Financial planning for the decommissioning of a nuclear power plant

Rolf Sjöblom[1], Anna Cato[2,3] and Staffan Lindskog[2]

(1) Luleå University of Technology / Tekedo AB
(2) Swedish Radiation Safety Authority
(3) Now at the Swedish Nuclear Fuel and Waste Management Company

LULEÅ UNIVERSITY OF TECHNOLOGY

TEKEDO

The structure of this presentation

1. The Swedish Nuclear Power programme(s)
2. Swedish NPP cost calculations
3. Objective
4. International perspective – method
5. International perspective – calculations
6. The California experience
7. The Barsebäck NPP
8. Discussion and conclusions

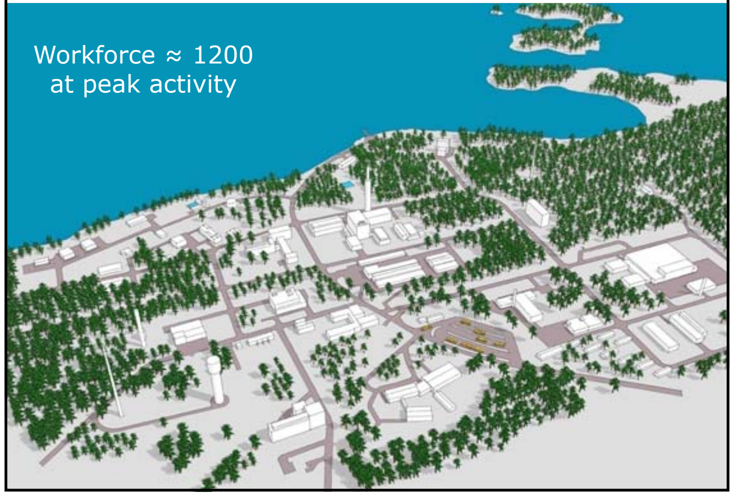
The structure of this presentation

1. The Swedish Nuclear Power programme(s)
2. Swedish NPP cost calculations
3. Objective
4. International perspective – method
5. International perspective – calculations
6. The California experience
7. The Barsebäck NPP
8. Discussion and conclusions

Quote taken from a compilation of the history of nuclear technology published by the American Nuclear Society

”*Only six countries took part in the rush to build the first nuclear power stations – the United States, the United Kingdom, France, the Soviet Union, Canada and Sweden. All other countries were in due course to turn to one or another of these pioneers for assistance with their first power reactors and subsequent nuclear construction programs*.”

The ”national laboratory” at Studsvik ≈ 1964



The Swedish heavy water NPP programme

- First Swedish reactor started in 1954 (a research reactor)
- The Ågesta Nuclear Power Plant
  - In operation 1963-1973
  - Total capacity 65 MW
    - Electricity 10 MW
    - District heating 55 MW
- The Marviken NPP, built but never commissioned

The Ågesta nuclear power plant in operation 1963-1973

Sweden one of six countries to build first nuclear power reactors

The Swedish light water NPP programme

- Shift in paradigm - Oskarshamn 1 contract signed in 1965
- BWR’s of ASEA-ATOM design, commissioned in 1972-1985
  - Oskarshamn 1-3
  - Barsebäck 1-2
  - Forsmark 1-3
  - Ringhals 1
  - Olkiluoto (Finland) 1-2
- PWR’s of Westinghouse design: Ringhals 2-4

Comparison between the ASEA-ATOM reactors

- Barsebäck 1-2 capacity each of 1800 MWt
  - B1 in operation 1975 – 1999
  - B2 in operation 1977 – 2005
- Closed as a result of political decisions
- Significant differences in design between early and late ASEA-ATOM reactors
- Large similarities between Oskarshamn 2 and Barsebäck 1 and 2

2 out of a total of 12 modern Swedish NPP:s have been closed

The structure of this presentation

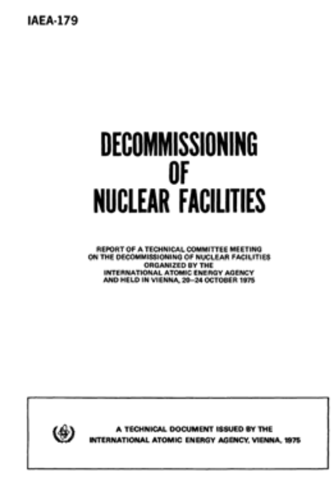
1. The Swedish Nuclear Power programme(s)
2. Swedish NPP cost calculations
3. Objective
4. International perspective – method
5. International perspective – calculations
6. The California experience
7. The Barsebäck NPP
8. Discussion and conclusions

Decommissioning awareness

- No mentioning of decommissioning in 517 reports published by Studsvik during 1956 and 1977
- First record in 1975 in
  - The AKA inquiry on radioactive waste and spent nuclear fuel
  - IAEA meeting on decommissioning with Swedish participation
- First Swedish decommissioning cost estimate in 1979

The AKA public enquiry 1973 - 1976

- State-of-the-art on spent nuclear fuel and radioactive waste
- Part of the planning process for the modern light water reactor programme
- AKA proposed:
  - *Research*: Programme Council for Radioactive Waste (PRAV)
  - *Finance*: Costs to be carried by the nuclear utilities


IAEA-179

DECOMMISSIONING OF NUCLEAR FACILITIES

REPORT OF A TECHNICAL COMMITTEE MEETING ON THE DECOMMISSIONING OF NUCLEAR FACILITIES ORGANIZED BY THE INTERNATIONAL ATOMIC ENERGY AGENCY AND HELD IN VIENNA, 20–24 OCTOBER 1975

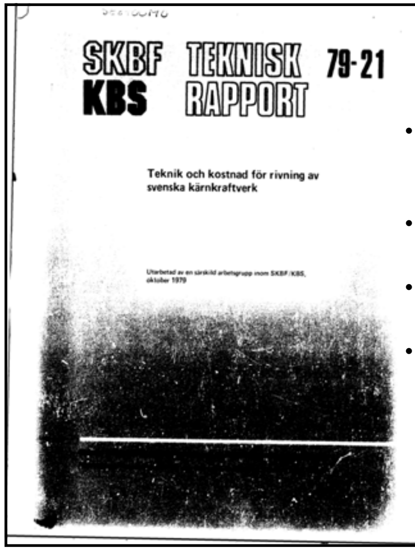
A TECHNICAL DOCUMENT ISSUED BY THE INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1975

A long journey

- Between the first controlled nuclear chain reaction in 1942
- And the first IAEA meeting on decommissioning in 1975

  in which the Swedish delegation stated the following:

  "*The current approach to decommissioning studies is to convene a specialist team with back-up resources to deal with situations as they arise*"


SKBF KBS TEKNISK RAPPORT 79-21

Teknik och kostnad för rivning av svenska kärnkraftverk

Utarbetad av en särskild arbetsgrupp inom SKBF/KBS, oktober 1979

But the Swedes didn't actually drag their feet

- First study of NPP decommissioning & associated cost in 1979
- B1 / O2 reference units 600 MW each
- Cost (including waste) = 10 – 15 % of new plant
- Cost estimate
  - 500 MSEK at 1979 level
  - 1581 MSEK at 2012 level
  - 178 M€ at 2012 level
  - 146 M£ at 2012 level
  - 233 M$ 2012 level

Decommissioning cost calculations for one of the reactors at Barsebäck

	1979	SKB 2004 [1]	TLG 2008 [1]
MSEK 1979	500		
MSEK 2004		802	
MSEK 2005			1632
MSEK 2012 [2]	1581	912	1848
M€ 2012	178	102	208
M£ 2012	146	84	171
M$ 2012	233	134	272

1. Differences between TLG and SKB/Westinghouse discussed/explained in SKB R-09-55
2. Swedish consumer price index used for calculation

IAEA 1975 decommissioning report

- Decommissioning is technically feasible
- Cost calculations are important for obligations to society & acceptance
- Need to establish standard method(s) with
  - Standardized itemisation, and
  - Unit cost factors
  - Potential cost raisers such as decontamination costs separate
- Open exchange of
  - Technology used
  - Costing information
  - Collective dose

The structure of this presentation

1. The Swedish Nuclear Power programme(s)
2. Swedish NPP cost calculations
3. Objective
4. International perspective – method
5. International perspective – calculations
6. The California experience
7. The Barsebäck NPP
8. Discussion and conclusions

Prerequisites

Principle	The polluter pays (subsidarity principle)
Corollary	It is those who benefit from e g nuclear electricity generation that should pay all the future costs for decommissioning and waste management
Implications	1. Cost must be estimated 2. Appropriate funds accumulated 3. Money available when needed

Purpose and scope

- Generic reasons for the deviations
- Barsebäck NPP specific reasons for the deviations
- To qualitatively analyse the significance of potential cost raisers
- To attempt to identify possibilities for improvement
- Lessons learned that may be of interest outside the circle of nuclear decommissioning specialists

The structure of this presentation

1. The Swedish Nuclear Power programme(s)
2. Swedish NPP cost calculations
3. Objective
4. International perspective – method
5. International perspective – calculations
6. The California experience
7. The Barsebäck NPP
8. Discussion and conclusions

Cost estimation methodology

- AACE International (Association for the Advancement of Cost Engineering)
  - Has been instrumental in the development of cost estimation methodology
  - Founded in 1956
- Response to need of chemical and other industries
- The need is different at different stages of planning for a new facility

Strongly maintained by AACE International

- A cost figure has no meaning unless it is associated with the pertinent uncertainty

At least three stages can be identified (IAEA-TECDOC-1476 from the year 2005)

- ***Order-of-Magnitude Estimate***: One without detailed engineering data. Expected level of accuracy ***-30% to +50%.***
- ***Budgetary Estimate***: One based on the use of flow sheets, layouts and equipment details. Expected level of accuracy ***-15% to +30%.***
- ***Definitive Estimate***: One where the details of the project have been prepared and its scope and depth are well defined. Expected level of accuracy ***-5% to +15%.***

Techniques for estimation of cost From *decommissioning handbook*

- ***Bottom-up.*** Quantities derived from e g drawings are multiplied with per unit costs from previous facilities.
- ***Specific analogy***. As bottom-up but with adjustments to account for differences in relative complexity of performance e t c
- ***Parametric.*** Historical databases and statistical analyses => cost equations / cost estimating relationships

Method versus stage, according to textbook knowledge

Order of magnitude -30 % to + 50 %	Parametric technique [1] others possible
Budgetary estimate -15 % to + 30 %	All possible
Definite estimate -5 % to + 15 %	Bottom-up technique [2] others possible

1. Parametric technique = parameter values used in mathematical expressions derived from statistical analyses of historical data
2. Bottom-up technique = sums over {amounts multiplied by unit costs derived from e g previous projects}

Experience from cost estimation at early stages

- Bottom-up technique
  - Either insurmountably tedious
  - Or gives results that are systematically too low
- Parametric technique
  - ”*Early costing cannot be done effectively any other way*”
  - According to ISPA = International Society for Parametric Analysis

C. Peter Rapier:
Toolmaking for Better Conceptual Estimates,
AACE Transactions, 1977

However, the facts of life are that very few companies value and maximize use of their feedback. Fewer still do anything in the way of casting their cost data into a useful form for application on future estimates. What happens is that, to get credibility into their conceptual estimates, companies resort to making preliminary designs and takeoffs to develop the estimate. Then after doing all that, they still lack faith in the results because the project has not really been designed yet. They know from experience there will be many changes to the details before the design is completed. This is a waste of engineering energy.

Discovered in the 1970's, cont

- *Parametric cost estimating* utilises
  - existence of numerical relations between ”system attributes” (e g a sub-system) and cost
  - relations not necessarily linear
- *Parametric cost estimating* implies / requires
  - That existing data must be sufficiently abundant to allow mathematical/statistical analysis (typically several completed facilities)
  - That existing data from completed facilities must be thoroughly analysed
  - That analysis of a plant at early stage of planning becomes simple, in comparison with other methods

ISPA Parametric Estimating Handbook

- *“Database development;*
- *Model Requirements;*
- *Resolution of model architecture and data availability;*
- *Model development;*
- *Model calibration and validation;*
- *Model documentation;*
- *Model updating.*"

The structure of this presentation

1. The Swedish Nuclear Power programme(s)
2. Swedish NPP cost calculations
3. Objective
4. International perspective – method
5. International perspective – calculations
6. The California experience
7. The Barsebäck NPP
8. Discussion and conclusions

Nuclear decommissioning

- Almost exclusively bottom-up
- Reasons include
  - Facilities exist and all items can readily be identified
  - Initially, the number of facilities decommissioned was low, thus making statistical analysis difficult
  - Focus on imminent decommissioning, less on assurance of financial resources in distant future

Deviations / agreement between plants, and between calculated and incurred costs

- OECD/NEA* 1991 ”*Decommissioning of nuclear facilities; an analysis of the variability of decommissioning cost estimates*”
  - Conclusion: Numbers should vary between different reactors
- OECD/NEA* 2003: ”*Decommissioning of nuclear facilities; Policies, Strategies and Costs*”
  - Conclusion: increased precision by bottom-up with
    - Improved items list
    - Improved scope and other cost raisers

* NEA = Nuclear Energy Agency

Last five years plus of international meetings

- Many sessions on lessons learned in decommissioning
- Few presentations on uncertainty in cost calculations
- Maintained by LaGuardia - founder of and affiliated to TLG Services - that agreement between calculated and incurred costs are
  - 8,8 % for Maine Yankee (880MWe PWR), and
  - About 6 % for Big Rock point (60MWe BWR)

  Paper also explains when calculations go wrong (NEA International workshop, Rome, 2004)

Proportionality and linearity

- The bottom-up technique essentially based on proportionality
- Discovered already in conjunction with the decommissioning of the small Elk River reactor in 1974:
  - Costs unrealistically high for modern NPP:s if proportionality is assumed
  - Might compete with that of building an NPP
- Lead to development of the UCF (Cost Unit Factor) method with weighing scheme based on difficulty

Proportionality and linearity, continued

- NRC (US Nuclear Regulatory Commission) prescribes linearity
- SKB (The Swedish Nuclear Fuel and Waste Management Company) has (largely) used proportionality

The structure of this presentation

1. The Swedish Nuclear Power programme(s)
2. Swedish NPP cost calculations
3. Objective
4. International perspective – method
5. International perspective – calculations
6. The California experience
7. The Barsebäck NPP
8. Discussion and conclusions

Public Utilities Commission of the State of California

- Had found lack of transparency and comparability of the decommissioning cost estimates provided for Commission review
- The commission therefore ordered an independent Panel of decommissioning experts to review cost estimates
- Report on March 1st, 2011
- Commission decision on July 14th, 2011

Examples of Panel Conclusions 1

- any conclusions about future decommissioning costs "*involve a significant amount of informed speculation about events that will only be fully understood in the future…and which may resemble historical events to a greater or lesser degree as circumstances change*."

Examples of Panel Conclusions 2

- the Panel found substantial barriers to comparing prior decommissioning experiences because reported estimates and costs from around the country are not always public, or even similar in what activities are included and the information disclosed

Examples of Panel Conclusions 3

- With the exception of Rancho Seco, all actual costs appear to exceed estimated costs by varying margins, e.g., Connecticut Yankee exceeded estimates by 82% and SONGS 1 by 32.5%.
- However, the Panel presented these results more as indications than actual factual findings due to the challenges of comparison.

Examples of Panel Conclusions 4

- As noted above, there were numerous problems in obtaining accurate and comparable figures.
- For example, some information is withheld as proprietary, public records can be incomplete, and estimates may not include identical activities or may even omit key elements such as site restoration.

Examples of Panel Conclusions 5

- Eight items were identified that account for 99.4% of the cost difference between SONGS 2 and 3, and Diablo Canyon 1 and 2.
- By a large margin, the assumed site condition at the end of decommissioning is the primary difference between the estimates

Examples of Panel Conclusions 6

- Historical experience in the U.S. has provided no consensus on the best way to decommission a nuclear plant because every site has different challenges, technology is improving, and new ideas are borne from experience.

Examples of Panel Conclusions 7

- The Panel was asked to develop a common format for decommissioning cost estimates that would result in greater transparency and comparability.
- However, the fact that cost estimators use proprietary and substantially different decommissioning cost models to develop their estimates, combined with the unique aspects of decommissioning SONGS, make a common cost model impractical.

Examples of Panel Conclusions 8

- The panel found a key error that reduced the Palo Verde estimate by about half.
- It took a lot of digging by the Panel and SCE to figure out that a double counting of waste volume had occurred.

Conclusions from the California experience

- Tempting to conclude that estimates on the costs for decommissioning of NPP’s are generally unreliable
- Should be observed that good precision has been obtained in some well defined cases
- (c f LaGuardia above with agreements estimated / incurred ´within 10 %)

The structure of this presentation

1. The Swedish Nuclear Power programme(s)
2. Swedish NPP cost calculations
3. Objective
4. International perspective – method
5. International perspective – calculations
6. The California experience
7. The Barsebäck NPP
8. Discussion and conclusions

The Barsebäck Nuclear Power Plant

Decommissioning cost calculations for one of the reactors at Barsebäck

	1979	SKB 2004 [1]	TLG 2008 [1]
MSEK 1979	500		
MSEK 2004		802	
MSEK 2005			1632
MSEK 2012 [2]	1581	912	1848
M€ 2012	178	102	208
M£ 2012	146	84	171
M$ 2012	233	134	272

1. Differences between TLG and SKB/Westinghouse discussed/explained in SKB R-09-55
2. Swedish consumer price index used for calculation

Comparison between calculations on the Barsebäck NPPs

- The SKB 1979 and the TLG studies were made on the two mutually very similar reactors at Barsebäck
- The SKB/Westinghouse estimate of 2004 was based on the much larger reactor Oskarshamn 3
  This result was scaled to the much smaller reactors at Barsebäck largely assuming proportionality

No cost raisers identified

- All piping and vessels are made of well characterized stainless steel
- Concrete surfaces are covered by epoxy
- Primary system has been decontaminated
- There have been no relevant incidents
- No active pipes are buried directly in the soil
- Asbestos has already been removed (mostly)
- There have only been few fuel leaks

Pipe systems at the Barsebäck NPP

Floor covered with epoxy paint

The structure of this presentation

1. The Swedish Nuclear Power programme(s)
2. Swedish NPP cost calculations
3. Objective
4. International perspective – method
5. International perspective – calculations
6. The California experience
7. The Barsebäck NPP
8. Discussion and conclusions

Conclusions

- Assumption of linearity better than that of proportionality
- Most cost estimations
  - Refer to early stages,
  - But use the bottom-up method
  - In spite of the systematic errors
- Possible reasons for lack of consistency:
  - Historic reasons
  - Bottom-up will have to be used eventually
  - Barriers against sharing of data

Conclusions, continued

- Swedish cost estimates internationally low at around 2003 according to OECD/NEA (NEA = Nuclear Energy Agency)
- One contributing factor overestimation of the influence of size
- Nothing found that would contradict that the TLG report represents state of the art
- Differences found for Barsebäck NPP within ranges observed elsewhere

Conclusions, continued

- However, better agreement is assessed to be attainable
- E. g. intercomparison can be improved
- No new cost raisers identified
- Decommissioning of the Barsebäck reactors in a few years time offers excellent opportunities for further development of cost estimation techniques
- It is suggested that parametric techniques be included in any such work

Conclusions, continued

- The present example of more than 30 years of cost estimations for the Barsebäck reactors illustrates some of the challenges that one may face in fulfilling obligations under the polluter pays principle
- This experience should be used in areas with more recent awareness and legislation