have to be absorbed by the utility stockholders. The inclusion of the first core costs introduces here a nuclear-specific issue. If we introduced here instead first coal pile cost or related cost component this equation could represent a coal-fired plant-specific case.

11.2.2. Plant operations period — regulated utility

Two mechanisms of regulatory costs review are available during the plant operations period and are used to control plant generation costs charged to the utility ratepayers. These apply separately to capital related costs and to operations costs. All allowed capital investment costs deemed prudent are allowed into the Rate Base and are depreciated using a regulatory approved rate of return r_{ALOW}. By design r_{ALOW} should be slightly higher than the real average cost of money r defined in Equation (2). The difference in recovering costs with the allowed rate of return - r_{ALOW} and with the real rate of return r, is the net profit allowed the utility by the regulatory agencies. If $r_{ALOW} \geq r$ then the utility obtains a net profit. However if financial conditions changed between periods of regulatory costs review and $r_{ALOW} \leq r$ then the utility might incur a loss, and must appeal to the regulators to hurry their review process so as to avoid a ‘Regulatory Lag’ phenomenon.

The operating costs including fuel and O&M expenses were usually allowed by the regulatory agencies with only limited prudence review to be directly passed through as they occur to the ratepayers. Recently a new regulatory review process related to operations costs has been instituted and is referred to as performance based regulations (PBR). Under PBR all operations costs are periodically reviewed to establish their prudence, and to create incentives to the utility to improve the operations efficiency and reduce the operations costs of its NPP. If operations targets, including capacity factors and O&M cost values are met, the utility can recover all its costs. If the performance targets are not met, the utility is penalized by having a portion of its operations costs disallowed. These disallowed costs must then be born by the utility stockholders and can not be passed through to the utility ratepayers.

Turning to the cost equations derived in Sub-section 10.2, we note that by definition REV(t) = 0 and the net annual cash flow obtained from the ratepayers equals the allowed capital depreciation and operations costs. Thus a modified equation (12) will read as

$$REGNCF(t) = REGOM(t) + REGFL(t) + REGDD(t) + REGI(t-1) \times \{(N - t + 1)^{-1} + r_{ALOW}\} \quad (28)$$

Where

REGNCF(t) – Regulatory approved net annual cash flow in year t, [M$/year]

REGOM(t) – Regulatory approved (PBR Process) annual O&M Costs in year t, [M$/year]

REGFL(t) – Regulatory approved (PBR Process) annual fuel costs in year t, [M$/year]

REGDD(t) – Regulatory approved annual outlay to the NPP Decommissioning Fund costs in year t, [M$/year]

REGI(t-1) – Regulatory approved allowed Rate Base accumulated by year (t-1) and depreciated at a r_{ALOW} rate, [M$]

The process of determining the allowed rate base and the allowed return on the rate base includes also a review of the annual capital addition costs so that only prudently incurred costs are allowed into the rate base. The explicit mention of a decommissioning fund cost component turns equation (28) into a nuclear specific equation, since other type power plants do not yet list this as an explicit cost item. Thus a modified equation (13) will include:

$$REGI(t) = REGI(t-1) \times \{(N-t) / (N-t+1)\} + REGCAPADD(t) \times P_{ALOW}(t) \quad (29)$$

Where

REGCAPADD(t) – Regulatory approved annual capital addition costs included in the rate base by the year t, [M$/year]

$P_{ALOW}(t)$ – Fraction of capital addition cost in year t, considered prudent and allowed into the rate base [%]

Proceeding along similar lines to Sub-section 10.2 we compute the discounted cumulative net cash flow by year t, as approved by the regulators through both allowed rate of return and PBR review processes. Similar to a part of equation (14) we define

$$REGCUMCF(t) = \sum_{k=1}^{t} \{REGNCF(k) \times (1+r)^{-K}\} \quad (30)$$

Where we defined above all component cost items. Note that we depreciate using the allowed rate of return r_{ALOW} while we discount using actual cost of money r. We choose the nominal cost of money r as the discount rate in all cases rather than the allowed cost of money r_{ALOW} in order to assure consistency and comparability with the plant operated by non-regulated utility cases.

Note also that the first term on the right hand side of equation (14) i.e. — REGI(t = 0) is not required and is not included in equation (30). This is so since in the regulated utility case we do not have a distinction between a (negative-value) investment and positive-valued net annual cash flows used to recover it. All cash flows represent costs (are negative). The allowed annual cash flows are determined such that they are just adequate to cover prudently incurred investment-related and operations costs. The utility collects revenues from the ratepayers such that it recovers all its allowed costs. The sum of the annually incurred net cash flow includes the amount required to return the initial plant investment and provide a return on it. We thus do not need to include the initial investment twice in equation (30).

The more detailed annual cost equations for the component cost items are identical to those derived in Sub-section 10.2, except all costs included are those allowed by the regulatory agencies through the various prudence review processes.

Finally, the boundary conditions in the transition between the operations and the decommissioning periods are modified versions of those defined in equations (19) and (20) such as

$$REGI(t = N) = REGCAPADD(t = N) \times P_{ALOW}(t = N), \text{ and}$$

$$REGCUMCF_{DD}(k = 0) = C_{DD} \times (1 + r)^{-N} - REGCAPADD(t = N) \times P_{ALOW}(t = N) \times (1 + r)^{-N} \tag{31}$$

Where we define all cost items as above. The second part of equation (31) implies that at the beginning of the decommissioning period for the regulated plant, the utility receives a large positive capital injection in the form of the decommissioning fund. When subtracting the last carry-over capital addition cost from the operations period, this is the sum available to pay all decommissioning period expenses. There is no net positive accumulated cash flow from the operations period, since only costs (and no revenues) are accrued to the plant. Allowed rate payments suffice just to pay for all allowed costs and thus no net positive cash flow accumulates. The graphic depictions of the annual and cumulative net cash flows of a regulated plant over its original design plant life span are shown in Figures 5b and 6b, respectively. These can be compared with the annual and cumulative cash flows of a plant operated by a non-regulated utility, shown in Figures 5a, and 6a, respectively. In these four cases we applied the detailed analysis specifically to a NPP, however the general computational methodology and resultant overall shape of the cash accumulation curves equally apply to all plant types.

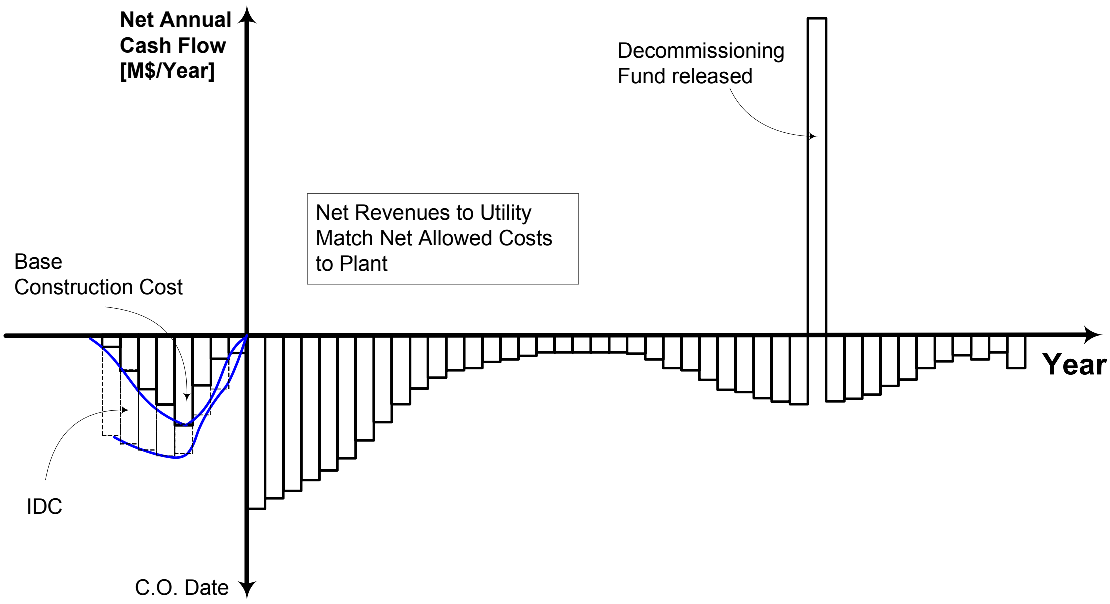

*Fig. 5b Plant net annual cash flow over original design plant life**
– Plant operated by regulated utility

*Axes and figures not drawn to scale

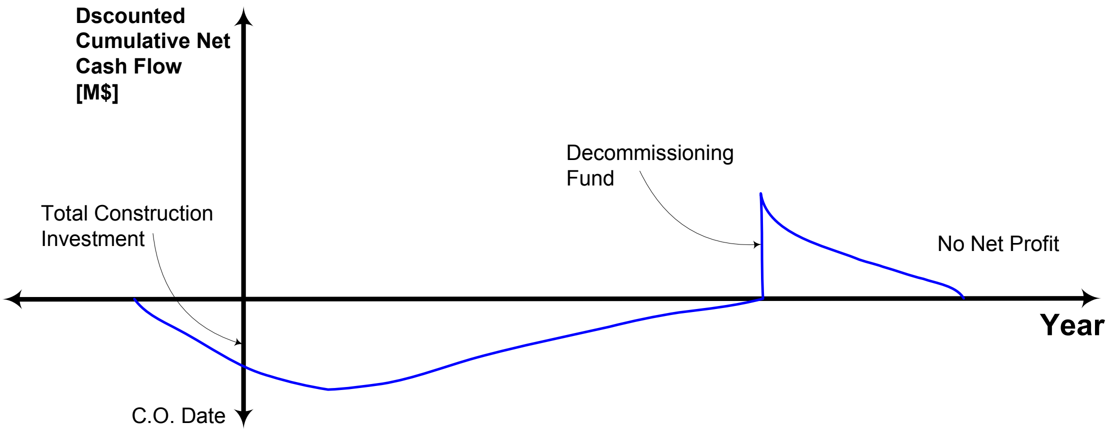

*Fig. 6b Plant cumulative net cash flow over original design plant life**
– Plant operated by regulated utility

*Axes and figures not drawn to scale

11.2.3. Plant decommissioning period — regulated utility

There exist only a limited experience set related to the regulatory review process of decommissioning activities, since there have been only few cases where a shut down plant has undergone through a complete decommissioning programme. Regulatory reviews mostly concentrate on analyzing the adequacy of the decommissioning funds, both with regards to the sufficiency of final amount of money the utility would like to accumulate, and with regards to the security of the financial instruments the decommissioning fund is invested in. The regulators are also interested in reviewing the financial health of the plant (in this case NPP) utility owner, its ability to continue paying annually the right amount into the decommissioning fund, and the impacts of utility mergers and acquisitions on the disposition of the decommissioning fund. A new issue under regulatory scrutiny now is the determination of who owns title to and responsibility for the stored nuclear spent fuel on or off the plant site in case of utility mergers and changes in corporate identity.

Regulatory review of actual decommissioning programmes has been limited to prudence reviews, and was intended more to guarantee that the various activities proposed will accomplish the declared tasks safely, with minimal radiation exposure to the plant staff and to the general public. The availability of low level waste (LLW) nuclear waste storage sites and the charges for storing LLW shipments in those sites (tipping charges) have also been reviewed by the regulators, to prevent overcharging by monopoly LLW site owners.

The above indicates that there exists little need to modify the decommissioning period cost equations derived in Sub-section 10.3 to account for NPP decommissioning performed within a regulated utility. All the equations derived in Sub-section 10.3 are applicable here using the notation indicating that we are dealing with a regulated utility case. Thus, the basic cost equation for the decommissioning period discounted cumulative net cash flow – equation (25), can be modified and expressed for the regulated NPP case as equation (32) below.

$$REGCUMCF_{DD}(k) = REGCUMCF_{DD}(k = 0) - \sum_{k=1}^{k} \{REGCAPADD_{DD}(k) + REGOM_{DD}(k)\} \times (1+r)^{-(N+k)} \qquad (32)$$

Where all the definitions of the cost component items in equation (32) are identical to those used in equation (25), and are applicable here to the NPP operated in a regulated utility case. All other cost equations from Sub-section 10.3 are similarly re-expressed.

12. EQUATIONS FOR CONTINUED OPERATION

12.1. General

In order to develop cash flow equations related to the plant continued operation we need to define the continued operation scenario. Later on we will develop an economic evaluation criterion for the decision whether to extend the plant operations period or not. The following discussion relates to a plant operated within a non-regulated or restructured utility. A discussion on net cash flow analysis of the continued operation option for a plant operated in a regulated utility is included towards the end of this section. We should mention here that the main motivation for extending the plant operations period is the need to generate more revenues from an existing plant asset with minimum incremental capital investment requirement and licensing reviews. Maintaining staff talent on site, increasing the value of the decommissioning fund, and deferring the decision on nuclear spent fuel disposition (in the case of a NPP) are the side benefits of the decision to extend plant operations, not the main motivating factors.

The following assumptions are made here in describing the continued plant operations (beyond original design plant life) process:

(a) The plant nears the end of its nominal operations period showing a positive and increasing discounted cumulative net cash flow.

(b) The plant has been maintained in good operational order and its performance did not degrade towards the end of its nominal operations period. This assumption should be qualified in cases where a substantial, high cost, capital addition project becomes necessary towards the end of the operations period such as, in a NPP a steam generators replacement in a PWR, or pressure tubes replacement in a CANDU reactor due to tube sagging. Such projects and the related investments are then evaluated in the context of the extended life decision. Until such projects are implemented plant operations might degrade during the last operations years due to steam generator tube plugging in a PWR or reduced power output in a CANDU to maintain margin to reactor scram.

(c) A significant capital addition expense is proposed to extend the operations period of the plant, up rate its capacity and possibly improve its capacity factor. For simplicity, we assume that all life extension capital addition costs accrue during the last nominal operations year.

(d) The original capital investment in the plant and all capitalized annual capital addition costs till the year before last have been depreciated through the nominal straight line depreciation method.

(e) A similar process of capitalization of large annual expenses and depreciation of capitalized investments, applying the recursive process described in Sub-section 10.2, will apply during the extended period though at a different average cost of money updated to the financial conditions during the extended period.

(f) The initial investment overhang to be depreciated during the extended period is only the refurbishment capital addition cost from the last nominal operations year however this cost must be recovered during the extended period which is shorter than the nominal operations period.

(g) At the end of the nominal operations period the fully funded decommissioning fund is released to the plant and is then re-invested to further increase its value during the extended operation.

(h) The delayed decommissioning period following the extended period, is similar to the nominal decommissioning period, but is delayed by the additional extended operation period.

(i) All costs are discounted to the zero time point defined at the start of plant commercial operation.

Based on the above, the life span of a plant (such as a NPP) with an extended operations period contains four distinct phases: Construction period, nominal operations period, extended operation period and decommissioning period. A different time index applies to each period, and costs are summed up within each period only. Transition of the cash flow computation from one period to the next is accomplished by defining the equations boundary value at the end of each period, which is then carried over to the following period and considered the initial value in the similar equation derived for that period. Even though we separately summarize within each period, all summed-up costs are discounted to the zero time point to allow inter period cash flow comparisons on a common basis.

A summary of the notation used in this section to describe the four computational periods is given in Table 1 below.

Table 1 Time indices used during four plant life periods under continued operation

Period	Period Length [years]	Time Index Used	Cumulative Time from C.O. Date [years]
Construction	$-N_C$	$j = -1, -2, \ldots - N_C$	$- N_C$
Nominal Operation	N	$t = 1,2,\ldots N$	N
Extended Operation	N_{LEX}	$k = 1, 2, \ldots N_{LEX}$	$N + N_{LEX}$
Decommissioning	N_{DD}	$m = 1,2,\ldots N_{DD}$	$N + N_{LEX} + N_{DD}$

There is no direct connection or impact between the construction period and the extended operation period. The equations derived in Sub-section 10.1 are equally valid in describing plant cash flow situation during the extended operation period. Similarly, the equations derived for the nominal operation period in Sub-section 10.2 are equally applicable here. The numerical value of the cash flow equations at the end of the last nominal operation year represents the original condition for the extended operation period. A new set of equations for the extended operation period is derived below. The numerical value of the cash flow equations at the end of the last year of the extended operation represents the boundary initial conditions for the delayed decommissioning period. The equations derived in Sub-section 10.3 above are slightly modified to account for new boundary conditions and deferred decommissioning period starting at the end of the extended period. The notation used here is summarized in Table 1.

12.2. Cash flow equations for continued operation period

The discussion in this section is divided into three parts: The boundary conditions for the transition from the nominal operations period to the extended operation period; the cash flow equations during the extended operation period; and the boundary conditions for the transition to the decommissioning period.

12.2.1. Boundary conditions — transition from nominal operation to extended operation period

Before developing the extended operation period's cash flow equations we need to define the boundary conditions for the transition from the nominal operation period to the extended operation period. As has been mentioned before, the cost equations for the nominal operation period are identical to those derived in Sub-section 10.2 above. We will now recapitulate the boundary conditions and connect them to the start of the extended operation period. Using a similar reasoning as has been used in equation (19) we can now specify

$$I(t = N) = CAPADD(t = N) = CAPADD_{LEX}(k = 0) = I_{LEX}(0) \quad (33)$$

Equation (33) which is the analogue to Equation (19), implies that the remaining investment to be recovered at the start of the extended operation period is the capital additions cost at the last year of the nominal operations period. In our definitions in Sub-section 12.1 we have specified that this is equal to the total refurbishment cost, necessary to improve the condition of the plant so that it can operate for an additional period of NLEX years under up rated conditions. In general, the higher the up rated cost, the longer the life extension period NLEX could be. We have further assumed that the entire plant refurbishment period occurs during the last year of the nominal operations period. Equation (33) is more complicated than equation (19) as in this case the remaining investment in the plant at the end of the nominal operation period needs to be further accumulated and depreciated during the extended operation period.

The second boundary condition deals with the discounted cumulative cash flows at the transition point between the nominal operation period and the extended operation period.

$$CUMCF(t = N) = COMCF_{LEX}(k = 0) \quad (34)$$

Equation (34) implies a direct transition of the discounted cumulative cash flow computational carry over value from the nominal operation to the extended operation period. At the end of the nominal operation period the value of the capital addition cost in the last year of operation carries over to the first year of the extended operation period, as specified in equation (33). The decommissioning fund CDD which is released at the end of the nominal operation period is re-invested at the beginning of the extended operation period and is allowed to accumulate further, as discussed below. Given these two exceptions the validity of equation (34) can be recognized.

12.2.2. Cash flow equations — extended operation period

We can now develop the basic cash flow equations during the extended operation period. We start with the recursive investment equation that drives the computational process during this period.

$$I_{LEX}(k) = I_{LEX}(k-1) \times \{(N_{LEX} - k) / (N_{LEX} - k + 1)\} + CAPADD_{LEX}(k) \quad (35)$$

Where

$I_{LEX}(k)$ – Remaining capital investment to be depreciated by year k, [M$]

$CAPADD_{LEX}(k)$ – Annual capital additions costs added to investment in year k, [M$/year]

N_{LEX} – Length of the extended operation period [years]

Equation (35) is the analogue of equations (5) and (13) derived above. Note that when k = 1, $I_{LEX}(k-1) = I_{LEX}(0) = CAPADD(t = N)$. Thus, per equation (33) the connection between the capital additions during the last nominal operation year and the net carry-over investment in the first extended operation year is established within the general recursive remaining investment computation. The capital addition during the last operation year, which represents the cost of the plant refurbishment for extended operation, is considered as a part of the net depreciable investment during the continued operation period.

The annual cash flow equation during the extended operation period can now be derived. By analogy with equation (8) and equation (12) above, we find

$$NCF_{LEX}(k) = REV_{LEX}(k) - OM_{LEX}(k) - FL_{LEX}(k) - DD_{LEX}(k) - I_{LEX}(k-1) \times \{(N_{LEX} - k + 1)^{-1} + r_{LEX}\} \quad (36)$$

Where all the components of equation (36) are the analogues of the similar components of equation (8) and equation (12) above. The specific definitions of each component in equation (36) are provided below. Equation (36) is also a part of the recursive process of net cash flow computation during the extended operation period.

Note that we have defined rLEX – the average cost of money during the extended operation period to be different than r – the average cost of money during the nominal operation period, reflecting possible changes in financial parameters during the later period. We will continue using r, which is also the discount rate, as the only rate used in all discounting computations within this analytical methodology.

Before addressing each component of equation (36) we will first define the discounted cumulative net cash flow equation for the life extension period as

$$CUMCF_{LEX}(k) = CUMCF_{LEX}(k = 0) + \sum_{k=1}^{k}\{NCF_{LEX}(k) \times (1 + r)^{-(N + k)}\} \quad (37)$$

Where we use the boundary condition between the nominal operation period and the extended operation period as defined in equation (34). This equation is the analogue to equations (3) and (14) above.

Having defined the basic equations which describe the recursive procedure for computing the net cash flows during the extended operation period, and anchored this computation into the analysis of the net cash flows during the previous nominal operation period, we can now define each component of equations (36) and (37). Starting with the first term of equation (36) we define

$$REV_{LEX}(k) = ELCPRC(k) \times CAP_{LEX} \times 8.76 \times 10^{-3} \times CF_{LEX}(k) \quad (38)$$

Where

$REV_{LEX}(k)$ – Annual revenues obtained from sale of electricity in extended operation period year k, [M$/year]

ELECPR(k) – Unit electricity sales price in extended operation period year k, [$/MWh]

CAP_{LEX} – Plant capacity during the extended operation period – possibly uprated, [MWe]

$CF_{LEX}(k)$ - Plant annual capacity factor in extended operation period year k, [%]

The equation dealing with the annual incoming revenues during the extended operation period is identical to the similar equation during the nominal operation period (15), with two possible changes. As a result of the refurbishment period, undertaken during the year t = N, the plant capacity may have been up rated, so that CAPLEX ≥ CAP. Similarly, the refurbished plant may be operated at a higher capacity factors range than was achievable during the nominal operation period, so that CFLEX(k) ≥ CF(t) for all k values, k = 1,2, …….. NLEX. And most values of t, t = 1,2,…….N.

The equation for the annual O&M expenses during the extended operation period $OM_{LEX}(k)$ is identical to the O&M costs Equation during the nominal operation period (16). Thus

$$OM_{LEX}(k) = NSTAF_{LEX}(k) \times SALAV_{LEX}(k) \times 10^{-3} + FOM_{LEX}(k) \times CAP_{LEX} \times 10^{-3} + VOM_{LEX}(k) \times CAP_{LEX} \times 8.76 \times 10^{-3} \times CF_{LEX}(k) \quad (39)$$

Where

$OM_{LEX}(k)$ – Annual O&M expenditures in extended operation period year k, excluding capitalized capital addition costs [M$/year]

$NSTAF_{LEX}(k)$ – Number of plant staff in extended operation period year k, [Persons]

$SALAV_{LEX}(k)$ – Average loaded salary for the mix of plant employees defined by NSTAF(k), in extended operation period year k, [K$/year]

$FOM_{LEX}(k)$ – Annual fixed O&M costs in extended operation period year k, excluding personnel costs, and including small capital additions costs and interim replacement costs which are expensed in the year they accrue [$/KWe –year]

$VOM_{LEX}(k)$ – Annual variable O&M costs in extended operation period year k, [$/MWh]

We assume here that the plant staff levels and professions mix, as well as the average staff person salary will not change during the extended operation period, as compared to the nominal operation period, despite the fact that the plant might have undergone significant refurbishments. While replacing old equipment with new machinery might allow reduced staffing levels, more equipment supervision and diagnostics position might have been created. Each refurbishment project is unique, so we can not specify a general rule for staffing levels and mix pre and post refurbishment. Given this, even though we denoted distinct terms, we assume $NSTAF_{LEX}(k) \approx NSTAF(t)$, and $SALAV_{LEX}(k) \approx SALAV(t)$, for all time values of k and of t. In similar fashion, while we designated possibly distinct values for $FOM_{LEX}(k)$ and for $VOM_{LEX}(k)$, we do not know whether these will be different after refurbishment from FOM(t) and VOM(t), respectively, during the nominal operation period. The conversion from the standard O&M cost units of [$/KWe-year] and [$/MWh] to annual sums in units of [M$/year] will, however, be affected by the possibly higher (up rated) plant capacity CAP_{LEX} and the potentially higher capacity factors $CF_{LEX}(k)$.

The equation for the fuel cycle costs during the extended operation period $FL_{LEX}(k)$ is identical to the fuel cycle cost equation during the nominal operation period – equation (17). This is the first equation in the plant continued operation section that is NPP-specific.

$$FL_{LEX}(k) = FFL_{LEX}(k) \times CAP_{LEX} \times 10^{-3} + \{VFL_{LEX}(k) + WMC(k)\} \times CAP_{LEX} \times 8.76 \times 10^{-3} \times CF_{LEX}(k) \tag{40}$$

Where

$FL_{LEX}(k)$ – Annual fuel costs including waste management charge in extended operation period year k, [M$/year]

$FFL_{LEX}(k)$ – Fixed portion of fuel cycle costs in extended operation period year k, including first core costs payable in year k (if any), or inventory charges on fresh fuel supplies held in storage for more than a year in year k, [M$/year]

$VFL_{LEX}(k)$ – Variable portion of annual fuel cycle cost in extended operation period year k, representing mostly costs incurred in the front end of the fuel cycle [M$/year]

WMC(k) – Annual payment in extended operation period year k towards the ultimate spent fuel disposal by the appropriate Government agency during the NPP Shutdown phase [M$/year]

While all components of equation (40) were given distinct values we do not think that any will vary in between the nominal operation period and the extended operation period, save for the up rated plant capacity CAP_{LEX} and the possibly higher annual capacity factors $CF_{LEX}(k)$. It is possible that the NPP up rate project will result in higher operating temperature and pressure during the extended operation period, leading to improved thermal efficiency, higher fuel burn up, higher fresh fuel enrichment requirement and higher fuel cost. The impacts of all these potential changes on the cost equations cannot be evaluated without further data on the plant up rate projects. We note, however, that nuclear fuel cycle costs represent the smaller component of the total unit electricity cost. Even a significant change in fuel cost will have limited impact on total generation costs. A change in the plant thermal efficiency (inverse of the heat rate) could have a more significant impact.

We do assume that the annual waste management unit charges paid to an outside agency will not change due to refurbishment. The annual sums paid could increase due to the up rated capacity and possibly higher capacity factors however the unit charge will not likely be affected.

A more significant change is likely to occur in the accumulated decommissioning fund during the extended operation period. We should note that an important side benefit of continued operation (though not the most important one), is to guarantee greater accumulation in the decommissioning fund prior to NPP closure. We do assume here that the NPP will, by choice, continue paying into the decommissioning fund a similar annual payment as that established during the nominal operation period and reported in equation (18).

$$DD_{LEX}(k) = DD(t) = C_{DD} \times SFF_{DD} = C_{DD} \times \{i_{DD} \times [(1 + i_{DD})^N - 1]^{-1}\} \qquad (41)$$

Where

$DD_{LEX}(k)$ - Decommissioning fund outlay in extended operation period year k, [M$/year]

All other values are defined below equation (18).

At the end of the nominal operation period the decommissioning fund accumulated – C_{DD} could be released and become available to the NPP. Since the plant will continue operating for N_{LEX} more years, we assume the following happens:

(a) The existing decommissioning fund C_{DD} will not be released and will remain invested in the original financial instruments bearing interest of i_{DD} for an additional period of N_{LEX} years.

(b) The NPP will choose to pay an annual outlay of $DD_{LEX}(k) = DD(t)$ into a new decommissioning fund over the extended operation period of N_{LEX} years.

(c) The new decommissioning fund will be invested in new financial instruments available at the end of the nominal operation period bearing interest if i_{DDLEX}. Each annual outlay will collect this interest till the end of the extended operation period.

Thus, the total decommissioning fund available at the end of the extended period $TDF(k = N_{LEX})$ can be expressed as

$$TDF(k = N_{LEX}) = C_{DD} \times (1 + i_{DD})^{NLEX} + \sum_{k=1}^{k = NLEX} DD_{LEX}(k) \times (1 + i_{DDLEX})^{NLEX - k + 1}$$

We note that the second term in the above equation represents a geometric series which can be summed up using the standard formulae, if the annual outlays $DD_{LEX}(k)$ are constant, and can be taken out of the summation process. In that case this equation can be re-written as

$$TDF(k = N_{LEX}) = C_{DD} \times (1 + i_{DD})^{NLEX} + DD_{LEX}(k) \times (1 + i_{DDLEX})^{NLEX} \times i_{DDLEX}^{-1} \quad (42)$$

Equation (42) represents the growth of the original decommissioning fund CDD which could become available at the end of the nominal operation period, if it continues being invested in its original instruments, and if the NPP continue setting aside (fixed) annual decommissioning outlays which are invested in new interest bearing financial instruments then available. Note also that the expression for the geometric series summation in equation (42) is the inverse of the sinking fund factor SFFDD used in equations (18) and (41).

Equation (42) represents one of the boundary conditions for the transition from the extended operation period to the NPP delayed decommissioning period. These conditions are discussed next.

12.3. Cash flow equations for the delayed decommissioning period

This section deals first with the boundary conditions for the transition to the delayed decommissioning period, and then includes a discussion on the relevant cash flow equations during that period. Note that the delayed decommissioning period, in terms of activities conducted and time lines is identical to the nominal decommissioning period except shifted several more years into the future. During the extra operation years, NLEX, the plant had the opportunity to increase its net cash flow and its accumulated decommissioning fund, in anticipation of its last phase of life.

The discussion of the boundary conditions for the transition from the extended operation period to the delayed decommissioning period is similar to the discussion in Sub-section 10.3 regarding the similar transition from the nominal operation period to the nominal plant decommissioning period. The differences are that the NPP has operated a number of additional years, N_{LEX}, has gained additional net discounted cash flows from the sale of electricity, has paid back its refurbishment cost and has accumulated a larger fund with which to pay for the delayed decommissioning expenses.

Following the discussions at the end of Sub-section 10.2 and the beginning of the discussion in Sub-section 10.3, we define

$$I_{LEX}(k = N_{LEX}) = CAPADD_{LEX}(k = N_{LEX}) \quad (43)$$

This equation implies that the only investment left un-depreciated at the end of the extended operation period is the capitalized capital addition cost (if any) at the last extended operation year.

The discounted cumulative net cash flow available at the beginning of the delayed decommissioning period then comprises the following components:

(a) The discounted cumulative net cash flow available at the end of the extended operation period.

(b) The total decommissioning fund accumulated by the end of the continued operation period, minus.

(c) The un-depreciated investment left over by the final extended operation year.

Following the formulation of equation (20) from Sub-section 10.3, and using values computed in equations (37), (42) and (43) for each of the terms in the right hand side of the following equation, respectively, we define

$$CUMCF_{LEXDD}(m = 0) = CUMCF(k = N_{LEX}) + \{TDF(k = N_{LEX}) - CAPADD_{LEX}(k = N_{LEX})\} \times (1 + r)^{-(N + NLEX)} \quad (44)$$

Where

$CUMCF_{LEXDD}(m = 0)$ — The discounted cumulative net cash flow at the end of the extended operation period and the beginning of the decommissioning period [M$]

Equations (42), (43), and (44) represent the boundary conditions between the extended operation period and the (delayed) decommissioning period.

From now on we proceed in similar fashion to the discussion in Sub-section 10.3. The net annual cash flow during each year of the delayed decommissioning period is defined similar to equation (23) as

$$NCF_{LEXDD}(m) = - \{CAPADD_{LEXDD}(m) + OM_{LEXDD}(m)\} \quad (45)$$

Where $NCF_{LEXDD}(m)$, $NCF_{LEXDD}(m)$, and $OM_{LEXDD}(m)$ are respectively the net annual cash flow during the delayed decommissioning period, the annual capital addition costs during the delayed decommissioning period and the annual O&M costs during the same period, all expressed in units of [M$/year]. Equation (45), just as equation (23) imply that there are only outgoing expenses during the delayed decommissioning period, equal annually to the sum of the O&M costs and the capital addition costs. All capital addition costs are expensed in the year they accrue out of the available total decommissioning fund. Salvage values, if available are assumed here to be considered negative capital addition costs.

The O&M costs during the delayed decommissioning period are assumed equal to the O&M costs during the nominal decommissioning period, and are computed based on equation (24).

$$OM_{LEXDD}(m) = OM_{DD}(k) \quad (46)$$

For all delayed decommissioning period years m = 1,2, …….N_{DD} and for all nominal decommissioning period years k = 1,2, …….N_{DD}. All values expressed in units of [M$/year].

Following the formulation of equation (25) we can now define the discounted cumulative net cash flow during each year of the delayed decommissioning period as

$$CUMCF_{LEXDD}(m) = CUMCF_{LEXDD}(m = 0) - \sum_{m=1}^{m} \{CAPADD_{LEXDD}(m) + OM_{LEXDD}(m)\} \times (1+r)^{-(N+NLEX + m)} \quad (47)$$

Equation (47) is the basic cash flow equation applicable during the delayed decommissioning period. The value of the first term on the right hand side of equation (47) is defined in equation (44). Finally, at the end of the delayed decommissioning period, when we set $m = N_{DD}$ in equation (47) we compute the discounted cumulative cash flow covering the entire plant (in this case a NPP) life span, including the construction, nominal operation, extended operation and delayed decommissioning periods — $CUMCF_{LEXDD}(m = N_{DD})$. If this value is greater than or equal to zero, than the NPP project has been a profitable one for its parent utility over its entire life span. A depiction of the cumulative net cash flow over the life span of a life-extended NPP is shown in Figure 7. This could be compared to the cumulative life span net cash flow of an original design plant life span NPP in Figure 6a. We should caution here that the regulatory agencies might not look favourably at a large accumulated cash flow remaining after the plant has been decommissioned, and blame this on the utility demanding higher decommissioning fund than was required. If such situations arise the regulatory agencies might try to take back the accumulated funds and apply them elsewhere.

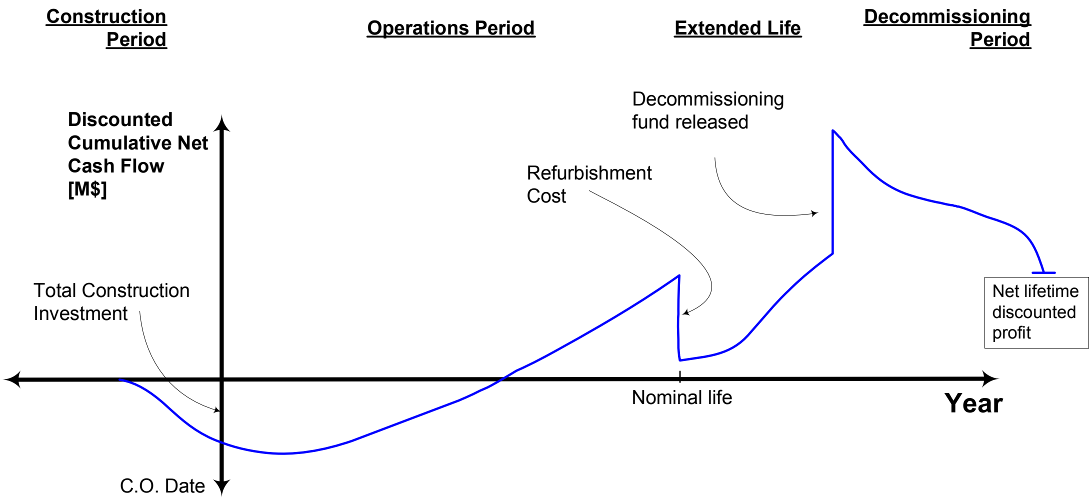

Fig. 7 Plant in a restructured utility
*– Cumulative net cash flow under extended operation decision**

* Axes and figures not drawn to scale

12.4. Economic evaluation criterion for the decision on continued operation

12.4.1. General

At the point of transition from the nominal operations period to either an extended operation followed by delayed decommissioning, or a nominal decommissioning period, there exist five value/cost elements we need to consider in order to reach a decision on which path to follow. Two of these value/cost elements we know at the point of decision, and three other elements, which will occur in the future, we need to estimate. These are:

(a) The discounted cumulative net cash flow at the end of the nominal operation period, $CUMCF(t = N)$. This accumulates (discounted) and is computed $t = N$.

(b) The NPP refurbishment and up rate cost which occurs during the last year of nominal operation, $CAPADD(t = N)$. This occurs at $t = N$.

(c) The extra revenues expected to accumulate during the extended operation period, $\{CUMCF_{LEX}(k = N_{LEX}) - CUMCF_{LEX}(k = 1)\}$. These will accumulate and be discounted over the period $N + 1$ to $N + N_{LEX}$ and will be computed at $t = N + N_{LEX}$.

(d) The total value of the decommissioning fund at the end of the nominal operation period, C_{DD} available at t = N, or TDF(k = N_{LEX}), available at the end of the extended operation period, t = N + N_{LEX}.

(e) The total discounted cost of the decommissioning operation carried over a period of N_{DD} years and computed either at the end of the nominal decommissioning operation t = N + N_{DD} or at the end of the delayed decommissioning operation, t = N + N_{LEX} + N_{DD}.

Items a, c, and d, represent positive values, such that a, is known and c and d could be estimated. Items b, and e represent negative values, or costs, such that b is known and e could be estimated. We can summarize the above value/cost elements notation in Table 2.

Table 2 Cost/Value elements during continued operation period of a plant in a restructured utility

Value/Cost Elements	**Original design plant life**		**Continued Plant Operation**	
	Element Designation	**Time Point Computed**	**Element Designation**	**Time Point Computed**
Nominal Operation Value	a	t = N	a	t = N
Refurbishment + Uprate Cost			b	t = N
Net Extended Operation Value			c	t= N + N_{LEX}
Decommissioning Fund Value	d	t = N	d'	t= N + N_{LEX}
Net Decommissioning Cost	e	t= N + N_{DD}	e'	t= N + N_{LEX} + N_{DD}

12.4.2. Exact decision criterion

The economic evaluation criterion for the decision on whether to extend the plant operation period or not is the value of the discounted cumulative net cash flow at the end of the plant life span. The plant operations option which results in a higher discounted cumulative net cash flow available at the end of its decommissioning period is the more economic option to follow.

If we can estimate on a year-by-year basis the different cost components affecting the net cash flow, sum up over each time period taking care to use the right boundary conditions, and then discount back to the zero time point, we can compute the desired value. This capability in spreadsheet format is available to many economic analysis departments of electric utilities operating NPPs and other large plants.

Note that from equation (25) we can compute the discounted cumulative net cash flow at the end of the nominal decommissioning period, designated CUMCFDD(t = N + NDD). In similar fashion we can compute from equation (47) the discounted cumulative net cash flow at the end of an extended operation period followed by a delayed decommissioning period, designated as CUMCFLEXDD(t = N + NLEX + NDD). Based on the above discussion if we do these two projected lifetime cost estimations and find

$$\text{CUMCFLEXDD}(t = N + NLEX + NDD) \geq \text{CUMCFDD}(t = N + NDD) \quad (48)$$

Then the extended operation option is the more economic option for the plant to follow. The life span cumulative net cash flow is shown in the extreme right of Figure 6a for an original design plant life, and in Figure 7 for an extended operation plant.

If after computing the life span discounted cumulative net cash flows for the two options we find

$$CUMCFDD(t = N + NDD) \geq CUMCFLEXDD(t = N + NLEX + NDD) \quad (49)$$

Then the original design plant life operation is the more economic option for the plant to follow and the extended operation period cannot be justified due to a combination of various factors which should be further investigated.

We should recall that the discussion here is limited to choosing between two nuclear plant related options – operating the plant for its original design life only, or proceeding to extended life operation. We did not discuss here the external options of building from the ground up and operating a new replacement generation plant, replacing the existing nuclear plant capacity after the end of nominal operation with increased generation from other plants the owner utility has, purchasing replacement power from within the region or from distant low cost generation plants, or expanding the transmission network and importing additional power into the region using the higher capacity transmission lines. These options are region, technology and utility specific and cannot be addressed within the contained scope of the economic analysis of Part II of this Publication.

12.4.3. Approximate decision criterion

If it is difficult to estimate year-by-year economic values and costs over the entire plant life span, it might be possible to devise an approximate decision criterion using Table 2 above. Such simplifying procedure could serve as an initial screening process to be followed by a more detailed and exact computation as described in Sub-section 12.4.2. If we need a simplified, short methodology for a preliminary evaluation, then the procedure outlined below may be more appropriate.

Each of the value/cost elements designated at that table could be computed using a combination of simplifying assumptions inserted into the right equations of the above text. It is possible to assume that many of the annual cost elements included in these equations are constant over time, or could be merged with other elements. Depending on data availability, time and ingenuity, each of the value/cost elements in Table 2, designated a to e’, could be computed and discounted from the time point of computation, indicated in the Table to the start of the plant commercial operation.

Given the designations of Table 2 and assuming the right discounting performed, we can define:

Net Value (Original design life) = a + d – e

Likewise for the extended operation option we can define:

Net Value (Life extension) = a + c + d’ – b – e’

Comparing these values, if we find

$$a + c + d' - b - e' \geq a + d - e \quad (50)$$

Then the extended operation option is the more economic option for the plant, given all simplifying assumptions. If the converse is true, than the original design plant life operation (no extended operation) is the better economic choice for the particular conditions of that plant. The evolutions of the cumulative net cash flow over the nominal or extended operation of a plant operated by a non-regulated utility are shown graphically in Figures 6a, and 7, respectively. These two Figures and Table 2 above demonstrate the changes in the cumulative net cash flow of the plant, as it transitions from one life phase to the next.

12.5. Continued plant operation decision for a regulated utility

The discussion of the continued operation option for a plant operated by a regulated utility follows the general discussion of a plant's net cash flow computation within a regulated utility in section 11, Part II of this publication, modified in part to address the extended operation period, as developed in Sub-sections 12.2 and 12.3 above. A general observation here is that since a plant operated by a regulated utility can spend only what the regulators approve, and since the utility management needs to decide whether to make up the shortfall from its own general funds, or not, it is difficult to develop an economic evaluation criterion, since the objectives of the plant and of the parent utility might diverge, to some extent, and since it is more difficult to identify the utility specific objectives. Furthermore, there exists the uncertainty as to how much will the economic regulators approve or reject of the annual operations costs and of large capital expenditures such as extended operation refurbishment cost. It is also difficult to estimate what portion of the non-approved costs the parent utility will be willing to absorb, given all other obligations it must meet. Unless we define specific scenarios and develop value/cost equations related to them, it might be difficult to perform a meaningful analysis here.

Another factor to consider here, from the regulator's perspective is that if they do not allow a plant continued operation option and call for an early closure of the plant, the regulatory agencies will also have to evaluate the cost and timing of the alternative power plants that could be constructed to replace the shutdown plant. It is not clear that a new generating plant that would be constructed and operated, from the ground up, will be the lower cost option than the refurbishment and up rating of an existing plant. The decision criterion does not involve the plant in itself – to extend or not the plant's operations period but rather, are there any other generation options more economic than either of the two existing plant related options. The true context for the continued operation or early shutdown decision related to an existing specific plant includes also an evaluation of the costs of alternative new generation options. Since the alternative power plant issues are so site, technology, regulatory regime and country specific, we did not address them in the analysis of Part II.

13. EQUATIONS FOR EARLY CLOSURE OPTION

13.1. Rationale for an early plant closure

Some power plants, particularly isolated NPPs, might face the decision on early plant closure rather than continued operation. The factors that might drive the utility to such a decision have to do with the external political situation, with the utility owner, and with the NPP itself. We will review these issues in reverse order. On the utility side, if we are dealing with a relatively small utility operating only a single nuclear plant within its generation mix, it may turn out that disproportionate amount of utility resources and of management attention are absorbed with problems related to the NPP operation while the small capacity NPP contributes only a relatively small share to the total utility generation and revenues. Further, the operation of a nuclear plant could present potential operation risks to the utility itself. If the NPP sustains a medium severity or even a small accident, the recovery costs, the costs and time delays in satisfying the demands of the safety regulatory agencies, and the incremental costs of replacement power might well exceed the net book value of the entire utility. The period over which all the commitments made in order to restart the plant are to be implemented will stretch well beyond the date of the plant restart and will negatively impact the economic performance record of the plant for several additional years. Furthermore, the uncertainty related to the accident, the plant's restart and the related commitments made, might lead to worsening relations with the local communities and to external political pressures on the utility. Utility management people might come to feel that the costs and risks do not justify the value, and that they are in the business of generating electricity and not that of operating nuclear plants.

From the NPP perspective the reasons for closure are mostly operational. Plant managers might feel that they do not have adequate resources to run the plant effectively. Sometime, being an isolated NPP (within their utility, or even geographically) they must keep on staff all craft and engineering disciplines, even though they may not be fully utilized, so that they have them on hand if and when they might need their services. A related problem is that of the spare parts inventory. In an isolated NPP, a larger stock of spare parts might have to be kept on hand in case it might be needed, thus increasing the annual interest charges on the spare parts inventory. In such cases the requirements of safety and reliability and of economics might diverge. In other cases the NPP management people may lack the requisite management skills of motivating their people, assigning down responsibility and supervising the meeting of commitments. Some organizations are better at these skills and some are not so. One way or another, the NPP management might not succeed in raising the plant's capacity factors, thereby increasing electricity send-out and revenues collection. Further, management might not be able to reduce operations costs in relation to incoming revenues. Particularly management may not effectively run maintenance outages where a large equipment interim replacement projects might take place. The length and cost of the outage might exceed expectations due to inadequate pre-planning and preparation. Thus the net annual cash flow might be negatively impacted.

Other causes for early shutdown might be beyond the NPP control: The country or the region where the plant is located might be under an economic recession and the demand for electricity is down. Electricity rates might be low due to recession or related political impacts, thus further reducing incoming revenue. Some clients receiving electricity from the plant are late in, or do not, pay for the energy they receive. Recall the times when generating plants in some countries were offered bartered goods for their services rather than cash payments. Political factors, though not well defined may have significant impact. A populist regional or state Government might have an anti-large business mentality, and might push the economic regulators to disallow utility rate increase requests even if justified on technical grounds. An anti-nuclear 'green' government might object to the operation of the NPP on environmental-ideological grounds, try to bring about its early closure, and object to a continued operation option. Other environmentally inclined political parties in power, might assume that an operating NPP represents unacceptable safety risks to the public a large and should be shut down at the earliest possible date.

The combined effect of all the above is that the NPP can not achieve high enough positive net annual cash flows to cover operational costs, depreciate remaining plant investment, collect an adequate decommissioning fund and bring in the assigned net profit the owner utility expects. Prospects for improved economic performance in the future might also look dim. A political settlement might then be arranged allowing for external cash injection to cover outstanding liabilities such as completely fund the decommissioning fund, pay off some of the depreciable plant investment, or completely fund the staff's pension plan. Under such situations the NPP and/or the utility management might decide that an early closure of the NPP is in the best interests of the NPP, the utility, the stockholders and the public at large. These considerations equally apply to NPPs operated within regulated or restructured utilities. Two situations may arise here:

1. The plant has started demonstrating positive annual cash flows however the prospects for significant increase in these positive cash flows are limited. The utility management might then feel that they have done as much as they could to improve the plant's prospects and they could do no more. Under such condition a decision on voluntary plant closure or sale to other entities might be reached.
2. The plant cannot achieve positive annual cash flows and it continues operating' in the red'. The relevant economic regulatory agencies might decide that continued operation of the plant is not in the economic interest of the region, the ratepayers or the utility itself. Under such conditions an early closure decision might be imposed upon the utility.

The cumulative cash flow histograms of the plant under voluntary and imposed early closure situation are graphically shown in Figures 8a and 8b, respectively.

Given that a decision-in-principle has been reached regarding early plant closure, the question is when is the earliest feasible date, politics aside, to arrange for an early plant closure? The economic criterion governing such decision and the related cash flow equations are discussed next.

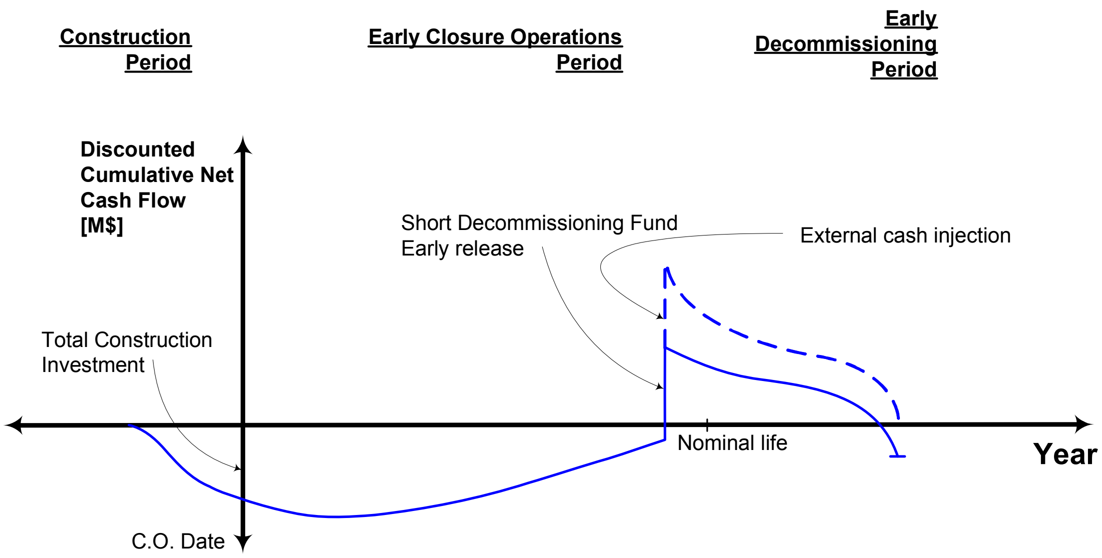

Fig. 8a Plant in a restructured utility
*Cumulative net cash flow under early closure decision**
– Imposed early closure

* Axes and figures not drawn to scale

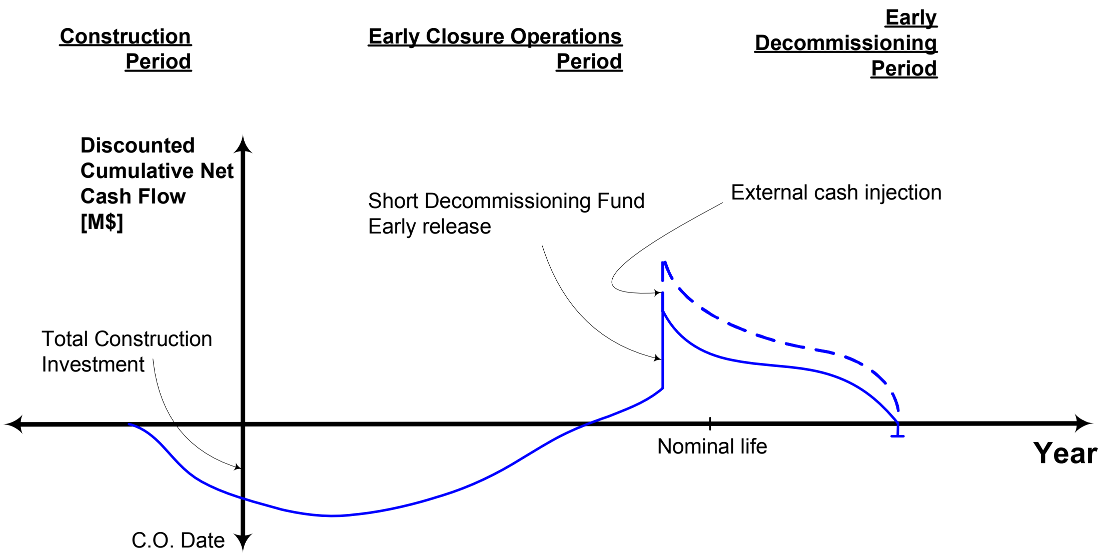

Fig. 8b Plant in a restructured utility
*Cumulative net cash flow under early closure decision**
– Voluntary early closure

* Axes and figures not drawn to scale

13.2. Economic criterion for early plant closure

The economic criterion for determining the earliest feasible date for an early plant closure is that the plant discounted cumulative net cash flow including all future obligations, i.e. at the end of the decommissioning period is greater or equal to zero. This criterion is applicable whether the plant operates within a regulated or restructured utility however the computational procedures slightly vary as discussed below. If we define the date of early plant closure N_{EPC} such as $N_{EPC} \leq N$, N being the plant's (or the NPP's in this example) nominal operations period, and we further define, as above, $CUMCF_{EPCDD}(t = N_{EPC} + N_{DD})$ the discounted cumulative net cash flow at the end of the decommissioning period following an early plant closure, then the economic criterion for an early plant closure is expressed as:

$$CUMCF_{EPCDD}(t = N_{EPC} + N_{DD}) \geq 0 \qquad (51)$$

and N_{EPC} is the earliest year for which equation (51) holds.

The total life span of the NPP beyond the start of commercial operation will be NEPC + NDD with two separate phases – a shortened operations phase till the date of early plant closure, and a decommissioning phase. We assume that the construction period is not affected by the later decision on early closure, and that the total plant investment I(t = 0) at the beginning of commercial operations that needs to be depreciated is the same, in all cases analyzed here. The cumulative net cash flow during an early plant closure cases are shown in Figures 6a and 6b, and can be compared to the life span cumulative net cash flow during a original design plant life operation shown in Figure 4a, and to the cumulative cash flow during an extended life operation, shown in Figure 5.

Equation (51) and its more elaborate form given in equation (53) below cannot be solved analytically to compute the value of N_{EPC} – the first year during which early plant closure could be economically justified. Rather, a numerical interpolative solution for equations (51) and (53) can be employed. Under this procedure equation (53) is solved for various assumed values of N_{EPC}. A judicious choice of N_{EPC} values will result in both positive and negative values for $CUMCF_{EPCDD}(t = N_{EPC} + N_{DD})$. If we plot the values of the discounted cumulative net cash flow as a function of the various values of N_{EPC} used, then the value of N_{EPC} for which the corresponding $CUMCF_{EPCDD}(t = N_{EPC} + N_{DD})$ is about zero, is our requisite earliest plant closure date, for which the lifespan discounted cumulative net cash flow is equal or greater than zero.

13.3. Cash flow equations for early plant closure in a non-regulated utility

We can now establish the boundary conditions at the transition point from the shortened operations phase to the early decommissioning phase, at the date of early plant closure. The discussion here is applicable to a plant operated by a non-regulated utility. The case of a regulated NPP is discussed in the next section.

The following assets and obligations are outstanding at the early closure date t = NEPC:

(a) The plant discounted cumulative net cash flow $CUMCF_{EPC}(t = N_{EPC})$ might already be positive, assuming voluntary closure (or might still be negative under imposed closure conditions).

(b) The decommissioning fund, or as much as has accumulated in it by $t = N_{EPC}$ and defined as $TDF(t = N_{EPC})$ is released for the NPP to use.

(c) A portion of the NPP investment $I(t = N_{EPC})$ has not yet been depreciated, and might be left ‘stranded’, since following closure there will be no more incoming revenues from which to pay this remaining obligation.

(d) The future (discounted) decommissioning expenses will need to be paid, even if inadequate sums to meet the requirements of this future activity have so far accumulated in the decommissioning fund.

(e) An external cash injection [ECI =?] might be arranged as part of the political deal facilitating an early plant closure.

We should mention that such an ECI might not be an overt one-time payment and might represent measures of financial support spread over several years, paid to the owner utility rather than to the NPP. Such indirect payments might include better financial terms to other plants the utility would like to bring online to replace the retired NPP capacity, further disguised through utility taxes breaks rather than straight outlays, through higher electricity rates charged to the ratepayers, or disguised through any other means to prevent public outcry regarding public giveaways to presumably inefficient and undeserving utility management. Nevertheless, we leave [ECI =?] in the equations as a placeholder for any direct (or indirect) cash injection to facilitate NPP closure that might be forthcoming.

We recall from previous Sub-sections 10.3 or 12.3 that the cash flow equations such as (25) representing the discounted cumulative decommissioning expenses can be expressed as

$$CUMCF_{EPCDD}(t = N_{EPC} + 1 \text{ to } t = N_{EPC} + N_{DD}) = -\sum_{k = NEPC + 1}^{k = NEPC + NDD} \{CAPADD_{EPCDD}(k) + OM_{EPCDD}(k)\} \times (1+r)^{-k} \quad (52)$$

Where

$CUMCF_{EPCDD}(t = N_{EPC} + 1 \text{ to } t = N_{EPC} + N_{DD})$ – Discounted cumulative net decommissioning expenses carried out during the decommissioning period following an early plant closure – years $t = N_{EPC} + 1$ to $t = N_{EPC} + N_{DD}$ and expressed in [M$]

$CAPADD_{EPCDD}(k)$ – Annual capital addition costs in year k during the decommissioning period following an early plant closure [M$/year]

$OM_{EPCDD}(k)$ – Annual O&M costs in year k during the decommissioning period following an early plant closure [M$/year]

The negative sign in equation (52) indicates that it represents a summation of annual expenses, rather than income sources. Using the above definitions we can express equation (51) as:

$$CUMCF_{EPC}(t = N_{EPC}) + \{TDF(t = N_{EPC}) + [ECI =?] - I(t = N_{EPC})\} \times (1 + r)^{-NEPC} - CUMCF_{EPCDD}(t = N_{EPC} + 1 \text{ to } t = N_{EPC} + N_{DD}) \geq 0 \quad (53)$$

Equation (53) expresses in symbolic form the summation of all the NPP assets and obligations outstanding at the time of early plant closure decision, as discussed above. The economic criterion requires that N_{EPC} be chosen as the earliest year such that the above summation is equal to or greater than zero. Note that at the early closure date, $t = N_{EPC}$ the remaining investment obligation is $I(t = N_{EPC})$, i.e. a return of the remaining investment. A return on the remaining investment (i.e. interest payments on debt and ROI payments to the stockholders) can not be arranged since the plant has stopped generating and there is no revenue source from which to pay return on the investment. This is the risk that the stockholders are taking when purchasing the utility stock. As to the bondholders holding the utility debt a partial repayment of the returns they expect on the debt obligation they hold might eventually be arranged as a component of the external cash injection needed to facilitate the early plant closure.

Based on previous definitions made in this Analysis, we can provide the following expressions for the various terms in equation (53).

The discounted cumulative net cash flow accumulated by the plant shutdown date can be expressed in the early plant closure case, as done in equation (14):

$$CUMCF_{EPC}(t = N_{EPC}) = - I(t = 0) + \sum_{k=1}^{k=N_{EPC}} NCF_{EPC}(k) \times (1+ r)^{-k} \quad (54)$$

Where the requisite definitions are given in equation (14) and related discussion. The Net cash flow equation for the early plant closure case, during any year k such that $1 \leq k \leq N_{EPC}$, is identical to the cash flow equation (12), Sub-section 3.2, computed for the nominal operations case. All further equations from Sub-section 3.2 describing components of the net annual cash flow are applicable here too.

The total decommissioning fund that has accumulated by the time of plant shutdown is computed based on the following assumptions: The annual decommissioning outlay is computed in equation (18) as $C_{DD} \times SFF_{DD}$. This amount is paid annually over an operations period of N_{EPC} years. The total accumulation in the decommissioning sinking fund by the time of plant closure is computed using the methodology defined in equation (40).

Thus, we define

$$TDF(t = N_{EPC}) = C_{DD} \times SFF_{DD} \times \{(1 + i_{DD})^{NEPC} - 1\} \times i_{DD}^{-1} \quad (55)$$

Where i_{DD} is the interest rate on the accumulating decommissioning fund [%/year]

SFF_{DD} – the sinking fund factor is computed as defined in equation (18) for a nominal plant operation period of N years. However the annual payment to the decommissioning fund at the rate computed from equation (18) accrues only for N_{EPC} years, as indicated in equation (55).

The total un-depreciated investment in the NPP by year $t = N_{EPC}$ designated $I(t = N_{EPC})$ is defined in a recursive manner in equation (13). That exact definition, taking into account both the depreciation of the original plant investment $I(t = 0)$ and the accumulation of capitalized annual capital addition costs CAPADD(t) until $t = N_{EPC}$, could be modified to provide an explicit rather than recursive definition of $I(t = N_{EPC})$. For the special case where a constant value of the annual capital addition costs is assumed CAPADD(t) = CAPADD for all t, such that $1 \leq t \leq N_{EPC}$ we can write an approximate equation for I(t) as:

$$I(t = N_{EPC}) \approx I(t = 0) \times \{(N - N_{EPC}) / N\} + CAPADD \times (N_{EPC} / 2) \times (N_{EPC} / N) \quad (56)$$

The last term in equation (53) has been defined in and can be computed from equation (52).

The above definitions can be used to compute the values of the various components of equation (53), for various assumed NEPC values. In this way a numerical interpolative solution of equation (53) can be achieved. The graphic representations of the life span cumulative cash flow during an early plant closure cases are shown in Figures 8a and 8b.

13.4. Cash flow equations for early plant closure in a regulated utility

We should comment here that situations resulting in early plant closure decisions are more likely to occur in a regulated utility, rather than in a non-regulated utility. In most cases a regulated utility having problems with an under performing NPP will attempt to sell it to a strong restructured utility experienced in operating NPPs rather than shut it down. Such a restructured utility will then likely reform the NPP operations practices to become more efficient and profitable. If the NPP management will not be able to improve the economic performance of the plant, it will be replaced by a new management team that could. In general, within the non-regulated system, any existing NPP is an asset with high revenue stream potential and low operating costs i.e. a potentially highly profitable asset which should be well managed to assure profits accumulation and control possible operations risks. In fact, most NPPs operating in non-regulated utilities will likely face extended operation prospects and not early closure decisions.

In the regulated utility system it is still possible that an operating NPP will shut down, either due to internal utility related problems (Voluntary early closure) discussed in Sub-section 13.1 above or due to external political problems (imposed early closure). In some cases the decision to shut down an under performing, or a perceived-to-be less safe NPP might be part of a larger package involving the privatization of its owner regulated utility.

We further note here that the economic decision criterion for the earliest year during the operations period — NEPC — in which a decision to shut the plant down could be economically justified, as defined in equations (51) and (53), is equally applicable here. The terms used in these equations need however be modified based on the discussion of a regulated utility cash flows in section 11 above.

Since in the regulated utility system the decision to shut down an operating NPP is mostly politically driven and facilitated, the importance of the external cash injection at the time of closure, symbolically designated here as [ECI =?], is even more pronounced, if not really critical. While we can not specify what might be included in this term, as it will significantly vary from one case to the other, the actual manifestation of it should be included explicitly in the early plant closure economic analysis. In fact, without such external cash injection plant closure might not be feasible without the owner utility taking a large loss which might push it into bankruptcy proceedings.

With these observations in mind we can investigate how the terms in equation (53) will change for the regulated utility analysis. Based on the terminology used in section 11 we can re-write equation (53) as

$$REGCUMCF_{EPC}(t = N_{EPC}) + \{TDF(t = N_{EPC}) + [ECI =?] - REGI(t = N_{EPC})\} \times (1 + r)^{-NEPC} - REGCUMCF_{EPCDD}(t = N_{EPC} + 1 \text{ to } t = N_{EPC} + N_{DD}) \geq 0 \quad (57)$$

Where we added the prefix REG to various terms in equation (57) to denote the fact that this equation represents a regulated utility computation.

The first term in equation (57), is computed in similar manner to that reported in equation (30), i.e.

$$REGCUMCF_{EPC}(t = N_{EPC}) = \sum_{k=1}^{k=N_{EPC}} \{REGNCF_{EPC}(k) \times (1+r)^{-K}\} \quad (58)$$

Where

$REGCUMCF_{EPC}(t = N_{EPC})$ – Regulatory approved discounted cumulative cash flow at the time of early plant closure in a regulated utility environment [M$]

$REGNCF_{EPC}(k)$ – regulatory approved annual cash flow in year k during the operations period in the early plant closure case, computed for a regulated NPP [M$/year]

The regulatory approved annual cash flow for a regulated NPP in an early plant closure case is determined from equation (28) where all the terms in the equation equally apply to the nominal plant operations case and to the earl plant closure case.

The regulatory approved and yet un-depreciated investment (remaining rate base) in the NPP is computed from the recursive equation (29), in Sub-section 11.2. In order to define an explicit expression for this term we use the simplifying assumption made in regards to equation (56) that REGCAPADD = REGCAPADD(t) × $P_{ALOW}(t)$ for all t, such that $1 \leq t \leq N_{EPC}$. With that, we can re-write equation (56) as

$$REGI(t = N_{EPC}) \approx REGI\ (t = 0) \times \{(N-N_{EPC}) / N\} + REGCAPADD \times (N_{EPC} / 2) \times (N_{EPC} / N) \quad (59)$$

All the other terms in equation (57) are computed in identical ways to the computation of the similar terms in equation (53). These terms equally apply to the regulated or non-regulated cases, assuming an early plant closure.

With these assumptions equation (57) can be numerically solved using the interpolative approach described above to compute N_{EPC} – the earliest, economically justifiable, date for NPP closure, in a regulated utility case.

14. UTILITY COSTS VERSUS PLANT COSTS

Some of the NPP costs discussed in the previous sections of Part II might be considered as general utility costs rather than plant specific costs, even though they are included in the above analysis for completion sake or due to current computational conventions. Thus during the plant construction period all owners' costs could be regarded as utility costs rather than plant costs. The conventional analytic methodology does however specify that at the start of commercial operations all costs incurred during construction, whether assigned to the utility or to the plant itself are converted into a new 'omnibus' operations investment, which represents the plant's initial investment in the non-regulated utility case, or the regulatory approved rate base in the regulated utility case, to be depreciated during the plant operations period.

We have mentioned during the discussion of the plant operated by a regulated utility in section 11 that all plant related costs deemed not prudent by the regulators either during the construction, operation, or decommissioning periods are passed to the utility and paid by the utility stockholders, rather than ratepayers. These then represent utility costs and not plant costs. It is possible to make the case that actual NPP decommissioning expenses in a regulated utility case are all utility costs rather than NPP expenses, since the plant stopped generating and has no net income base of its own except the decommissioning fund managed by the utility.

In this section, however, we deal with additional costs not yet discussed that are more clearly the responsibility of the owner utility rather than the plant, whether in a regulated or non-regulated environment.

14.1. Property tax and sales taxes

Property tax and sales taxes are specific taxes that the state and local communities impose on the utility to account for the value of the plant land and property constructed thereon, and to account for the sale of the plant's product – generated electricity – to customers. Property tax is levied against the value of the land area of the plant and of the facilities constructed. The value of this tax (tax rate schedules on land and facilities) will vary among different communities and countries. Usually these taxes are included in the plant owners' costs and are capitalized to the start of commercial operation and included in the rate base, together with all other construction related costs. Property taxes levied on the plant during the operations period are either included in the utility taxes statement or are considered part of the plant fixed O&M costs, depending on the more favorable tax treatment.

Sales taxes on electricity send-out by the plant are usually lumped together with all other similar sales taxes levies on generation by other plants owned by the utility, and are paid as a part of the utility consolidated annual tax payments. Given all other tax credits, deductions and exemptions, it is not clear what portion of the consolidated tax burden can be assigned to each plant separately.

14.2. Reliability costs and ancillary services costs

A regulated utility has to operate to a specified reliability standard – so many hours of unavailable generation in a year. In order to meet this standard, and account for planned and unplanned outages of generating facilities the utility must have on its system available generation reserve that can be called upon to meet the load if some of the operating power plants shut down. Likewise, each time the utility adds new generating plant to its system it must add a pre-specified fraction of that capacity as separate generation reserve to maintain its overall operational reliability criterion. Alternately, the utility can improve the capacity of its transmission network and upgrade transmission equipment within its grid. The utility costs in maintaining its generation reserve margin and its transmission network, so as to achieve its reliability goals represent an integrated reliability cost. This cost is integrated in a regulated utility and is a part of the non-plant-specific operations cost, born by the entire generation and transmission systems.

In a restructured utility the plant cannot rely on the owner utility to provide reliability services, and it must purchase reliability services, referred to as ancillary services, on its own. Ancillary services include: Regulation Reserve operated on automatic generation control and available to provide power to the grid within seconds; Spinning Reserve includes the unused portion of a generator's spinning capacity that can be called upon to provide power to the grid within ten minutes or less; Non-Spinning Reserve capacity which includes generators not connected to the grid that can ramp up and deliver energy to the grid within ten minutes; Replacement reserve which include generating plants that can start up, connect to the grid, and ramp up to specific capacity within one hour; and Voltage Support and Black start Services which help maintain grid voltage and frequency within pre-specified limits to maintain grid operation. We should recognize here that there exist different types of classifications of reserve categories and different countries might use different reserve definitions and performance requirements. The reserve breakdown mentioned here is used as an example only. The principle embodied in this discussion is however true, regardless of the exact reserve classification used.

Each power plant in a non-regulated utility must purchase these reliability services from the grid administrator agency for each MWh they inject into the grid or buy from the grid. To that extent the purchase of reliability (ancillary) services represents a tax-like cost burden on each MWh sold by the plant and reduces its net incoming revenues value. In practice, however, the purchase of ancillary services from the grid or market administrator agency is handled by the owner utility and not by individual plant. The reason is that the utility can integrate and consolidate its ancillary services purchases and credits across its entire power plant spectrum, each of which either performs a reliability service for the grid, purchases different class of reliability service from the grid, or does both at the same time. Due to these possibilities of ancillary services costs reductions through integrated bids, it is difficult to assign specific reliability cost to each power plant, unless the utility first figures its integrated system-wide cost and then distributes it among the generating plants based on actual generation by each plant at each time interval considered.

14.3. Replacement power costs

Replacement power costs are payments the plant or the utility on its behalf makes to purchase additional power, or to generate additional power from its other available power plants, if the plant can not meet its contractual obligations to deliver so many MWh and MWe to the grid within a specified time period. Particularly in a non-regulated environment the plant will attempt to contract out all its capacity and all the MWh it could generate in between two planned outages on the long term energy markets. Some more enterprising NPP managements will hold off a portion of the plant capacity and attempt to sell it in the better paying ancillary services markets or even on the real time and imbalance energy markets. NPPs could also provide grid stabilization services such as voltage support, or be declared as regulatory–must-run (RMR) plants, which guarantee them capacity payments whether they generate or are just available for generation.

All of the above depend on the plant being available to generate when the demand is there and contractual obligations are in force. However the plant is always subject to unplanned outages that cause complete or partial shutdowns in the midst of a normal operations period. Furthermore, when the plant is on a planned maintenance outage and is planned to resume commercial operation by a pre-determined date, it sometime happens that new problems are discovered, that specific equipment to be replaced was not delivered to the plant on time, or that the outage work was not executed as efficiently as planned. The result is that the plant must extend the outage period longer than planned and is unavailable to meet its contracted generation commitments during the extra outage period.

In the non-regulated world, the plant must also plan on delivering its ancillary services obligations. As mentioned above the energy market administrator agency might designate the NPP as a RMR plant, the NPP might have contracted to provide certain ancillary services to the grid, or the NPP must provide some reserve services to the grid in conjunction with the contracted-for generation it injects into the grid. The NPP might even have to purchase ancillary services for the replacement power it purchases.
In all such situations the plant or the owner utility must purchase replacement power on the short term energy markets, so as to fully deliver its contracted MWe and MWh obligations to the grid (either from its own resources, or from other owner utility resources, or from external purchased sources). The cost of purchasing replacement power instead of the power the plant contracted to deliver but could not do so on its own, is a (negative income) annual cost that the plant or the owner utility must pay. The higher the amount of purchased replacement power, the greater the reduction in the incoming revenues is and thus less is available to pay for plant operations costs, depreciation charges and decommissioning fund allowances.

In general the owner utility tries to consolidate all replacement power purchase requests from its plant fleet so it could get a lower cost for its purchases. In some cases the utility could call on other plants in its fleet to meet the shortfall and avoid having to purchase power from the outside. Since replacement power purchase is a utility expense it could well be a deductible item on the utility tax statement. Thus it may be in the utility interest to integrate all the replacement power purchase request of all its generating plants even in a restructured environment. It may be in the utility interest to ramp-up available capacity in some of its own plants rather than purchase outside replacement power. This will be determined by the difference between own-generation costs and external generation purchases. The regulated utility always manages replacement power issues on an integrated basis. Thus even though this is a plant specific issue, replacement power purchases may not appear on a non-regulated plant books, and may instead be consolidated in the owner utility books.

14.4. Pollution emission charges

An operating NPP does not emit harmful gases to the atmosphere as a result of fuel combustion in the power generation process. The more nuclear power or other non-fossil fuel generation resources such as hydro, wind, geothermal photovoltaic or even tidal power, are available, the less fossil generation is required to meet the utility contracted generation obligations, and the lesser amount of combustion process pollutants is emitted. Since most countries now tax fossil pollutant emissions, such as SO2, NOX, Mercury and in the future CO2 and all carbon-related emissions, the less fossil-fuelled generation the utility must call upon the lower the pollution charges it must pay. We should note that emission trading market in CO2 rights already exist in the European Union, whereas such trading is not instituted in the United States which does not subscribe to the requirements of the Kyoto Agreement.

The pollutant emission charges paid by the utility are also consolidated on the utility books for all the fossil power plants the utility operates and all the fossil based external power and replacement power it purchases. As mentioned in the previous discussion on replacement power, pollutant emission charges represent a deductible expense for the utility which lowers its taxable income. Thus, both from the perspective of the state which levies the pollutant emission charges on the utility as the responsible corporate entity, and from the utility's own desire to reduce its tax obligations, the pollutant emission charges are handled at the utility level, rather than at the individual fossil fired generating plant level.

From the NPP perspective, when it goes on an outage, the energy it does not generate is then generated by other fossil fired plant the owner utility operates or by purchasing replacement power from external sources. If these sources are other fossil fired plants within the same state, then the NPP owner utility might be responsible for the pollutant emission from those power plants providing the replacement power the utility purchases. Thus by incurring an outage, the NPP increases the overall pollutant emission charges its parent utility must pay. In a regulated utility, this is automatically charged to the utility consolidated pollution charges account. In a non-regulated environment it might be possible to claim that the incremental pollutant emission charges due to an NPP outage, particularly an unplanned outage, should be charged to the NPP itself. In most cases however, pollutant emission charges are handled at the utility level rather than being charged to individual plant accounts.

14.5. Payments for social services costs

An operating power plant causes a social disturbance in nearby communities. Those communities are called upon to provide housing, health care, education, transportation, recreation and other social services firstly to the construction crews and then to the plant's operating staff throughout the operations period. Local communities must increase and improve the level of social services they provide both to account for the long term presence of the plant staff in their communities, and to cater to the sometime higher service level expectation of the newly arriving plant staff members and their families. These expectations introduce a financial burden on the local communities which the owner utility, responsible to constructing the power plant in their midst, is called upon to help alleviate.

The utility then provides support to the local communities through the payment of property tax during construction and during the plant operations period. In some countries where the property tax venue of supporting local community services does not exist, other form of social services payments are introduced, depending on local customs, traditions and laws. Examples vary but they include support for local farmers who must give up their farm land for the plant site, support for local fishermen whose catch might suffer from the hot thermal plume emitted from the plant cooling water system, payment for maintaining the local police force – gendarmerie – and the local fire department which are tasked to provide emergency services to the plant, payments for the local school district, hospital, etc. All these charges are considered owner type costs and are charged to the utility owning the power plants rather than to the plants themselves.

When the plant is about to start on its decommissioning process the reverse phenomenon happens to a degree. With a significant portion of the plant staff leaving the community, the expanded social services, created in part to cater to their requirements, must now scale down their activities as the provision of the expanded level of services is no longer justified. There is a cost to shrinking a public service, just as there is a cost for expanding it. The utility might claim that it is no longer responsible as it stopped generating from the power plant, however it is still responsible for creating the problem to start with, and it will have to live with the local communities throughout the plant decommissioning period. Thus social services payment to the local communities will continue albeit in a modified form throughout of the remainder of the plant life span. All these costs are born by the utility rather than being charged to the generating plants themselves. This is particularly true when the utility plans to construct a new modern power plant on the existing decommissioned plant site.

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ANNEX

ECONOMIC IMPACT OF NPPs TO THE COMMUNITY

NPPs, like other industrial facilities, impact their local communities by creating jobs and stimulating the local economy through spending by the operating organization, its employees and contractors.

Systematic analysis of such impacts, for a certain extended period of time, is available by the use of macro economic models. The example presented here is the assessment done by the local bank (“Hokugin” Bank) on the impact of Kashiwazaki-Kariwa NPPs site, which has a generating capacity of 8.012 MWe from a seven Boiling Water Reactor fleet owned and operated by the Tokyo Electric Power Company of Japan. The construction of the nuclear plants was commenced in 1978 and ended in 1997. The assessment, made in 2001, looked into the economic impact on the Niigata Prefecture (population of 2.5 million), which has the NPP site in its jurisdictional boundary. Several variables to identify the impact by comparing the real case and the hypothetical case of having no such NPP site were selected.

Only a summary of the results of the study, without explanation of the assumptions made, is presented. The aim is to highlight that the economic impact upon the community should be considered. The results presented cover a relative short time span close to reactor start (thus not encompassing the full range of benefits), without parallel data on reactor's performance during the years of study.

The summary of the assessment shows the following impacts:

A-1. Population

Increased population of 30,000 (2.462 million versus 2.492 million) by 1997.

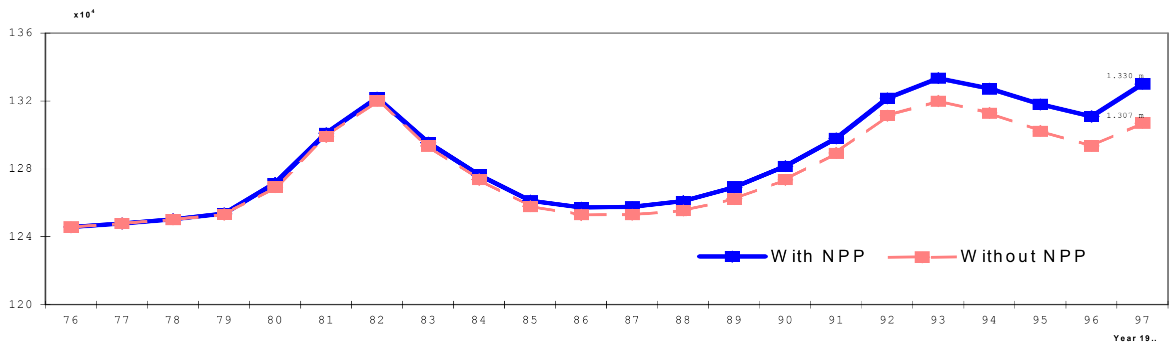

Fig. A.1 Impact to the prefectures’ population

A-2. Job increase

Increase of 23,000 jobs (1.330 million versus 1.307 million) by 1997.

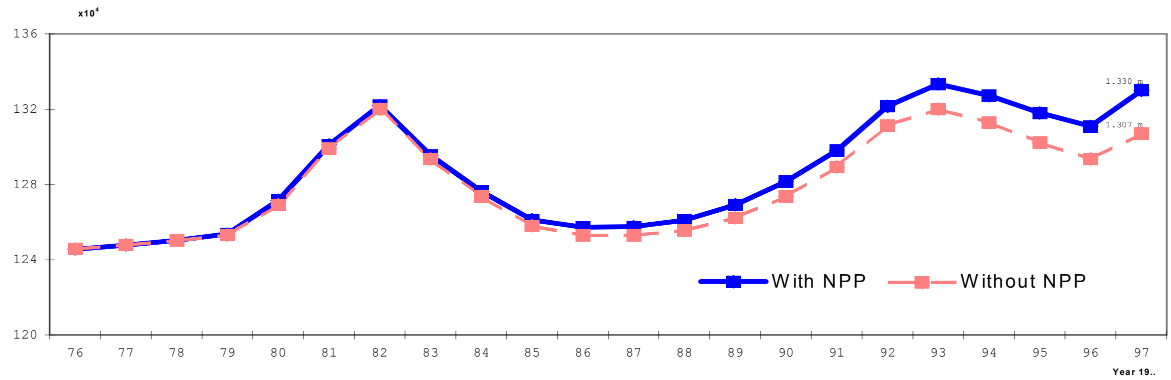

Fig. A.2 Impact to the prefecture's job

A-3. Local GDP

Increased local GDP of 5 Billion US$ (assuming currency exchange rate of 110 yen/US$) (84 Billion US$ versus 79 Billion US$) for year 1997 alone. Of this 5B US$ difference, 55% was from the production of electricity, as all the electricity produced by Kashiwazaki-Kariwa NPPs was transmitted to the Tokyo Metropolitan area and consumed there (the utility business is a local monopoly and the transmission line is not connected to the local grid). The rest of the share went to construction business, service sector and others. Figure 3 shows the historical trend.

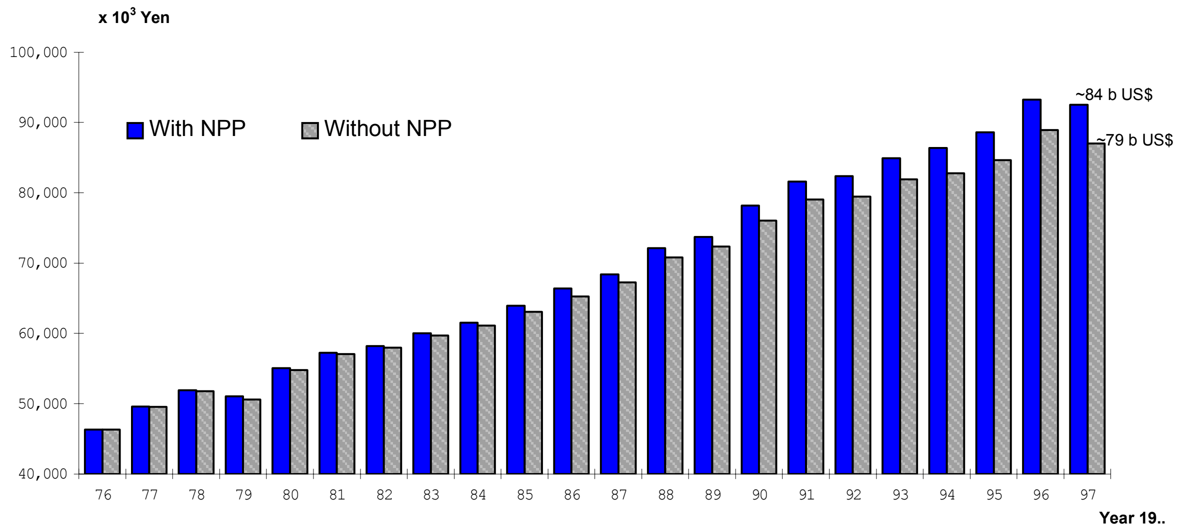

Fig. A.3 Impact on prefecture's GDP

A-4. Income to residents

Increased income of the residents of Niigata Prefecture of 3.3 Billion US$ assuming currency exchange rate of 110 yen/US$ (64.95 Billion US$ versus 61.65 Billion US$) for year 1997 alone. The increase was mostly for the employees (around half) and the local businesses.

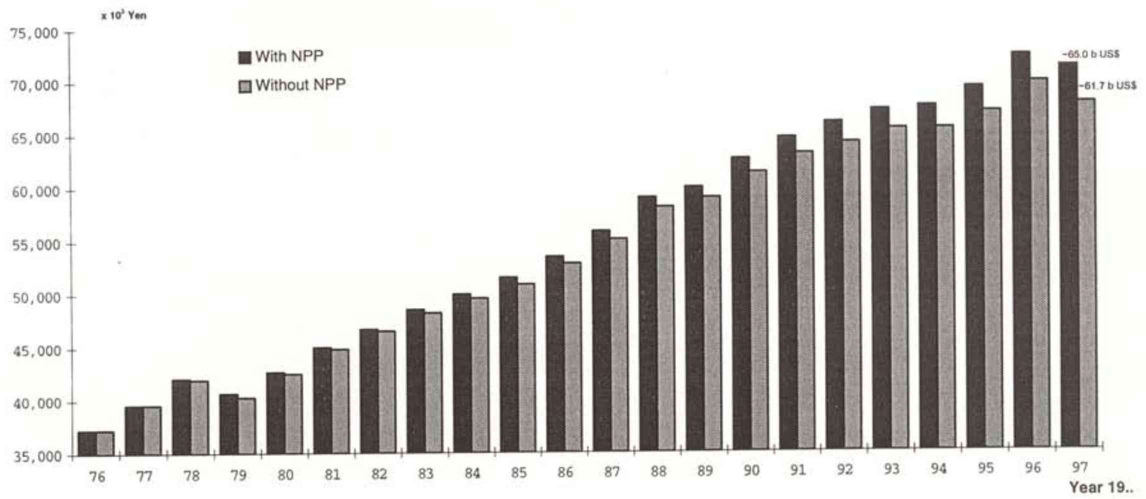

Fig. A.4 Impact on the income of the prefecture's residents

A-5. Local tax

Increased tax income of Niigata Prefecture of 0.19 Billion US$ assuming currency exchange rate of 110 yen/US$ (2.44 Billion US$ versus 2.25 Billion US$) for year 1997 alone.

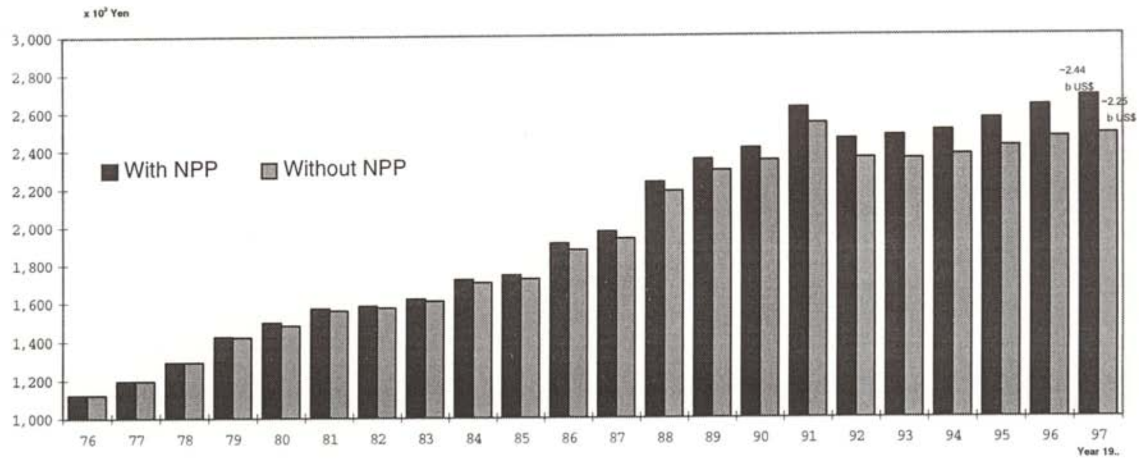

Fig. A.5 Impact on the prefecture's tax income

A-6. Income to the Niigata Prefecture

Increased income of Niigata Prefecture of 0.44 Billion US$ assuming currency exchange rate of 110 yen/US$ (11.34 Billion US$ versus 10.9 Billion US$) for year 1997 alone. Part of this increased income to the Prefecture is attributable to the subsidies from the Government to the local communities where NPPs are located in their jurisdictional boundaries. This subsidies system was established after the Arab Oil Embargo of 1974 by law, in order to diversify power-generating sources from oil and to assist the site of power stations not using oil as their fuel source.

Reference: Outline of the assessment published by TEPCO in 2001 (in Japanese)

CONTRIBUTORS TO DRAFTING AND REVIEW

Bazile, F.	Commissariat à l'Energie Atomique, France
Braun, C.	Stanford University, USA
Clark, C. R.	International Atomic Energy Agency
Condu, M.	International Atomic Energy Agency
Dahlgren Persson, K.	International Atomic Energy Agency
Facer, R.I.	International Atomic Energy Agency
Friedrich, R.	University of Stuttgart, Germany
Georgiev, J.	Ministry of Energy and Energy Resources, Bulgaria
Hagen, R.	Energy Information Administration, US Department of Energy, USA
Hopton, G.	British Nuclear Fuel Ltd., United Kingdom
Langlois, L.	International Atomic Energy Agency
Laraia, M.	International Atomic Energy Agency
Louis, P.	International Atomic Energy Agency
Omoto, A.	International Atomic Energy Agency
Pieroni, N.	International Atomic Energy Agency
Pryakhin, A.	International Atomic Energy Agency
Rogner, H.-H.	International Atomic Energy Agency
Vilemas, J.	Lithuanian Energy Institute, Lithuania
Wilson, D.J.	New Brunswick Power Nuclear, Canada

Consultants Meetings

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