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Planning for Decommissioning of Ontario Power Generation's Nuclear Facilities

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Abstract

Ontario Power Generation owns and operates nuclear generating stations at Pickering and Darlington and has leased Bruce generating stations A and B to Bruce Power (who will return them to OPG once the lease expires). OPG owns and operates interim radioactive waste management facilities on the Bruce site and used fuel storage facilities at Pickering and Bruce sites and plans are underway to design and build a similar facility on the Darlington site by 2007. OPG will decommission all these facilities when they are shutdown permanently.

Planning for decommissioning at OPG started in the early 1980's when various options were conceived, subsequently developed and suitable strategies was formulated. OPG's plans for decommissioning the nuclear generating stations are to shutdown and store the stations in a safe storage mode for 30 years, followed by dismantling and site restoration. Plans for decommissioning of OPG's interim radioactive waste management facilities will involve: removal of the stored waste, re-packaging if required and transporting the waste to a long-term facility followed by dismantling the facilities and site restoration. The costs for decommissioning OPG's nuclear facilities are estimated based on the above plans, collected through electricity rates from customers and deposited in a decommissioning fund.

This paper examines some of the decommissioning options considered, provides details of OPG's decommissioning strategy, gives cost estimates, and outlines OPG's achievements towards meeting its liabilities and fulfilling the regulatory requirements with respect to decommissioning.

Current Status of OPG's Nuclear Facilities

Ontario Power Generation owns and operates CANDU nuclear generating stations (NGS) at Pickering and Darlington and has leased Bruce generating stations A and B to Bruce Power (who will return them to OPG once the lease expires). Pickering NGS A & B comprise of four 515 MWe units each, Darlington NGS comprises of four 880 MWe units and Bruce NGS A & B comprise of four 750 MWe units each, totaling 20 CANDU reactors and associated support facilities. OPG's tritium removal facility is located on the Darlington NGS site. Various other auxiliary support facilities will be added to the stations as and when required.

OPG's Pickering NGS A is the oldest of its nuclear fleet and was brought in to service in 1971. For planning purposes, OPG currently assumes that all its NGSs will operate on a 40-year life cycle. Based on this reference 40-year life cycle, the planned shut down date for Pickering NGS A is 2011. However, Pickering NGS A was shut down in 1998 and is currently undergoing upgrades to re-start the shut down

reactor units. Bruce NGS A, which came into service in 1977 and shut down in 1998, is also currently undergoing upgrades to re-start the shut down reactor units. Furthermore, plans for future re-tubing of some reactor units are being assessed. When the shut down reactor units are brought into service and plans for re-tubing of reactors are approved, the shut down dates for these reactors will no longer be based on the reference 40-year life cycle. The reference life-cycle plans will be revised to establish new shut down dates for these NGSs and their decommissioning planning assumptions will be updated accordingly.

OPG owns and operates interim radioactive waste management facilities to store the radioactive waste generated from OPG's and Bruce Power's reactors on the Bruce site and used fuel storage facilities at Pickering and Bruce sites and plans are underway to design and build similar facilities on the Darlington site by 2007. The Western Waste Management Facility (WWMF) located on the Bruce site started operation in 1974 to store low and intermediate level radioactive waste from OPG's and later Bruce Power's stations. This facility has been expanded several times. The WWMF now includes separate processing and storage buildings for storage of used fuel in Dry Storage Containers (DSCs). WWMF will continue to be expanded until all of OPG's and Bruce Power's reactors reach end of life. OPG's reference plans are to transfer all stored low and intermediate level waste from WWMF to a disposal facility prior to decommissioning its sections for low and intermediate level waste storage.

In April 2002, the Municipality of Kincardine and OPG signed a Memorandum of Understanding to develop a plan for a long term management facility for low and intermediate level waste on the Bruce Site. It is assumed that when this plan is fully developed and approved, OPG's low and intermediate-level waste from decommissioning will be deposited in this facility.

Used fuel from Pickering NGS A & B and Bruce NGS A & B are transferred into DCSs and are being stored in DSCs at the Pickering Waste Management Facility (PWMF) located on the Pickering site and the WWMF respectively. Used fuel from Darlington NGS will be transferred into DSCs and stored in the Darlington Waste Management Facility (DWMF) starting in 2007. Some used fuel will remain in station water pools following station shutdown. The used fuel will be stored in DSCs and water pools until a long term used fuel management strategy for Canada is determined and implemented. For planning purposes, OPG has assumed that all used fuel will be transferred from station sites to a long term used fuel management facility by 2064. Decommissioning of PWMF, DWMF and used fuel storage facilities at WWMF will commence after all the used fuel is removed from these facilities.

Decommissioning Options Considered

Planning for decommissioning of OPG's NGSs started in the 1980s. Decommissioning of NGSs involves the dismantling of radioactive and non-radioactive systems and structures. Dismantling the radioactive parts of the stations is considered to be the most challenging and labour and cost intensive parts of decommissioning. Hence, reducing the amount of radiation exposure to workers, public and the environment was one of the most important factors considered when developing the strategy for decommissioning. Other important factors considered were cost to customers and social acceptability of the strategies. Three basic decommissioning options were considered and a suitable strategy was selected based on the above factors as OPG's reference plan. The decommissioning options considered were:

(a) Immediate Dismantling, where the reactors and station will be dismantled and the site restored immediately after shut down,
(b) Safe Store, where after shut down, the reactors and stations will be safely stored for several decades to allow radiation levels to decay prior to dismantling and site restoration, and

(c) Entombment, where after shut down, the non-radioactive parts of the station will be dismantled and the radioactive parts will be entombed until the radioactivity has decayed to a level that allows workers to dismantle the entombed parts using simple tools.

Table 1 shows the ratings of the three options considered.

Table 1, Summary of Decommissioning Options Considered

Option	Amount of Radiation Exposure	Cost to Customers (NPV)	Social Acceptability	Comments/Other Factors
Immediate Dismantling	High	High	High	• Staff familiar with NGSs available • Radiation hazard is removed immediately from site • Security risk to public eliminated immediately • No maintenance of buildings required • No radioactive waste disposal facilities available • Technology not fully developed
Safe Store	Medium	Low	Medium	• 30 year safe store period • Radiation hazard will decrease during storage period • Security risk to public will remain for duration • Buildings can be made to remain in-tact with moderate maintenance for a 80 year life cycle • Radioactive waste disposal facilities will be available • Technology will be more developed • Staff familiar with NGSs may be available
Entombment	Low	Medium	Low	• 100 year or more entombment period • Radiological hazard will decrease further, but will remain on-site • Security risk to public will remain for duration • Safety of entombment structure not known and cannot be predicted, may require periodic maintenance/upgrades • Staff familiar with NGSs not available

NPV : Net Present Value

The amount of radiation exposure during decommissioning is dependent on the radionuclides present in the station after shut down. Once the irradiated fuel is removed, the most dominant radionuclide contributing to radiological dose in nuclear reactors is Cobalt-60 (Co-60), see Figure 1[(1)]. Co-60 is found in activated steel structures (reactor core) and as a corrosion product in nuclear process systems. Co-60 is a strong gamma emitter with a relatively short half life of 5.3 years and remains the dominant radiological hazard for several decades after shutdown. After about 30 years of decay, the level of Co-60 activity

would be reduced by almost two orders of magnitude and would have a minimal contribution to radiological dose.

Although dismantling costs fall over time, the costs of ensuring the safety of structures containing a significant quantity of radioactivity will increase with time and become unpredictable. Deferring costs far into the future was found to be financially non-prudent and would make it difficult to allocate these costs fairly to customers who benefit. When the three options described above were compared, it was concluded that deferred dismantling will be the most suitable option for decommissioning OPG's NGSs and when the costs of maintenance and controls, surveillance and loss of site availability are considered, 30 years was considered a reasonable time to defer dismantling [(2)].

Based on the above factors, OPG has adopted the Safe Store option with a 30 year deferred dismantling strategy as the reference option for decommissioning its NGSs. Since there are no activated structures in radioactive waste storage facilities, dismantling is assumed to begin immediately after the stored waste is removed.

Options Considered for Dismantling NGSs - Early Studies

The most technically challenging and potentially cost intensive task in decommissioning of a CANDU NGS will be the dismantling and disposal of the Calandria and internal components, which have become highly radioactive after a lifetime of exposure to radiation produced in the core. Therefore, it is important to investigate and develop suitable options for dismantling these components early in the planning stages of decommissioning. Several factors were considered for dismantling OPG's CANDU reactors:

- Availability of radioactive waste disposal facilities, their timing and location
- Location of stations, their transportation access, i.e., road, rail and water (barge)
- Nuclear material transportation regulations
- Radiological dose to workers
- Dismantling technology
- Cost to customers
- Environmental impacts
- Social acceptability
- International experience

One option for dismantling reactors is the piece-by-piece method, where the reactor is cut up into small pieces that will fit into approved transportation packages and shipped to an off-site disposal facility. Figure 2, describes the concept of piece-by-piece dismantling of a CANDU reactor [(3)]. Shipping to an off-site disposal site may be achieved by one, or a combination of, road, rail or barge. Depending on where the disposal facility is located (if not located on or close to the shore of a Great Lake), barge shipments may require intermediate trans-shipment facilities and transport by another mode to the disposal facility. Rail shipments may be suitable from Pickering or Darlington, however there are no railways close to the Bruce site and it was not known if rail will be provided to the disposal facility. Assuming that there will be good road access to the disposal facility, transport by road from all NGSs to the disposal facility appears to be the only mode without any of the restrictions or unknowns associated with the other modes.
The other option is to remove the reactor as one-piece without cutting up and dispose of it either on-site or at an off-site disposal facility. The one-piece removal and on-site disposal option was developed in concept for the Bruce NGS reactors. With this option, the shield tank of the Bruce reactors will be used

as the reactor's own disposal container and the reactor package will be deposited directly beneath its present location in a specially built vault along with other radioactive waste, see Figure 3 A. The geology of the Bruce site is most suited for this type of disposal compared to OPG's other sites (i.e., Pickering or Darlington). This option would result in an integrated and optimized approach to dismantling, transportation and disposal. This option was presented to the international decommissioning community [4, 5, & 6] and received favourable reviews as a safe, low cost and technically sound alternative to piece-by-piece dismantling and off-site disposal. Other variations of this option were also considered, see Figure 3 B. However, further development was not pursued at the time due to unknowns associated with the social acceptability of these concepts.

The one-piece removal and off-site disposal of reactors would require transportation of the reactor packages via international waterways. This option was abandoned due to the unknowns associated with this mode of transport.

Based on the above, and for planning purposes, OPG has adopted a conservative strategy for dismantling and disposal of the reactors, i.e., piece-by-piece dismantling and road transport to an off-site disposal facility.

Decommissioning Plans

Planning for decommissioning of OPG's nuclear facilities is based on a number of fundamental assumptions:

- Prior to shut down of the NGSs and radioactive waste facilities, OPG will conduct a public information program, perform an environmental assessment of the decommissioning and apply for a Licence to Decommission from the Canadian Nuclear Safety Commission (CNSC) [7],

- Following approval by the CNSC, OPG will decommission the NGSs using the deferred dismantling strategy and dismantle radioactive waste facilities immediately after all stored waste has been removed,

- All radioactive waste resulting from decommissioning will be disposed of at an off-site waste disposal facility,

- Deferred dismantling of NGSs will have three phases:

    - Phase 1, preparation for safe storage, where the reactors will be shut down in an orderly manner, used fuel and heavy water will be removed, reactor systems will be decontaminated and the station will be placed in a safe storage mode,

    - Phase 2, safe storage, where the station will be in a safe storage mode and monitored by a small staff for up to 30 years, and

    - Phase 3, dismantling, disposal and site restoration, where reactors are dismantled in sequence, radioactive wastes are sent to disposal and the site is restored to acceptable regulatory criteria, and

- After decommissioning is complete, a Licence to Abandon the site will be obtained from the CNSC [7].

Using the reference 40-year operating life for NGSs and the deferred dismantling strategy with a safe storage period of 30 years, PNGS A, which was brought into service in 1971, will be fully decommissioned by 2050. Similarly, decommissioning will be completed for BNGS A by 2056, PNGS B by 2062, BNGS B by 2063 and DNGS by 2070.

Although OPG has assumed that all radioactive waste from decommissioning will be disposed of at an off-site waste disposal facility, this assumption will be revisited for the Bruce reactors once the proposed long term management facility for low and intermediate level waste on the Bruce Site is approved. In October 2004, the Municipality of Kincardine and Ontario Power Generation reached an agreement on the terms and conditions under which Kincardine would volunteer to host a Deep Geologic Repository (DGR) facility, subject to achieving all regulatory approvals. This proposed GDR will be comprised of a series of underground emplacement rooms horizontally-excavated and arranged in parallel rows with access provided via two vertical concrete-lined shafts. The emplacement rooms are assumed to be constructed at a depth of about 660 m within limestone. After the approved facility is constructed, the initial operating phase would begin in about 2018, when low and intermediate level waste from WWMF will be transferred to the facility. Future phases of the facility would involve construction of additional emplacement rooms and is assumed to be kept open for a total of about 50 years for accepting low and intermediate level waste from reactor operation and decommissioning of OPG's nuclear facilities [8].

Planning for used management is not covered under decommissioning of OPG's nuclear facilities. Although some used fuel will be stored in the station pools for several years prior to transfer to a long term used fuel management facility, plans and costs for these storage activities are accounted for elsewhere. Decommissioning of WWMF, PWMF and DWMF will begin following transfer of the used fuel stored in DSCs to a long term used fuel management facility by 2064, and will be completed by 2066.

Table 2 shows the estimated low and intermediate level radioactive waste quantities from decommissioning OPG's nuclear facilities. Figure 4 shows the estimated annual arisings of radioactive waste from decommissioning of OPG's NGSs.

Table 2, Estimated L&IL Waste Quantities from Decommissioning OPG's Nuclear Facilities

OPG Nuclear Facility	Low Level Waste (m^3)	Intermediate Level Waste (m^3)	Total (m^3)
PNGS A	20,200	2,000	22,200
BNGS A	15,700	2,500	18,200
PNGS B	14,300	2,000	16,300
BNGS B	16,800	2,500	19,300
DNGS	16,800	3,100	28,500
WWMF	2,941	-	2,941
PWMF	66	12	78
DWMF	100	-	100
Total	95,407	12,212	107,619

OPG has prepared Preliminary Decommissioning Plans (PDPs) based on the above planning assumptions for all its nuclear facilities and submitted them to the CNSC. The PDPs are required by the CNSC for issuing Operating Licences for these facilities [7].

The PDPs contain an overview of the existing knowledge of the facilities and a decommissioning approach that is technically and financially appropriate in the interest of the health, safety, security and protection of the public and the environment. The topics covered in the PDPs include: the preferred decommissioning strategy and end-state objectives, the major decontamination, dis-assembly and remediation steps, the estimated quantities and types of waste generated, and overview of the hazards and impacts of decommissioning activities on humans and the natural environment and protection strategies, an estimate of cost and the methods of guaranteeing financing for the decommissioning activities as required by the CNSC.

OPG has retained the services of an external contractor, Thomas LaGuardia Inc. (TLG) with international experience in decommissioning to perform the cost estimates for decommissioning its NGSs. The current cost estimates for decommissioning of OPG's nuclear facilities are shown in Table 3.

Table 3, Cost Estimates for Decommissioning of OPG's Nuclear Facilities

OPG Nuclear Facility	Decommissioning Cost Estimate (2004 M Dollars)
PNGS A	1,308
BNGS A	1,424
PNGS B	1,354
BNGS B	1,423
DNGS	2,030
WWMF	80
PWMF	20
DWMF	10

OPG has established and maintains segregated funds for nuclear waste management and decommissioning under the Ontario Nuclear Funds Agreement between OPG and the Province of Ontario. Based on the above cost estimates, OPG makes annual contributions to these funds over the planning life of the nuclear facilities to cover all estimated liabilities [9, 10]. The financial guarantee required by the CNSC, is provided in part by the segregated funds and supplemented by a commitment for the balance by the Province of Ontario.

OPG updates the PDPs periodically when the planning assumptions, regulations, facilities, operational information or cost estimates change. The financial guarantee is submitted to the CNSC every five years and annual updates are submitted on the status of the guarantee. OPG continuously monitors international experience on decommissioning and will continue to update the PDPs and cost estimates until the nuclear facilities are shutdown. Six months prior to shut down of a nuclear facility, OPG will prepare and submit a Detailed Decommissioning Plan [7] to the CNSC in order to obtain a Licence to Decommission.

Summary and Conclusions

OPG plans to decommission all its 20 CANDU reactors and three radioactive waste management facilities located at Pickering, Darlington and Bruce after they have been permanently shut down. Various options were considered for decommissioning during the initial stages of planning. The current reference plan for the NGSs is to decommission them using deferred dismantling after a 30 year safe storage period and dispose of the radioactive waste at an off-site disposal facility. The current reference plan for the radioactive waste management facilities is to dismantle them immediately after all the waste has been removed and dispose of the radioactive waste from dismantling at an off-site disposal facility.

OPG has estimated the cost of decommissioning the nuclear facilities and based on these cost estimates, contributes an annual sum into an external segregated fund. OPG's reference plans, cost estimates and the financial guarantee are described in a Preliminary Decommissioning Plan (PDP) for each facility. The PDPs are kept up to date and submitted to the CNSC for review on a periodic basis as part of supporting the applications for Operating Licences of the nuclear facilities.

Just prior to decommissioning, OPG will conduct public information programs and environmental assessments and prepare detailed decommissioning plans, in order to obtain Licences to Decommission its nuclear facilities from the Canadian Nuclear Safety Commission (CNSC). After decommissioning is complete, Licences to Abandon the sites will be obtained from the CNSC.

The implementation of a Deep Geologic Repository for long term low and intermediate level radioactive waste management on the Bruce site, may affect the reference plans for disposal of decommissioning waste from the Bruce site and possibly from other reactor sites.

Other impending issues such as: restarting of Bruce A and Pickering A reactor units and/or possible re-tubing of reactors to extend their operating lives and shutdown dates, may have an effect on the planning for decommissioning.

When such issues have been dealt with and plans are fully approved, OPG will update its decommissioning planning assumptions, plans and cost estimates.

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(10) Van den Hengel, J., (2005) "Financial Assurances for Decommissioning and Waste Management Activities at Ontario Power Generation", CNS Conference, Waste Management, Decommissioning and Environmental Restoration, Ottawa, Ont.

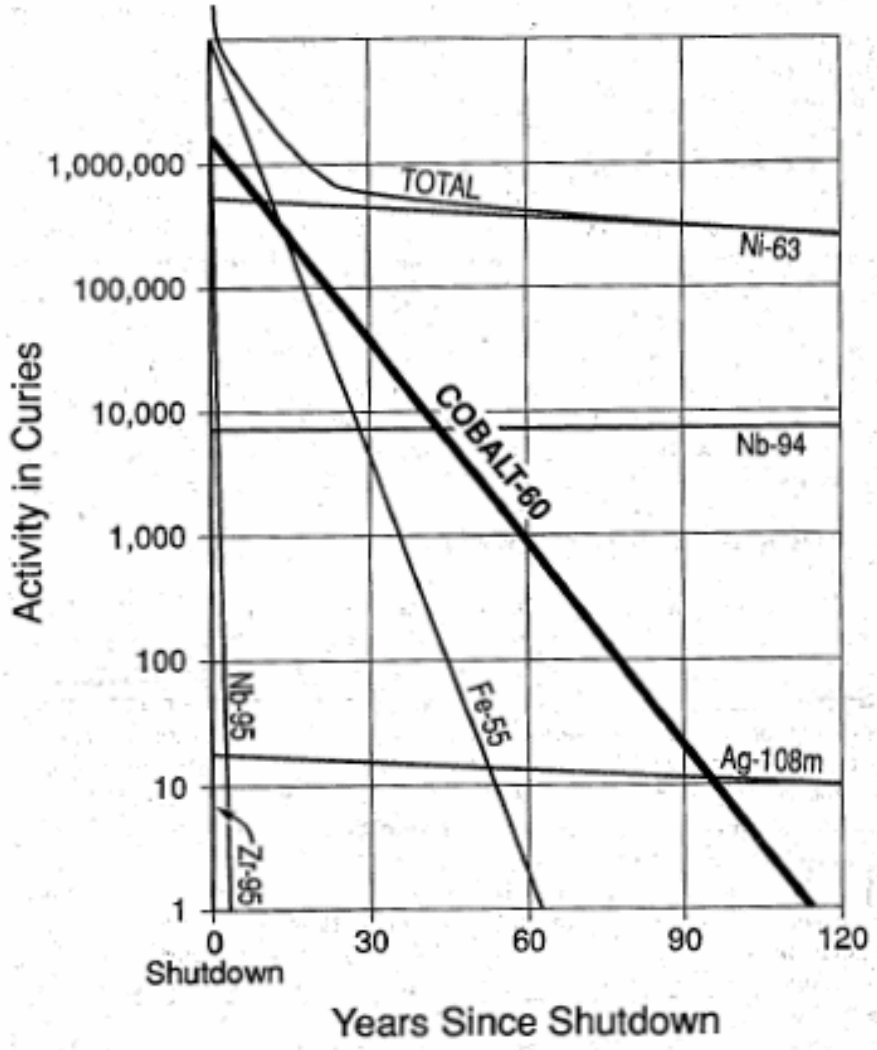


Figure 1, Activity of Major Radionuclides Following Reactor Shutdown

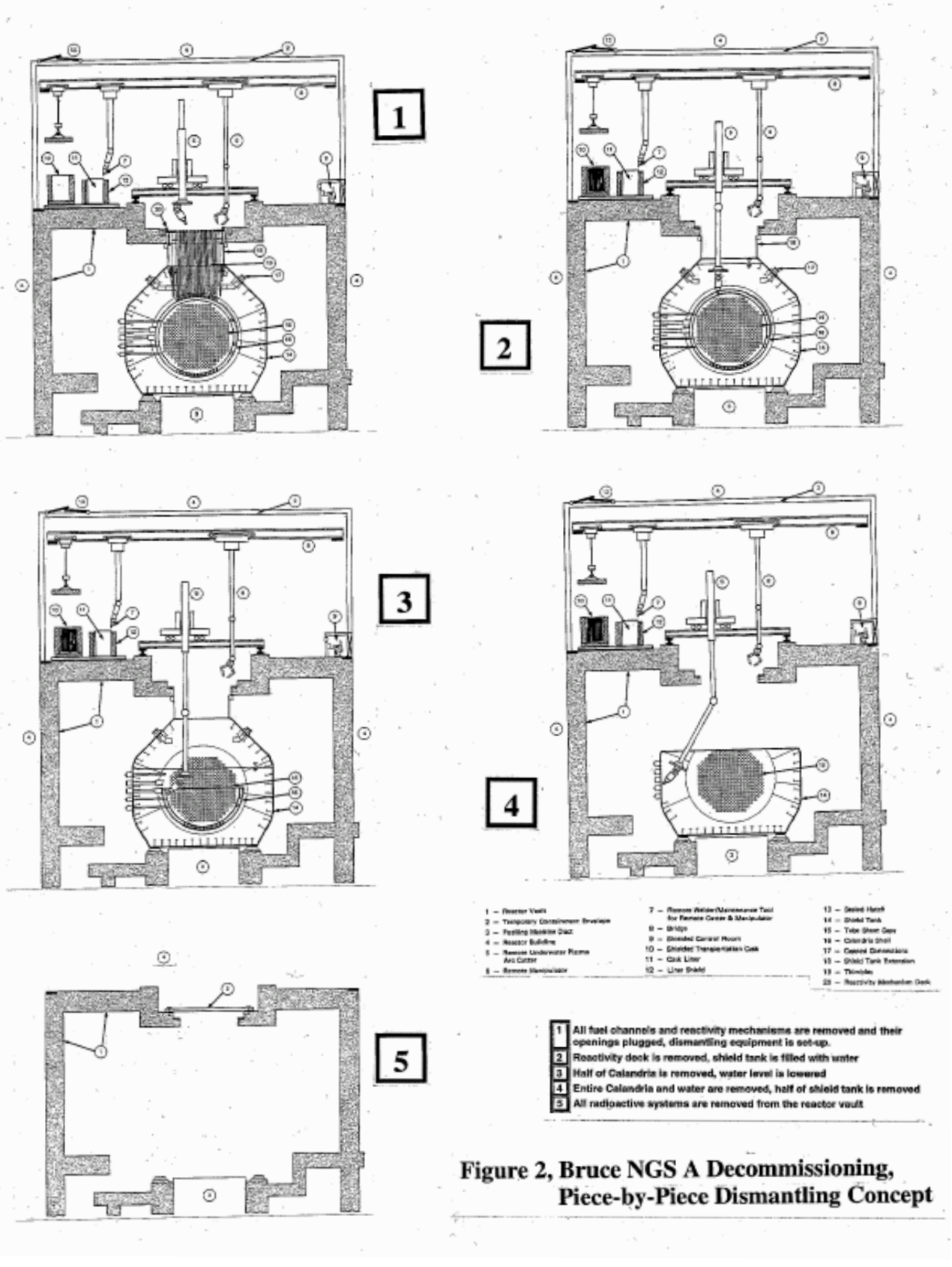


Figure 2, Bruce NGS A Decommissioning, Piece-by-Piece Dismantling Concept

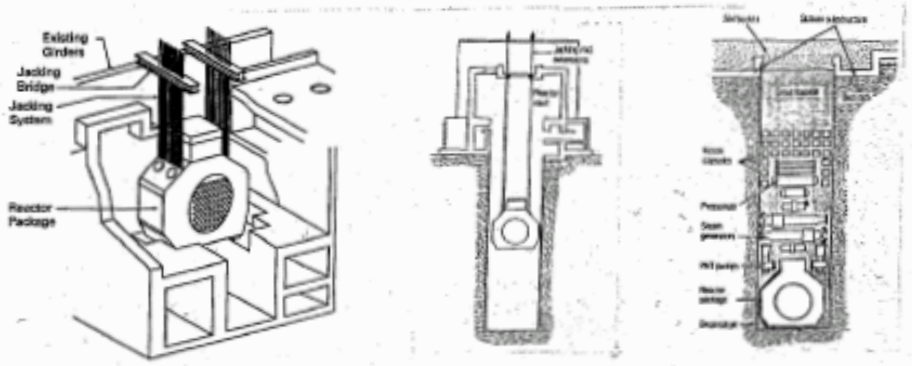
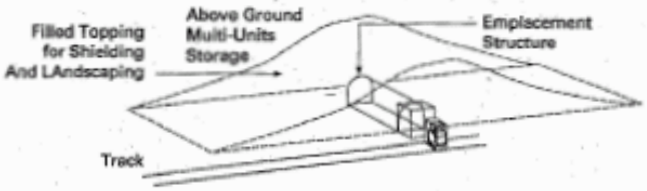


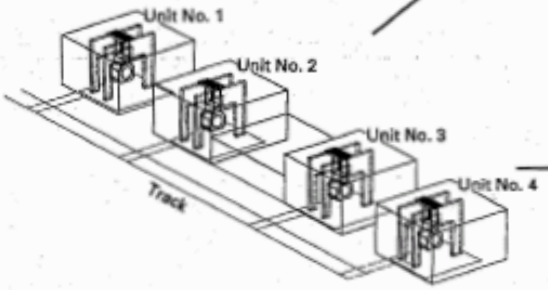
Figure 3 A **IN-STATION** UNDERGROUND

Figure 3 B

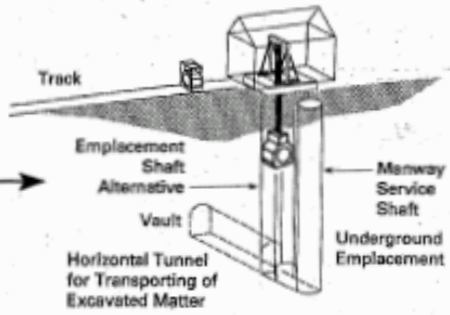
OUT-STATION ABOVE GROUND



BRUCE N.G.S. A



OUT-STATION INTERMEDIATE DEPTH UNDERGROUND



OUT-STATION SHALLOW UNDERGROUND

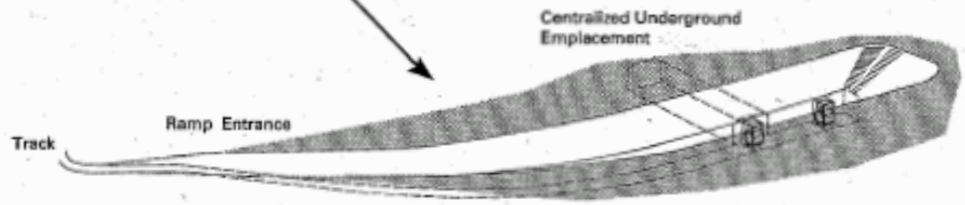


Figure 3, One-Piece On-Site Disposal of Decommissioned Reactors

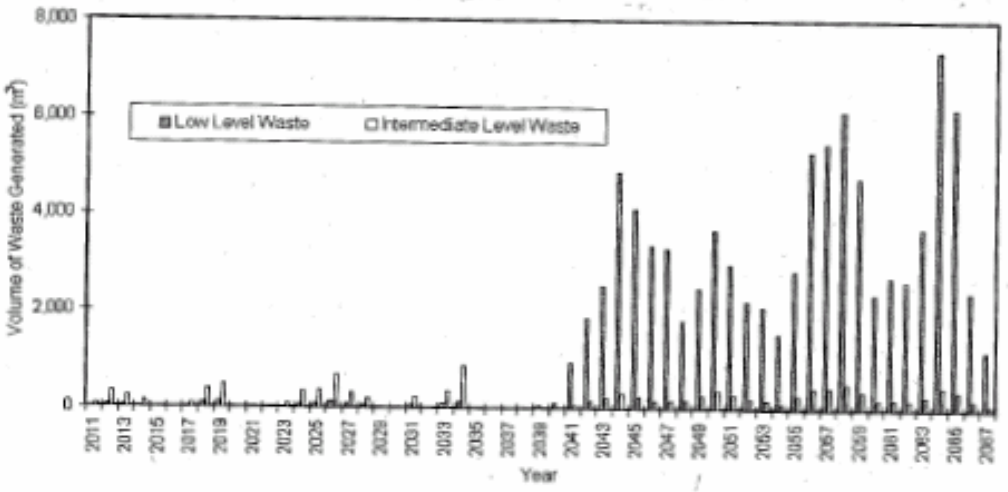


Figure 4, Annual Arisings of Radioactive Waste (LLW & ILW) from Decommissioning of OPG's Nuclear Generating Stations