CMD 26-H101.4

Date: 2026-02-16

Written Submission from Canadian Coalition for Nuclear Responsibility

Mémoire du Regroupement pour la surveillance du nucléaire

In the matter of

À l'égard d'

Hydro-Québec

Hydro-Québec

Application to renew its power reactor decommissioning licence for the Gentilly-2 Facilities for a period of 20 years

Demande visant à renouveler pour 20 ans son permis de déclassement d'un réacteur de puissance pour les installations de Gentilly-2

Hearing in writing based on written submissions

Audience par écrit fondée sur des mémoires

March 2026

Mars 2026

Facing up to the task

a report by the

Canadian Coalition for Nuclear Responsibility

presented to the

Canadian Nuclear Safety Commission

in relation to Hydro-Quebec's application

for a 20-year extension of the

Gentilly-2 Decommissioning Licence

principal researchers and authors

Dr. Gordon Edwards

Dr. Sunil Nijhawan

February 16 2026

RECOMMENDATIONS

Recommendation 1.
That Hydro-Quebec's G-2 licence not be extended for more than five years, during which time the licensee shall bring off-site emissions of tritium and carbon-14 to zero.

Recommendation 2.
During the shortened licence extension period, Hydro shall also eliminate the ongoing]emissions into the environment of radioactive alpha-emitting and beta-emitting particulates (emissions are now, and have been, tens of millions of becquerels yearly).

Recommendation 3.
That CNSC not extend the G-2 licence for more than five years to allow the licensee to refocus on radiological characterization work and detailed dismantlement planning.

Recommendation 4.
That Hydro-Quebec be tasked by CNSC to use the shortened licence extension period to prepare a detailed plan for the radiologically challenging work of dismantling the core area of Gentilly-2 reactor, treating each major component, one at a time – fuel channels, calandria vessel, heat shield, reactor vault, biological shield, feeder pipes, and the remainder of the primary cooling circuit, including the steam generators.

Recommendation 5.
That Hydro-Quebec prepare for the task above by conducting a thorough well-documented radiological characterization of each of the major components to be dismantled, providing a full radioactive inventory of gamma, beta, and alpha emitters – as well as neutron sources – accompanied by a series of radiological maps showing the geometrical distribution of radioactivity within each component – all to be quantified.

Recommendation 6.
That before the end of the shortened licence extension period, Hydro Quebec present CNSC with a new detailed dismantling plan, together with a new disaggregated cost estimate for dismantling the Gentilly-2 reactor based on the new plan – that is, assigning a cost to each of the major components to be removed, segmented, packaged, and labelled for either storage on site or transport to a final destination.

RECOMMENDATIONS

Recommendation 7.
That Hydro Quebec be instructed to prepare a report for CNSC on the short-term, medium-term and long-term handling, monitoring, storage and transport of spent ion-exchange resins, with special attention to carbon-14 loadings in these resins and the challenges involved in preventing the escape of carbon-14 through resin degradation.

Recommendation 8.
That in future public announcements by the CNSC, or involving CNSC, care be taken to make clear any subtle aspects that may not be apparent from an unconventional use of language; for example, that the Gentilly-1 Nuclear Waste Management Facility includes a defunct nuclear reactor that is awaiting final decommissioning.

Recommendation 9
That the licensee be required to employ **continuous module-level condition monitoring** to provide early detection of factors that may be causing, or may eventually cause, fuel degradation inside the dry storage modules.

Recommendation 10.
That any licence extension for Gentilly-2 include these monitoring provisions on all dry storage modules as a licencing condition to ensure continued protection of workers, the public, and the environment.

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To:	**Canadian Nuclear Safety Commission (CNSC)**
From:	**Canadian Coalition for Nuclear Responsibility (CCNR)**
Re:	**Licence renewal for Gentilly-2 Waste Management Facility (G-2)**
Date:	**February 16, 2026**

Introduction

Hydro-Quebec has applied to CNSC for a 20-year extension of its licence for the Gentilly-2 nuclear waste facility (G-2) at Bécancour, Québec. The waste facility includes a defunct CANDU nuclear power reactor – the Gentilly-2 reactor – that was permanently shut down in December 2012. It will eventually be dismantled. The current "decommissioning licence" for the G-2 site covers a 10-year period from 2016 to 2026.

This report is an intervention in writing (as no oral interventions are allowed) from the Canadian Coalition for Nuclear Responsibility, based on the research and expertise of Dr. Gordon Edwards and Dr. Sunil Nijhawan. CCNR understands that Hydro-Quebec, the licensee for the site, does not intend to dismantle the G-2 reactor for many years to come.

Nevertheless, CCNR urges the CNSC and Hydro-Quebec to make good use of the shortened licence extension period by developing detailed plans for the eventual dismantling work, based on careful characterization of the radioactive inventory, detailed methodologies for carrying out the dismantling of these radioactive structures, and a more realistic cost estimate for the total decommissioning of the reactor. CNSC's requirement for a financial guarantee depends on accurate financial data from the licensee.

CCNR's recommendations in this regard are listed on page 4. But first, we will address a more pressing issue that should be dealt with immediately – the continuing large annual emissions of radioactive tritium and carbon into the environment from the Gentilly-2 facility, which is supposed to be in a safe shutdown state.

Annual ongoing emissions of tritium and carbon-14 from Gentilly-2 and Point Lepreau, from 2011 to 2024 inclusive

CCNR took the liberty of consulting the Radionuclide Release Datasets available on the Open Canada web site, which specifies radionuclide releases from all of Canada's nuclear generating stations for the last 15 years (from 2011 to 2024). From the downloaded government spread sheet it is clear that, every year, the Gentilly-2 facility continues to release large amounts of radioactive hydrogen (tritium) and radioactive carbon-14 into the environment.

For the sake of comparison, we copied the year-by-year emissions data from Gentilly-2 and from Point Lepreau onto another excel spreadsheet, for the years 2011 to 2024 inclusive. A printout of those data is given on the next page. There one can see that, over the entire fifteen year period, Gentilly-2 has emitted annually from tens to hundreds of trillions of becquerels of tritium into the air and into the water – presumably, the St. Lawrence River. As for carbon-14, the annual atmospheric emissions and liquid effluents from Gentilly-2 range from hundreds of billions to hundreds of millions of becquerels of radioactive carbon. A becquerel is one atomic disintegration every second.

A note on the exponential notation: The expression E+14 means "multiply by 10 fourteen times". The expression E-3 means "divide by 10 three times." So 4.7E+14 = 470,000,000,000,000 = 470 trillion, while 5.1E-3 = 0.0051.

The Gentilly-2 and Point Lepreau reactors are very close to being identical twins – they are both CANDU-6 reactors, much the same as those that were sold to South Korea, Argentina, Romania and China. The main difference between the Quebec and New Brunswick reactors is that Gentilly-2 has been totally shut down since late 2012, while Point Lepreau went back into service after a long and expensive refurbishment. The shocker is that the defunct Gentilly-2 plant is still giving off huge quantities of tritium and carbon-14 every single year, very much like the Lepreau plant that is operational.

In fact, over the entire 15-year period, the amount of carbon 14 given off by the shut-down Gentilly-2 plant was 4 trillion becquerels, which is almost double the amount given off by the fully operational Point Lepreau plant! Over that same period, Gentilly-2 released 3,190 trillion becquerels of tritium – about half as much as Point Lepreau released, but wow! That's an awful lot of radioactive pollution from a plant that is supposed to be completely inactive!

Why is this happening? Where are these emissions coming from? Why aren't they stopped? It makes a mockery of industry claims that they know how to keep radioactive wastes out of the environment for millions of years. Even more to the point, why are these massive ongoing radioactive releases not even documented or discussed by Hydro-Quebec or by CNSC staff? Do they not know? Do they not care? Or have they simply chosen to turn a blind eye to the situation?

Recommendation 1.
That Hydro-Quebec's G-2 licence not be extended for more than five years, during which time the licensee shall bring off-site emissions of tritium and carbon-14 to zero.

Hydrogen and carbon are basic building blocks of life. Every organic molecule incorporates both hydrogen and carbon atoms, including our DNA molecules. Releasing radioactive varieties of hydrogen and carbon has an impact on all living things. Since carbon-14 has a half-life of 5,700 years, it will be around for many millennia.

Recommendation 2.
During the shortened licence extension period, Hydro shall also eliminate the ongoing] emissions into the environment of radioactive alpha-emitting and beta-emitting particulates (emissions are now, and have been, tens of millions of becquerels yearly).

Emissions of TRITIUM AND CARBON-14 from Gentilly-2 and Point Lepreau (2011-2024)

		GENTILLY-2		POINT LEPREAU		RATIOS G2/PL	
Radionuclide	**Year**	Tritium (HTO)	Carbon-14	Tritium (HTO)	Carbon-14	Tritium (HTO)	Carbon-14
Facility		Gentilly-2	Gentilly-2	Point Lepreau	Point Lepreau	RATIO G2/PL	RATIO G2/PL
stack	2024	1.11E+13	3.94E+09	1.57E+14	1.29E+11	7.07E-02	3.05E-02
Direct Discharge	2024	4.31E+11	1.56E+07	2.98E+14	2.43E+09	1.45E-03	6.42E-03
stack	2023	2.89E+13	5.94E+09	1.71E+14	1.12E+11	1.69E-01	5.30E-02
Direct Discharge	2023	2.30E+11	3.35E+07	1.82E+14	2.72E+09	1.26E-03	1.23E-02
stack	2022	3.20E+13	4.38E+09	2.16E+14	1.63E+11	1.48E-01	2.69E-02
Direct Discharge	2022	5.23E+13	2.71E+07	4.28E+14	8.87E+08	1.22E-01	3.06E-02
stack	2021	4.43E+13	6.17E+09	2.70E+14	1.60E+11	1.64E-01	3.86E-02
Direct Discharge	2021	1.56E+14	6.07E+07	8.20E+13	2.10E+09	**1.90E+00**	2.89E-02
stack	2020	8.11E+13	8.19E+09	2.87E+14	1.60E+11	2.83E-01	5.12E-02
Direct Discharge	2020	1.97E+13	4.92E+07	4.61E+14	1.01E+09	4.27E-02	4.87E-02
stack	2019	7.21E+13	2.70E+10	2.46E+14	2.77E+11	2.93E-01	9.75E-02
Direct Discharge	2019	8.22E+13	1.90E+08	3.40E+14	7.60E+09	2.42E-01	2.50E-02
stack	2018	9.17E+13	4.63E+10	1.40E+14	3.30E+11	6.55E-01	1.40E-01
Direct Discharge	2018	5.46E+13	1.71E+08	2.40E+14	4.90E+09	2.28E-01	3.49E-02
stack	2017	7.32E+13	4.47E+11	1.50E+14	3.10E+11	4.88E-01	**1.44E+00**
Direct Discharge	2017	2.17E+14	2.79E+11	1.20E+14	1.80E+09	1.81E+00	**1.55E+02**
stack	2016	7.32E+13	3.79E+11	1.50E+14	1.10E+11	4.88E-01	**3.45E+00**
Direct Discharge	2016	3.83E+13	5.64E+10	1.80E+14	2.90E+09	2.13E-01	**1.94E+01**
stack	2015	1.12E+14	4.10E+11	1.40E+14	7.10E+10	8.00E-01	**5.77E+00**
Direct Discharge	2015	1.51E+14	3.00E+11	1.40E+14	1.00E+10	1.08E+00	**3.00E+01**
stack	2014	1.19E+14	4.83E+11	6.60E+13	8.40E+10	1.80E+00	**5.75E+00**
Direct Discharge	2014	3.56E+14	5.28E+10	3.20E+14	6.60E+09	1.11E+00	**8.00E+00**
stack	2013	1.14E+14	7.49E+11	9.10E+13	8.00E+10	**1.25E+00**	**9.36E+00**
Direct Discharge	2013	2.15E+14	1.15E+10	2.90E+14	4.30E+09	7.41E-01	**2.67E+00**
stack	2012	2.09E+14	4.41E+11	1.40E+14	3.70E+10	**1.49E+00**	**1.19E+01**
Direct Discharge	2012	3.52E+14	2.88E+10	7.80E+14	1.40E+10	4.51E-01	**2.06E+00**
stack	2011	1.90E+14	2.71E+11	4.50E+13	2.80E+10	**4.22E+00**	**9.68E+00**
Direct Discharge	2011	2.44E+14	1.88E+10	3.40E+13	3.80E+07	**7.18E+00**	4.95E+02
TOTALS		3.19E+15	4.03E+12	6.16E+15	2.11E+12	5.18E-01	1.91E+00
average >2013		8.48E+13	1.14E+11	2.17E+14	8.86E+10	3.90E-01	1.29E+00
minimum >2013	except 2023/24	1.97E+13	2.71E+07	6.60E+13	8.87E+08		
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Time to Do the Work

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No time to delay

Hydro-Quebec is currently asking for a 20-year extension of the Gentilly-2 licence as a Nuclear Waste Facility. Hydro has indicated that it has no intention of tackling the major radiological challenge of dismantling the core of the G-2 reactor during those two decades. Instead it will focus on dismantling the other structures on the site and managing whatever low-level and intermediate level radioactive wastes that will arise from those activities. CCNR is strongly opposed to this long delay in tackling the main radiological challenge while carelessly countenancing large radioactive emissions,

From one point of view delay makes sense, because there is as yet no final destination for the used nuclear fuel, currently in dry storage on site. There is likewise no final destination for the very long-lived intermediate level waste that will result from completely dismantling the shut-down, defueled and dewatered reactor.

From another point of view, however, such delay can be seen as a wasted opportunity. After twenty additional years of waiting, Hydro-Quebec's nuclear expertise may well be at its lowest ebb ever. Senior resource people with the greatest nuclear and/or radiological expertise will have retired or moved on to other jobs. The number of workers who know the Gentilly-2 plant thoroughly, inside and out, will be fewer in number, and much older. The plant itself will have deteriorated. Corrosion will be more extensive, and radioactive dust – like carbon-14 particulates and alpha-emitting aerosols – will be more abundant, posing a greater internal hazard to the health of workers and a greater contamination risk for the environment. There will more tiny radioactive corrosion particulates, ready to become airborne or to easily flushed into the waste water.

It is important for us to heed the hard-won lessons from Ontario. At one time, during a retubing operation, workers at the Pickering nuclear plant tracked carbon-14 dust off-site, day after day for weeks, contaminating the bedclothes and furniture in their homes. At Bruce, during the refurbishment of unit 1, more than 500 local tradesmen inhaled alpha-emitting dust into their lungs for 2 ½ weeks before the problem was identified and corrected. Such "internal emitters", whether airborne or not, have proven to be devilishly hard to detect if you don't know they are there. They are also hard to measure. As a result, unforeseen and totally preventable contamination of workers and/or the environment has occurred. The high-energy alpha particles and low-energy beta particles given off by these mote-like radioactive dust particulates have very short tracks. They can be shielded by something as thin as a sheet of paper, and do not trigger the usual radiation alarms. They can easily escape detection.

Postponing a difficult or a dangerous task like radioactive demolition, or avoiding advance planning for it, may carry its own risks. Expertise may be lost. Accurate characterization of the radioactive inventory may become more difficult. Specialized tools and detailed procedures may not be in place when needed. Costly mistakes may be made as workers "cut corners" to get the job done on schedule, without having an adequately detailed plan or a complete understanding of the risks that may present themselves. Recording useful information about the radioactive contents of each decommissioning waste package, for the benefit of this and future generations, may be difficult or even impossible.

There is a middle path between action and inaction. It is planning. In the case of Gentilly-2 it would entail a form of research and development – research into the precise nature of the radioactive inventory of each radioactive structure or component to be disassembled or extracted, and then development of precise methodologies to be utilized in carrying out the disassembly or extraction of each one of those structures or components. Training materials can be produced well ahead of time for a future work force that will be ready to do the job but need careful instruction to do it safely, while dealing competently and quickly with any hard-to-measure radioactive contaminants that may be stirred up during each stage of the dismantling operation.

There is already a wealth of operating experience in Ontario and New Brunswick on the removal of irradiated pressure tubes and calandria tubes, based on the history of refurbishment activities carried out at Bruce, Darlington, and Point Lepreau. There are lessons to be learned also. But there is much that is still unknown about how best to tackle the radiological demolition of the surrounding structures in the core area – the disaggregation, volume reduction, and packaging of the remains of the reactivity mechanisms, the calandria vessel, the heat shield, the reactor vault, the biological shield, and the rest, not to mention the optimal sequencing of those tasks.

The Nuclear Energy Agency (OECD), which Canada joined in 1975, strongly recommends that, before complete decommissioning of a reactor begins, a thorough characterization of the radioactive inventory of each major component be carried out. This work can be more accurately done today, when the radionuclides are more radioactive than they will be 20 years from now, and hence easier to identify and measure. If the characterization work is carried out conscientiously and accurately now, identifying all significant radionuclides and their current level of activity, the future inventory can be calculated from data collected now and verified against future measurements.

There is no reason why that radiological characterization work cannot be done in the next five years. If it is carried out in conjunction with the development of a detailed plan for dismantling each major component in the reactor core area – and in the primary cooling circuit of the reactor – it will then be possible for Hydro-Quebec to provide a more detailed and disaggregated cost estimate for the future dismantling of the reactor. That information will allow CNSC to better fulfill its obligation as a regulator, by more precisely assessing the amount needed for an adequate financial guarantee to cover the cost of final decommissioning based on the most accurate data.

Decommissioning – an untested industry

It is important to bear in mind that dismantling a large nuclear power reactor of any kind has very seldom been accomplished. The cost estimates given in the past may therefore turn out to be severely underestimated. The time has come for Canada – and Hydro-Quebec – to be more hard-nosed about the challenges and the costs associated with radioactive demolition.

The 2023 report entitled "Decommissioning of nuclear power plants: Regulation, financing, and production" had this to say:

> The global decommissioning industry is still developing and remains largely untested. Around the world, only about a dozen *commercial* nuclear reactors have been decommissioned…. Historically, licensees viewed decommissioning as a distant obligation and focused on constructing and operating NPPs rather than decommissioning them (Laraia 2012). The combination of inexperience and insufficient planning has led to some undesirable outcomes, such as cost and schedule overrun…. Stakeholders are concerned about how the government is regulating the industry, particularly regarding financial liability.
>
> Table 1-3 shows the progress of decommissioning commercial NPPs by country. The majority of all the plants are in the early stages of decommissioning, not yet dismantling the reactor building and its internals (hot-zone).

Table 1-3: Decommissioning progress as of June 2022

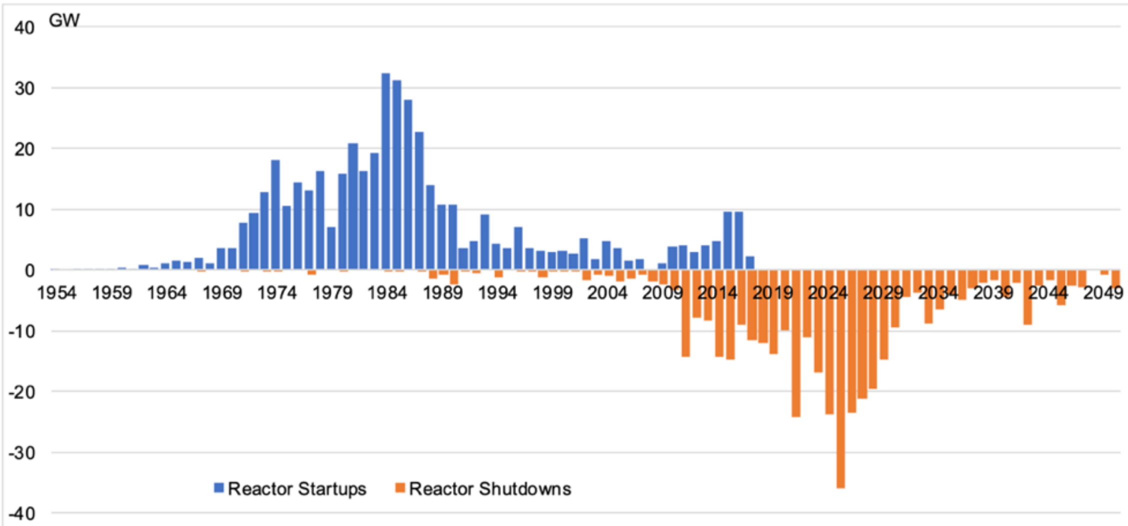
Country	Closed reactors (total)	Warm-Up	Hot-Zone	Ease-Off	LTE	Radiologically Decommissioned (of which are Greenfield)
France	14	4	2	0	8	0 (0)
Germany	30	9	8	9	1	4 (3)
Sweden	7	3	4	0	0	0 (0)
Switzerland	1	1	0	0	0	0 (0)
United Kingdom	34	13	9	0	8	0 (0)
United States	41	7	3	1	13	17 (6)

Alexander Wimmers et al. (2023).
Decommissioning of nuclear power plants: Regulation, financing, and production.
DIW Data Documentation, No. 104,
Provided in Cooperation with: German Institute for Economic Research (DIW Berlin)
https://www.econstor.eu/bitstream/10419/268719/1/1833051734.pdf

The term "radiological decommissioning" is used by the authors to indicate that the plant is completely dismantled, including the most radioactive portions of the reactor. Note that only two of the six countries listed in Table 1-3 above – Germany and the USA – have radiologically decommissioned commercial power reactors. And in each of those two countries, there are only two commercial facilities that have been fully dismantled. The extra 15 decommissioned reactors in the USA, as indicated in the table above, are all non-commercial reactors. France has no radiological decommissioning experience. As we have seen with reactor construction, where radiological considerations are not a factor but nuclear safety considerations are, as well as with CANDU refurbishments, where radiological considerations are paramount, there have been a number of shocking cost overruns and schedule delays. Without careful advance planning, it may be the same story with reactor dismantling. If the cost of such an unavoidable and necessary operation turns out to be two or three times greater than predicted, it will not only elicit criticism of the licensee and the regulator, but it will also make the nuclear option itself more costly and less desirable than ever.

On a more positive note, there are CANDU reactors in New Brunswick, South Korea, Argentina, Romania, and China, and they will all have to be dismantled sooner or later. Reactor decommissioning promises to become a multi-billion dollar service industry in the coming decades, as more and more reactors are permanently shut down, requiring dismantlement. If Quebec makes an early start on the dismantling of CANDU reactors, there may be business opportunities from other jurisdictions by CANDU owners who are searching for the tools and expertise needed to carry out a safe and responsible decommissioning exercise. If success is achieved for Gentilly-2, even at the advanced planning stage, based on a disciplined and well-thought-out approach, opportunities for Quebec could materialize in both CANDU and non-CANDU markets. It all has to begin with a meticulous radiological characterization of the plant's internal structures,

Figure 1-1: Distribution of global nuclear reactor startups and shutdowns



Note: Assuming a 40-year reactor lifetime. Based on data from Wealer et al. (2018).

This graph is reproduced from Wimmers et al (2023), previously cited

Preparing for the dismantling of Gentilly-1

To date, no CANDU reactor has been completely decommissioned (dismantled). As it happens, the federally-owned Gentilly-1 reactor – right next to the provincially-owned Gentilly-2 reactor at Bécancour – will likely be the first one to be radiologically decommissioned. Gentilly-1 was never a commercially viable reactor. Structurally it was an anomaly – a prototype heavy-water moderated reactor, with vertical fuel channels. It was designed as a boiling water reactor using light water coolant. The reactor was somewhat unstable, and was shut down frequently. It only functioned for 183 days over a period of seven years. It never contributed any electricity to the Quebec electrical grid. It has been permanently shut down now for over 40 years, and partially dismantled – except for the core area.

Now the licensee, Canadian Nuclear Laboratories (CNL) is asking for a revision to its licence that will allow for the final dismantling of all structures in the Gentilly-1 site, including what remains of the Gentilly-1 reactor. Hydro-Quebec should follow this work closely, including the preparatory planning stages; there will be lessons to be learned.

Gentilly-1 to the right and Gentilly-2 to the left are close neighbours on the St. Lawrence River.

Canadian Nuclear Laboratories (CNL) is the licence-holder for the Gentilly-1 Nuclear Waste Facility, which includes the defunct G-1 reactor. Despite its name, CNL is not a government agency but a private contractor led by a consortium of US multinationals. The consortium has been hired by Atomic Energy of Canada Limited (AECL), a crown corporation, to manage Canada's federally-owned nuclear facilities, including all radioactive waste for which the government has assumed responsibility. That includes the voluminous "historic radioactive wastes" in the Port Hope and Port Granby area.

CNL has applied to CNSC to amend the licence for the Gentilly-1 Nuclear Waste Management Facility. The amendment would allow the dismantling of all structures related to the Gentilly-1 operation, including the total dismantling of the most radioactive portions of the shut-down Gentilly-1 reactor – the only portions of that reactor that remain in place within the outer concrete shell. The CNSC will make a determination in 2026 whether or not to approve the requested amendment of the G-1 licence.

The consortium that currently runs CNL **is Nuclear Laboratory Partners of Canada (NLPC).** It is a joint venture of BWXT, Amentum, and Kinectrics. NLPC has signed a 20-year contract worth $24 billion (Canadian taxpayers' money). The money is to be transferred to CNL from AECL, which in turn is wholly owned and funded by the federal government, for services to be rendered, including "reducing Canada's nuclear liability".

Those services sometimes seem inscrutable. In 2025, for example, CNL decided to move all of the high-level radioactive waste (irradiated nuclear fuel) from the Gentilly-1 site in Bécancour to the Chalk River site, on the Ontario side of the Ottawa River. No rationale was given for this action, which was carried out without public process, notification, consultation, or justification. Despite assurances from the government of Canada, from CNSC and from CNL, that all parties will respect the provisions of the UN Declaration on the Rights of Indigenous Peoples (UNDRIP), Kebaowek First Nation was not officially informed of this "parking" of G-1 used fuel at the Chalk River site, located on traditional unceded territory of the Algonquins,. According to UNDRIP, there should be no storage or disposal of toxic wastes on the land of Indigenous people without their "free, prior and informed consent." Consent was not given, and was not even asked for.

Since radioactivity cannot be "turned off" by any method known to science, radioactive wastes cannot be eliminated or neutralized, but only (a) repackaged or (b) moved from one place to another. The transport of highly radiotoxic material from G-1 to Chalk River cost 42 million dollars – almost 18 million for planning alone. However, it is difficult to see how Canada's radioactive legacy has been in any way reduced by this expenditure. The liability has not changed, it has just been relocated further upstream.

The hazardous nature of the waste shipments is indicated by the fact that CNL refused to reveal to a Quebec journalist which communities the trucks passed through, so as not to endanger or compromise security. Support was obtained by CNL from CSIS, the RCMP, and Quebec police, The rationale for the transfer at this time remains obscure, but it is certain that the costs and risks will be doubled when the same wastes will have to be moved a second time to a postulated permanent location, still to be prepared by the Nuclear Waste Management Organization (NWMO) many hears hence.

Under the existing G-1 licence, CNL was authorized to manage radioactive wastes at the G-1 site under conditions of "storage and surveillance". Members of the public, including CCNR and its supporting organizations, were shocked to learn that that term – storage and surveillance – also allowed CNL to "transfer" radioactive wastes to an entirely different location. It seems to be a very deceptive choice of words, as most people would not assume that "storage and surveillance" may actually mean "transport.

Moreover, in CNSC's public notice inviting the public to intervene on CNL's request for a licence revision, there was not one word about the dismantling of a nuclear reactor, but only the "decommissioning" of the Gentilly-1 "nuclear waste facility". Again a somewhat deceptive use of words. Who in the general public would understand that a "nuclear waste facility" can be include a shut-down nuclear power reactor, unless it were explicitly pointed out? One gets the impression that neither CNL nor CNSC really wants the public to know what is actually going on, by using words in unusual ways.

Recommendation 8.

That in future public announcements by the CNSC, or involving CNSC, care be taken to make clear any subtle aspects that may not be apparent from an unconventional use of language; for example, that the Gentilly-1 Nuclear Waste Management Facility includes a defunct nuclear reactor that is awaiting final decommissioning.

The transport of used nuclear fuel was carried out without benefit of any public process – even though the transfer involved many shipments of very hazardous material, over a period of several months, along 500 kilometres of public roads and bridges, through several municipalities, ending at an entirely different site operating under an entirely different licence. It turns out that changing the location of the waste under the terms of one licence, also involves changing the licence governing the waste altogether. It is in effect a licencing change without any formal public process.

Where does decommissioning waste go?

NWMO is a not-for-profit corporation owned by the three nuclear utilities in Canada – Ontario Power Generation, Hydro-Quebec, and New Brunswick Power. NWMO is mandated by federal law to find a willing host community to receive all of Canada's used nuclear fuel for emplacement in a Deep Geological Repository (DGR). Such a site has already been selected by NWMO, in northwestern Ontario, near the small village of Ignace that has been somewhat arbitrarily named as the willing host community. (The actual waste site is not in the jurisdiction of Ignace. It would have been equally possible for NWMO to have asked the much larger town of Dryden to act as the willing host community.) In any event, it will be many years before a DGR is ready to receive high-level radioactive waste. Indeed, the NWMO has stated in print that the used nuclear fuel (high-level waste) from Gentilly-1 site in Quebec was not scheduled to be moved away from that site until 2050.

As noted, the first DGR is of course not yet ready – work has not even started – but NWMO is already searching for a second site to construct a second DGR, this one for "intermediate level waste". That category includes much of the decommissioning waste resulting from dismantling the structures in the core area and the primary cooling circuit of a defunct nuclear reactor. Until a second willing host community is found and the second DGR is built, there will be no final destination for any of the more highly radioactive decommissioning waste that may be generated.

Presumably, then, if CNL is allowed to dismantle the G-1 reactor, the intermediate level waste will be either packaged and transported to Chalk River – raising the same concerns that were raised by last year's shipments of high-level radioactive waste from G-1 to Chalk River – or stored at the Gentilly-1 site until a final destination exists. As discussed earlier, moving highly radioactive waste more than once will multiply the risks and the costs to Canadian citizens. CCNR therefore recommends that the intermediate level radioactive waste from decommissioning G-1 – or G-2 for that matter – be securely packaged and stored at the Gentilly site until a permanent destination for such waste becomes available. This practice would be in line with the continued on-site storage of refurbishment wastes at Bruce, Darlington and Point Lepreau. Refurbishment waste is primarily intermediate-level waste. In some respects, refurbishment is like a "mini-decommissioning" operation as it involves the removal of thousands of contaminated and activated pipes and tubes from the calandria vessel and the primary cooling circuit.

Radioactive Poisons in Decommissioning Waste

The dismantling of the core components of the Gentilly-1 reactor was discussed in some detail at a conceptual level in an article published by the Canadian Nuclear Society in 1984, entitled "Gentilly-1 Reactor Dismantling Proposal" by Robert S. Vogt. The article is attached as Annex 1. Mr. Vogt writes:

> The proposal shall cover the dismantling of the reactor including reactivity mechanism, fuel channels, calandrla and thermal shield assembly and the inner biological shield…. The dismantling plan described in this paper comprises four major stages…. The third stage is the removal of the calandria and thermal shield vessel by remotely controlled underwater cutting. This stage is the most technically ambitious. The potential for high radiation exposure levels dictates the use of remotely controlled, underwater cutting.
>
> Gentilly-1 Reactor Dismantling Proposal, Robert S. Vogt, CSN, 1984

By flooding the reactor structures and equipping the workers, suited up as divers, with plasma torches or other underwater cutting tools, frequently used in marine salvage work, those tasked with dismantling old reactors can be shielded from the intense gamma radiation given off by the highly radioactive steel of the calandria vessel and the thermal shield. The watery environment also helps to entrain radioactive dust produced by cutting. That water can be filtered to collect the dust, whereupon the filters themselves become radioactive waste.

The main reason why these components are so very radioactive is "neutron activation". Neutrons are subatomic projectiles that pass through steel easily. They are released in enormous quantities by fissioning atoms during the normal operation of a nuclear reactor. When a stray neutron is absorbed by a stable, non-radioactive atom, the nucleus of that atom is dramatically altered. In many cases, the new atom is radioactive. It has become a radioactive "activation product", in most cases not found in nature. Stray neutrons create dozens of different activation products. A list of 47 such newly created radioactive poisons is displayed on the following two pages; the list is restricted to long-lived activation products that have half-lives of at least five years.

The longer a reactor operates, the more radioactive the core materials become, as more and more activation products are created every day. The Gentilly-1 reactor only operated for 183 days, so the internal structures are much less radioactive than those in a reactor that has been running for decades. Even so, radiation fields from the G-1 heat shield, not long after shutdown, are too intense for crews to confront without shielding.

All of the radioactive materials listed in the table below are created inside the core area of a nuclear reactor but outside the nuclear fuel assemblies. Of the 47 activation products listed in this table,10 have a half-life of over a million years,18 have a half-life of over a hundred thousand years, 26 have a half-life of over a thousand years, and 31 have a half-life of over a hundred years. www.ccnr.org/activation_products.pdf

Radioactive atoms eventually disintegrate, giving off a kind of subatomic shrapnel called "atomic radiation". A radioactive emission can be either an electrically charged fast-moving particle – alpha particle or beta particle – or a powerful photon called a gamma ray, like an x-ray but more powerful, or an uncharged particle called a neutron. All of these emissions are damaging to living cells and all are classified as human carcinogens by the IARC – International Agency for Research on Cancer. The "half-life" of a radioactive element is the time it takes for half of its atoms to disintegrate.

Why the structural materials in a nuclear reactor become radioactive

After irradiated fuel ("high-level radioactive waste") is removed from a nuclear reactor, the empty structures themselves remain radioactive for thousands of years. Here's why.

During normal operation subatomic projectiles called neutrons are flying in all directions inside the reactor core, originating from the atoms that are being split. Stray neutrons bombard any nearby materials, including metal, concrete, water and air, making them dangerously radioactive by a process called "neutron activation".

When a non-radioactive atom (the "target") absorbs a stray neutron, it is destabilized and is transformed into a radioactive atom (the "activation product"). This happens outside the fuel, in the core area. Here is a partial list of long-lived activation products.

Long-Lived Activation Products with Half-Lives Greater Than 5 Years

Radioactive Activation Product	Half-life (years)	Non-radioactive Target
Hydrogen-3 (aka tritium)	12.3 y	*Lithium-6 Hydrogen-2 (aka deuterium)*
Beryllium-10	1 million 600 thousand y	*Beryllium-9 Boron-10*
Carbon-14	5 thousand 730 y	*Nitrogen-14 Oxygen-17*
Aluminum-26	720 thousand y	*Aluminum-27*
Chlorine-36	301 thousand y	*Chlorine-35 Potassium-39*
Argon-39	269 y	*Potassium-39*
Calcium-41	103 thousand y	*Calcium-40*
Manganese-53	3 million 700 thousand y	*Iron-54*
Nickel-59	80 thousand y	*Nickel-58 Copper-58*
Cobalt-60	5.3 y	*Cobalt-59*
Nickel-63	100 y	*Nickel-62 Copper-62*
Selenium-79	377 thousand y	*Selenium-78 or -80 Bromine-79*
Krypton-81	210 thousand y	*Strontium-84 Rubidium-81-*
Krypton-85	10.7 y	*Rubidium-85*
Zirconium-93	1 million 530 thousand y	*Zirconium-92*
Niobium-92m	27 million y	*Niobium-93*
Niobium-93m	12 y	*Niobium-93*
Molybdenum-93	3 thousand 500 y	*Molybdenum-92*
Niobium-94	20 thousand	*Niobium-93 Molybdenum-94*
Technetium-97	2 million 600 thousand y	*Rubidium-96*

These data are adapted from J.C. Evans et al (1984), Long-lived activation products in reactor materials.

Activation Product	Half-life (years)	Target
Technetium-99	213 thousand y	*Molybdenum-98*
Palladium-107	6 million 500 thousand y	*Palladium-106*
Silver-108m	130 y	*Silver-107*
Cadmium-113m	14.6 y	*Cadmium-113*
Tin-121m	50 y	*Tin-120* *Antimony-121*
Iodine-129	15 million 700 thousand y	*Tellurium-128*
Barium-133	10.4 y	*Barium-132*
Cesium-135	2 million 300 thousand y	*Barium-135*
Cesium-137	30.1 y	*Barium-137*
Lanthanum-137	50 thousand y	*Cerium-136*
Praesodymium-145	18 y	*Samarium-144*
Samarium-146	100 million y	*Samarium-147*
Europium-150m	36 y	*Europium-151*
Gadolinium-150	1 million 800 thousand y	*Europium-151*
Samarium-151	93 y	*Samarium-150*
Europium-152	13 y	*Europium-151*
Europium-154	8.6 y	*Europium-153*
Terbium-158	150 y	*Terbium-159*
Holmium-163	33 y	*Erbium-164*
Holmium-166m	1 thousand 200 y	*Holmium-165*
Hafnium-178m	30 y	*Hafnium-177*
Iridium-192m	241 y	*Iridium-191*
Platinium-193	50 y	*Platinium-192 or -194*
Lead-205	14 million y	*Lead-204 or -206*
Bismuth-208	368 thousand y	*Bismuth-209*
Bismuth-210m	24 thousand 390 y	*Bismuth-209*

Source: ***Long-Lived Activation Products in Reactor Materials, 1984, NRC FIN 82296***

Some of these activation products give off powerful, highly penetrating gamma rays, such as cobalt-60 and cesium-137. Exposure to intense gamma radiation, without proper shielding, can be deadly to a human being in a relatively short period of time. It is estimated that 400 rems of gamma exposure (equal to 4 sieverts) will cause severe radiation sickness and kill half of those exposed within 30 days. According to the Pickering Preliminary Nuclear Decommissioning Cost Study, shortly after shutdown, each one of the 380 pressure tubes removed from the core of a Pickering reactor will deliver a gamma dose of 850 rems per hour – that's a lethal dose in 28 minutes. The gamma dose from the thermal shield of a shut-down Pickering reactor is a staggering 260,000 rems per hour – giving a lethal exposure in 5 $^{1}/_{2}$ seconds.

The Gentilly-1 thermal shield would be far less radioactive than that, but still potentially deadly, so Robert S. Vogt recommended underwater cutting techniques back in 1984.

Not all activation products give off gamma rays. Some just emit beta particles. Beta radiation is a lot less penetrating than gamma radiation and poses much less of an external threat. Beta emitters can however be very damaging inside the body, as "internal emitters" lodged in specific organs. Internal contamination with such materials – through inhalation, ingestion, or absorption through the skin – can deliver a cumulatively large chronic radiation dose, sometimes very slowly, from inside the body. That is damaging to living cells and can eventually lead to cancers of various kinds.

Radiotoxicity is the term used to express the biological damage that is done by radioactive materials taken into the body, whether they be gamma emitters, alpha emitters, beta emitters, or even neutron sources. Workers engaged in dismantling a nuclear reactor must not only be well shielded against highly penetrating gamma rays and neutrons, they must also be meticulously protected from the radiotoxic effects that can result from inadvertent bodily contamination with pernicious internal emitters.

The very long-lived beta-emitters constitute a perpetual radiotoxic threat if they find their way into the food chain or the drinking water or the air we breathe. They are not just a danger to workers, but a long-term threat to future generations. That's why NWMO is looking for a site to build a second DGR for intermediate level wastes. It is hoped that if they are stored deep underground, radioactive poisons will not find their way back to the surface to cause harm. Many of these beta-emitting radionuclides are very mobile. Carbon-14 can percolate to the surface as radioactive carbon dioxide gas. Radioactive hydrogen (tritium) forms radioactive water vapour, which can return to Earth as radioactive precipitation – rain drops, snowflakes, or morning dew. The krypton isotopes are noble gases. Some very long-lived solids, like technetium-99 (213,000 year half-life), are particularly mobile. For example, the extremely long-lived iodine-129 is one of the more problematic radionuclides, and it can "sublimate" from a solid to a gas.

Characterization of the radioactive inventory – a case study

The foregoing discussion highlights the importance of having an accurate and detailed characterization of the radioactive contents of each of the major components involved in the dismantling of a defunct nuclear reactor. This knowledge is not only needed to protect the workers who are dismantling the reactor, it will provide vital information for future generations to know exactly what human-made toxic materials are in the radioactive legacy that we are leaving them.

The International Atomic Energy Agency points out that responsible decommissioning planning and careful waste characterization is not just a short-term affair. It must take into account the long term burden as well as the task at hand.

> Planning and implementing a decommissioning project is a complex and multi-disciplinary process that involves both technical and non-technical aspects and requires timely and effective management. A fundamental requirement of decommissioning safety is the protection of workers and the public against radiation, now and in the future. It also includes … protection of the environment during project implementation and afterwards.
>
> IAEA , "Decommissioning of nuclear installations"
> https://www.iaea.org/topics/decommissioning

The Nuclear Energy Agency observes that an ideal time to carry out such characterization work is during the "transition phase" following shutdown, but before actual dismantling has begun.

> When a nuclear installation is about to be shut down permanently, a radiological characterisation programme should be established as soon as possible. It should define the principles, methods and steps necessary for the determination of the residual activity in all relevant media and structures, providing a reliable database of information on quantity and type of radionuclides, and their physical and chemical states.
>
> In general, the term "radiological characterisation" represents the determination of the nature, location and concentration of radionuclides at a nuclear installation. It is one of the fundamentals on which to build a decommissioning project.
>
> Radiological Characterisation for Decommissioning of Nuclear Installations.
> Nuclear Energy Agency-OECD Paris.
> https://www.oecd-nea.org/upload/docs/application/pdf/2020-01/rwm-wpdd2013-2.pdf

An interesting and informative case study is discussed in an article by Margarita Herranz et al,, entitled "Radiological characterisation in view of nuclear reactor decommissioning: On-site benchmarking exercise of a biological shield". The paper was published by Progress in Nuclear Energy in 2021. It only concerns the on-site benchmarking exercise performed at the activated biological shield of the Belgian Reactor 3 (BR3).

> The total volume of the biological shield, consisting of reinforced high-density concrete, and considered to be potentially activated by neutrons is about 600 m³ … The main goal of the BR3 biological shield radiological characterisation program consists of an economic optimisation of the biological shield dismantling strategy, using a waste-led approach.
>
> In order to reach this main goal, the [team] established three sub objectives •
>
> - Create a 3D specific activity distribution map;
> - Quantify and localize the different end-stage volumes; and
> - Economically optimise volumes in view of a waste-led approach.
>
> Pre-existing data such as neutron activation calculations and initial sampling radiological characterisation were used as basic input for the sampling design.
>
> The overall operator sampling and analysis programme consisted of total gamma measurements at the inner surface of the biological shield (secondary data) and gamma spectrometry measurements on drill core samples (primary data).
>
> The characterisation program showed the presence of the following radionuclides in the concrete and reinforcement: H-3, C-14, Ca-41, Fe-55, Co-60, Ni-63, Ba-133, Cs-134, Cs-137, Eu-152, Eu-154 and Eu-155.
>
> Radionuclides with low occurrence and relatively short-lived nuclides (Fe-55, Cs-134, and Eu-155) are nearly all decayed and difficult to measure nuclides (C-14, Ca-41, Ni-63) are specifically being examined in the sample interlaboratory and benchmarking exercises.
>
> The essential beta/gamma emitters for the in-situ benchmarking exercise were basically limited to the activation products Eu-152, Ba-133, Co-60 and Cs-137 for potential traces of contamination. Therefore, the gamma ray energy range to be measured in this intercomparison campaign is up to 1408 keV.

It is an interesting and a challenging exercise to carry out such a thorough characterization of the panoply of radionuclides involved, but it provides valuable information not just to support the dismantling operation but for the very long term transmission of knowledge to future generations.

Used Ion Exchange Resins – A Tricky Radioactive Waste Problem

Ion exchange resins are light and porous solids, usually prepared in the form of granules, beads, or sheets. They are used as a medium for removing dissolved impurities from liquid solutions, primarily water. They function by exchanging specific ions (electrically charged atoms or molecular fragments) within the resin structure for the unwanted ions (pollutants) in a liquid. They play a critical role in water softening, demineralization, and purification.

In a nuclear power plant, ion exchange resins are used to remove a host of unwanted radioactive pollutants from water used to cool the nuclear fuel or to moderate the nuclear reaction in the core of the reactor. As a result, the used IX resins from a nuclear plant are very, very radioactive. At Gentilly-2, used IX resins are stored on-site in specific containers designed to hold them.

Ontario Hydro's 1996 Annual Report outlines that importance if these highly radioactive waste materials:

> Spent ion exchange (IX) resins from Ontario Hydro's CANDU pressurized heavy water reactors contain high levels of C-14 [carbon-14] in addition to the usual radionuclides such as H-3 [tritium], Cs-137 [cesium-137], Sr-90 [strontium-90], etc. **These resins constitute the major fraction of Hydro's intermediate level radioactive waste**. The current Ontario Hydro inventory of spent resin is about 2300 m^3, of which about 65% is expected to contain significant amounts of C-14 (i.e. >2 Ci/m^3) [greater than 2 curies per cubic metre].

It is somewhat shocking to realize the magnitude of the problem: the used ion exchange resins "constitute the major fraction of Hydro's intermediate level waste", and they are absolutely loaded with radioactive carbon-14 – all of it human made. Carbon-14 is a beta-emitter with a half-life of 5,700 years. The beta particle that is given off when an atom of carbon-14 disintegrates has very little penetrating power. It is difficult to detect even with sensitive radiation monitors, and equally difficult to measure with accuracy.

Ontario Hydro's total spent resin inventory as of 1996 consist of 1500 m^3 in storage at the Bruce Reactor Waste Operations Site and 800 m^3 in bulk storage at the stations.

Based on current resin usage trends in nuclear power plants, Dr. Frank Greening – a retired nuclear expert of the first caliber – estimates that the total IX resin waste inventory by end-of-life for all current nuclear stations in Ontario will be about 6000 cubic metres. From the Annual Report cited above, each cubic metre contains more than two curies of carbon-14. A curie is an older unit of radioactivity, equal to 37 billion becquerels. At 2 curies per cubic metre, the carbon-14 alone in these used resins will amount to more than 444 trillion becquerels.

So Ontario can look forward to having a huge volume of used resins – enough to fill a warehouse 10 metres high, with a floor space measuring 30 metres by 20 metres, from floor to ceiling and from wall to wall. And all of it is highly radioactive, containing more than 444 trillion becquerels of carbon-14 alone. If you wait patiently for 5,700 years, there will be only half as much carbon-14 – 222 trillion becquerels. Another 5,700 years will see a further reduction to 111 trillion becquerels. The amount of radioactivity left after 11,400 years is still enormous. At this point it may be beneficial to recall that the most ancient pyramids in Egypt are about 5000 years old, and the Great Lakes themselves are about 10,000 years old. These radioactive resins are a helluva problem.

But it gets worse. Most of the carbon-14 in CANDU reactors is created by neutron activation of heavy water used as a moderator in the CANDU reactor vessel called a calandria. And lo and behold, the moderator is also where most of the used ion exchange resins come from. Dr. Greening calculates that those used resins from the moderator contain about 82 curies of carbon-14 per cubic metre, a figure 41 times greater than that suggested in the Ontario Hydro Annual Report cited above.

Presumably, this all may have a bearing on the situation at Gentilly-2, where sometimes more carbon-14 is given off annually, after shutdown, than is given off by the still operating Point Lepreau reactor, as detailed on page 1 of this report.
In its application for a 20-year licence extension, Hydro-Quebec makes no mention of the fact that all of the radioactively contaminated heavy water from the moderator is now stored on-site, but outside of the reactor building. If the storage is slipshod, large

quantities of radioactive carbon dioxide could be escaping from the stored heavy water. Alternatively, large quantities of radioactive carbon dioxide may be escaping from the used ion exchange resins that are also stored on-site but outside the reactor building. It is also possible that both the contaminated heavy water and the radioactively saturated resins are giving off radioactive carbon dioxide without Hydro-Quebec's awareness. Those emissions may be taking place, unmonitored and unreported, thereby adding to an already bad situation – large unwarranted releases of carbon dioxide and tritium – that Hydro should be obliged to address with urgency

There is also a more fundamental very long-term problem: what, exactly, is Hydro-Quebe going to do with these used ion exchange resins? There are reports that the used resins are inclined to degrade, becoming more friable (easily crumbled) and ever more likely to release portions of their enormous radioactive inventory in a highly unsatisfactory manner. This can potentially result in the formation of a difficult-to-handle gelatinous material.

It is imperative that Hydro-Quebec not only stop the ongoing monitored carbon-14 emissions from Gentilly-2 as soon as possible, and fully investigate the extent of unmonitored emissions of carbon-14 from contaminated heavy water and used ion exchange resins, but also probe the spectrum of short-term, medium-term, and long-term management options for these very problematic resinous waste forms, producing a report on the subject for the CNSC before the next licence renewal application in no more than five years time.

Monitoring Dry Storage Modules to prevent Fuel Degradation

Requirement 11 of International Atomic Energy Agency's General Safety Requirements, Part 5, deals with the predisposal storage of radioactive waste. It says:

> Waste shall be stored in such a manner that it can be inspected, monitored, retrieved and preserved in a condition suitable for its subsequent management. Due account shall be taken of the expected period of storage, and, to the extent possible, passive safety features shall be applied. For long term storage in particular, measures shall be taken to prevent degradation of the waste containment.
>
> IAEA General Safety Requirements, Part 5,
> Predisposal management of radioactive waste
> https://tinyurl.com/nkxewcwr

Used nuclear fuel is classified as high-level radioactive waste. It represents the lion's share of nuclear power's radioactive legacy (more than 95 percent of the total radioactive inventory) that will endure for hundreds of thousands of years.

The used fuel from a nuclear power reactor must be maintained in very good physical shape, not only to protect workers and the local environment from harm, but to protect future generations from the dissemination of radiotoxic cancer-causing elements into the environment of living things. The intact fuel bundle (or fuel assembly) is the container for all those poisonous materials; if the container degrades, the contents may more easily escape.

Bear in mind that used fuel will one day have to be removed from the dry storage module and placed in a different container, whether for transportation, for burial, or for a more secure type of confinement. Any degradation in the fuel will make it more susceptible to damage of various kinds during handling – pinholes, tiny cracks, breakage, or even crushing. Non-degraded fuel is the gold standard.

As of 2020, all of the used fuel produced by the Gentilly-2 nuclear power reactor is] stored in 11 CANSTOR dry storage modules on the same site as the reactor which has been shut down since 2012.

The principal safety functions of dry storage modules are:

1. **Confinement of radioactive material**
2. **Passive removal of decay heat**
3. **Radiation shielding**

Environmental sampling by CNSC and the licensee verifies that there is little or no off-site impact (i.e. radioactive contamination), but such sampling does not directly confirm continued performance of the safety functions at the module level.

Decay heat is due to the disintegration of radioactive atoms. When an unstable atom disintegrates, nuclear energy is released and manifests itself in the form of heat (called "decay heat") and radiation (emission of alpha particles, beta particles, gamma rays or neutrons). If the decay heat is not adequately removed, the solid fuel may overheat and become degraded. Fuel that is sufficiently degraded may release radioactive materials, some of which may escape from the module and be observed in nearby soil or in living things.

It is sometimes assumed that declining decay heat implies declining risk. However:

- The decay heat decreases smoothly over time.
- The radiological hazard (e.g., inhalation dose potential) is governed by specific radionuclide inventories and biological dose coefficients.
- Different radionuclides dominate the risk calculation at different cooling times.
- Hazard reduction does **not** necessarily track thermal power reduction in a linear or proportional manner.

Analysis of radionuclide inventories shows that while short-lived isotopes decay rapidly, causing a decline in decay heat, longer-lived fission products and actinides remain significant contributors to radiological consequence potential over multi-decadal periods. Thus decay heat reduction over time not an indication of – or at least not the same as – reduction in radiological risk from the used fuel over the long term. We should not jump to the false conclusion that decreasing decay heat equates to negligible monitoring needs.

The current monitoring approach for the CANSTOR dry storage facility is indirect. It relies primarily on periodic environmental sampling (e.g. air, fruit, vegetation) and general site surveillance. While some such environmental monitoring is indeed necessary, it is inherently a "lagging indicator" of potential degradation. By the time an environmental effect is observed, the damage has already been done inside the module. Environmental monitoring is, by design, a retrospective indicator.

Over an extended period of time, aging mechanisms affecting ventilation performance, confinement integrity, and the strength of structural materials may develop gradually. Such mechanisms may go undetected by annual environmental sampling.

Annual sampling of fruit, vegetables, and ambient air:

- Detects only **off-site impact**, not incipient on-site degradation.
- Provides no module-specific diagnostic capability.
- Cannot identify gradual ventilation degradation, airflow obstruction, or structural ageing.
- Cannot detect early confinement degradation before radioactive material has reached the broader environment.

For long-term storage, we feel that early-warning condition monitoring is more protective than downstream environmental confirmation of confinement failure.

Recommendation 9

That the licensee be required to employ **continuous module-level condition monitoring** to provide early detection of factors that may be causing, or may eventually cause, fuel degradation inside the dry storage modules.

International regulatory guidance (IAEA, WENRA, U.S. NRC aging management guidance) emphasizes:

- Structured **Aging Management Programmes (AMPs)**
- Monitoring and inspection provisions tied to safety functions

- Detection of degradation mechanisms before safety margins are compromised
- Trending and corrective action frameworks

Continuous or periodic monitoring of key parameters such as temperature, ventilation performance, and structural strength is consistent with international expectations for extended dry storage periods. We are not proposing novel technology, but rather application of established aging-management principles at the module level.

Proposed Continuous Monitoring Requirements

The following monitoring elements are technically feasible, proportionate, and aligned with safety functions.

(a) Ventilation / Heat Removal Performance (Continuous)

For each CANSTOR module:

- Outlet air temperature
- Inlet air temperature (or ambient reference)
- Continuous ΔT (outlet minus inlet) trending
- Alarm thresholds for deviation from expected signature
- Investigation criteria for abnormal trends

Ventilation signature trending is a low-cost, early-warning indicator of:

- Vent blockage
- Debris accumulation
- Ice formation
- Animal nesting
- Concrete spalling affecting airflow
- Unanticipated internal heat transfer changes

(b) Module-Level Radiological Change Detection

For each module or defined module grouping:

- Continuous gross gamma change-detection sensor at or near exhaust pathway

- Periodic automated particulate sampling at module outlets (e.g., weekly/bi-weekly, rotating manifold acceptable)
- Laboratory gamma spectroscopy trending
- Investigation and reporting thresholds

This provides direct verification of confinement performance at the module boundary rather than relying solely on site-wide environmental sampling.

(c) Structural Aging Surveillance

As part of the Aging Management Programme:

- Documented inspection of concrete condition (cracking, spalling, freeze-thaw damage)
- Monitoring of moisture ingress pathways
- Evaluation of airflow geometry preservation
- Defined inspection intervals tied to degradation mechanisms
- Corrective action criteria

This ensures continued performance of:

- Shielding
- Heat removal airflow
- Structural integrity

Data Integrity and Access Framework

To address concerns about inappropriate public dissemination or misuse of raw real-time data, the following tiered access model is proposed:

Tier 1 – Real-Time Access (Restricted)
CNSC staff, licensee operations, emergency response, authorized reviewers.

Tier 2 – Periodic Technical Reports
Monthly or quarterly trend summaries including:

- ΔT trends per module
- Alarm events and corrective actions
- Monitoring system uptime

Tier 3 – Public Reporting
Annual summary including:

- Monitoring performance
- Exceptions and resolutions

- Confirmation of safety function preservation

This approach balances transparency, security, and technical responsibility.

Proposed Licence Conditions

The Commission is respectfully requested to include the following conditions:

1. **Module-Level Monitoring Requirement**
   The licensee shall implement and maintain continuous condition monitoring for each CANSTOR module sufficient to detect degradation of heat removal and confinement performance.
2. **Trending and Alarm Criteria**
   The licensee shall establish alarm thresholds, investigation criteria, and corrective action protocols for monitored parameters.
3. **Aging Management Enhancement**
   The licensee shall update the Ageing Management Programme to explicitly address module ventilation performance and concrete ageing impacts on airflow and shielding.
4. **Data Integrity and Availability**
   Monitoring systems shall maintain defined availability targets, calibration schedules, and secure data logging with audit trails.
5. **Periodic Reporting**
   The licensee shall provide periodic monitoring summaries to the CNSC and publish annual public summaries.

Conclusion

The requested monitoring enhancements:

- Are technically feasible.
- Are proportionate to the duration of the licence extension.
- Align with international ageing-management principles.
- Provide early-warning detection rather than reliance on downstream environmental confirmation.
- Strengthen public confidence without compromising security.

Recommendation 10.

That any licence extension for Gentilly-2 include these monitoring provisions on all dry storage modules as a licencing condition to ensure continued protection of workers, the public, and the environment.

The following table summarizes the need and justification of CNSC taking proactive actions to ensure safe storage, handling, transportability, retrieval and repackaging of the spent fuel storage

Degradation Mechanism	Driving Factors	Early Indicator	Monitoring Tool	Proposed Licence Condition	Corrective Action Trigger
Annulus airflow obstruction	Debris, ice, spalling, nesting	ΔT drift, airflow reduction	**Continuous inlet/outlet T, ΔP sensor**	**LC-1**	ΔT deviation beyond baseline envelope
Reduced natural convection	Geometry change, surface roughness	Elevated outlet temperature	**Continuous T trending**	**LC-1**	Sustained abnormal thermal profile
Residual moisture effects	Incomplete drying, micro-crevices	Moisture presence, corrosion trend	**Moisture verification, periodic sampling**	**LC-3 / LC-4**	Moisture detection above defined threshold
UO_2 oxidation	Oxygen + heat + time	Fission product trace, corrosion byproducts	**Exhaust gross gamma + particulate sampling**	**LC-2**	Detectable radiological change
Hydride reorientation	Temperature + stress + time	Fuel condition uncertainty	**Surveillance canister validation**	**LC-4**	Validation interval findings
Concrete carbonation	CO_2 ingress	Increased crack width	**Crack gauges, carbonation testing**	**LC-3**	Depth exceeds defined margin
Chloride-induced corrosion	Chloride ingress + moisture	Rebar corrosion potential	**Electrochemical probes**	**LC-3**	Corrosion potential threshold
Freeze–thaw scaling	Moisture cycling	Spalling, debris in annulus	**Visual inspection + vent inspection**	**LC-3**	Visible obstruction or delamination
Galvanized cylinder corrosion	Humidity, zinc depletion	Surface corrosion trend	**Visual inspection + corrosion trending**	**LC-3**	Zinc depletion beyond defined %
Groundwater transport	Migration pathway	Tritium increase	**Sentinel wells quarterly**	**LC-5**	Above background trend threshold

Annex 1

Gentilly-1 Reactor Dismantlement Proposal

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GENTILLY-1 REACTOR DISMANTLING PROPOSAL

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ABSTRACT

Studies have been undertaken to establish the feasibility and costs involved in the decommissioning of the Gentilly-1 Nuclear Power Station. This paper outlines a method of dismantling of the reactor, if such an option would be considered. It demonstrates that the dismantling of the Gentilly-1 reactor is feasible and also serves to highlight the inherent decommissionability of all CANDU reactors.

INTRODUCTION

Historical Perspective

Since the advent of nuclear power generation it has been known that decommissioning of reactors would require special attention. As many reactors in the world are nearing the end of their design lives, the effort expended on decommissioning studies and demonstration projects has grown dramatically. Nearly every jurisdiction now requires that decommissioning feasibility, both technical and financial, be demonstrated at the time of license application. Standards and regulations pertaining to decommissioning have blossomed in most OECD nations.

The number of nuclear reactors which have been or are presently being decommissioned is approaching 100 with the majority destined for the storage with surveillance mode. Most of these reactors are research or demonstration reactors with outputs less than 10 megawatts of thermal energy (MWt).

The extent of dismantling experience in the world is somewhat more limited. To date only two land based nuclear power reactors rated larger than 10 MWt have been completely dismantled: The Elk River Reactor (58 MWt) in Minnesota USA was dismantled from 1971 to 1974 and the Sodium Reactor Experiment (30 MWt) in California USA was dismantled from 1974 to 1982. The Windscale AGR (33 MWe) in the UK is in the process of being dismantled with completion anticipated towards the end of this decade. It is also planned to begin dismantling the Shippingport Atomic Power Station in Pennsylvania USA (72 MWe) in the near future.

Canadian reactor dismantling experience includes the removal and replacement of the cores of the NRU and NRX reactors at CRNL.

Station History and Scope of Proposal

Criticality of the Gentilly-1 (G-1) reactor was first achieved in 1971. Full power was achieved in 1972. After having run the reactor for only a short period of time, it was decided in 1980 to put the station in a "lay-up" state, pending a decision with regard to its future use. Several options were considered, including dismantling of the reactor as described in this paper.

The scope of the Gentilly-1 Reactor Dismantling Proposal is as follows: The proposal shall cover the dismantling of the reactor including reactivity mechanism, fuel channels, calandria and thermal shield assembly and the inner biological shield. It is assumed that the steam drums, feeders and headers as well as the helium piping on the west side will already have been removed and hence are not covered by this proposal. Dismantling of the reactor is assumed to be part of a near term unrestricted site use scenario. The reactor building polar crane, fuelling machine service crane and main service building crane shall be available for dismantling. All equipment, material and personnel shall pass through existing airlocks. All activities shall conform to Canadian laws and regulations as well as IAEA rules.

Reactor Description and Status

The Gentilly-1 reactor (Figure 1) is a heavy water moderated, boiling light water cooled, design with vertically oriented fuel channels. The heart of the reactor consists of the calandria which is traversed by 308 fuel channels. The cylindrical reflector baffle and dump port separate the core and reflector region from the dump annulus into which the moderator can be forced by pressurizing the core with helium. The moderator boundary is thus the calandria shell, the two inner tubesheets and the 308 calandria tubes.

The calandria is surrounded radially and structurally supported by the thermal shield vessel, through which light cooling water is circulated. Axial shields above and below the calandria attenuate radiation and are also light water cooled.

The 308 fuel channels consist primarily of an upper and lower end fitting joined by a pressure tube which traverses the core. The Gentilly-1 fuel channel is fueled from the bottom. Light water enters each fuel channel via its feeder which is connected to the lower end fitting. Steam exits from each fuel channel via its upper end fitting.

The thermal shield vessel is surrounded by a cylindrically shaped inner biological shield made of reinforced concrete.

The core has been entirely defuelled. Both the moderator and heat transport systems have been drained and dried, and are now nitrogen gas filled. The light water thermal shield cooling system is circulating. The fuel channels are intact except that the lower shield plugs and closure plugs have been replaced with rubber seals plugs. The radiation fields in the reactor building are very low: 0.2 mSv/h or less in readily accessible areas and

0.5 mSv/h adjacent to the end fittings.

DISMANTLING PLAN

Overview

The dismantling plan described in this paper comprises four major stages. The first stage is the removal of the reactivity mechanisms. Since all of the reactivity mechanisms were designed to be maintained and even replaced, this plan draws on existing maintenance procedures and experience. Due to the small number of mechanisms and their variety an automated or remote removal process is neither desirable nor efficient, therefore a manual procedure is proposed.

The second stage is the removal of the fuel channels, calandria tubes and extension tubes, which is again a manual operation. This stage takes advantage of the fact that the G-1 fuel channel was designed to be removed in one piece through the bottom of the reactor. The procedure a'so makes use of the savings which are possible to the economies of scale of a repetitive process.

The third stage is the removal of the calandria and thermal shield vessel by remotely controlled, underwater cutting. This stage is the most technically ambitious. The potential for high radiation exposure levels dictates remotely controlled, underwater cutting.

The fourth and final stage is the removal of the calandria support structure and inner biological shield. This would be a manual operation since the concrete is not very active.

Only that portion of the work taking place in the reactor building is covered by this paper.

Reactivity Mechanisms Removal

All of the reactivity mechanisms penetrate the biological shield or the axial shield and most also penetrate the calandria. This then defines the overall approach to their removal. In all cases access to the penetration tubes is easily available and either by unbolting or by breaking a circumferential weld, the mechanism can be slid or screwed out. The mechanism is then pulled into a handling flask and moved to the hot cutting room

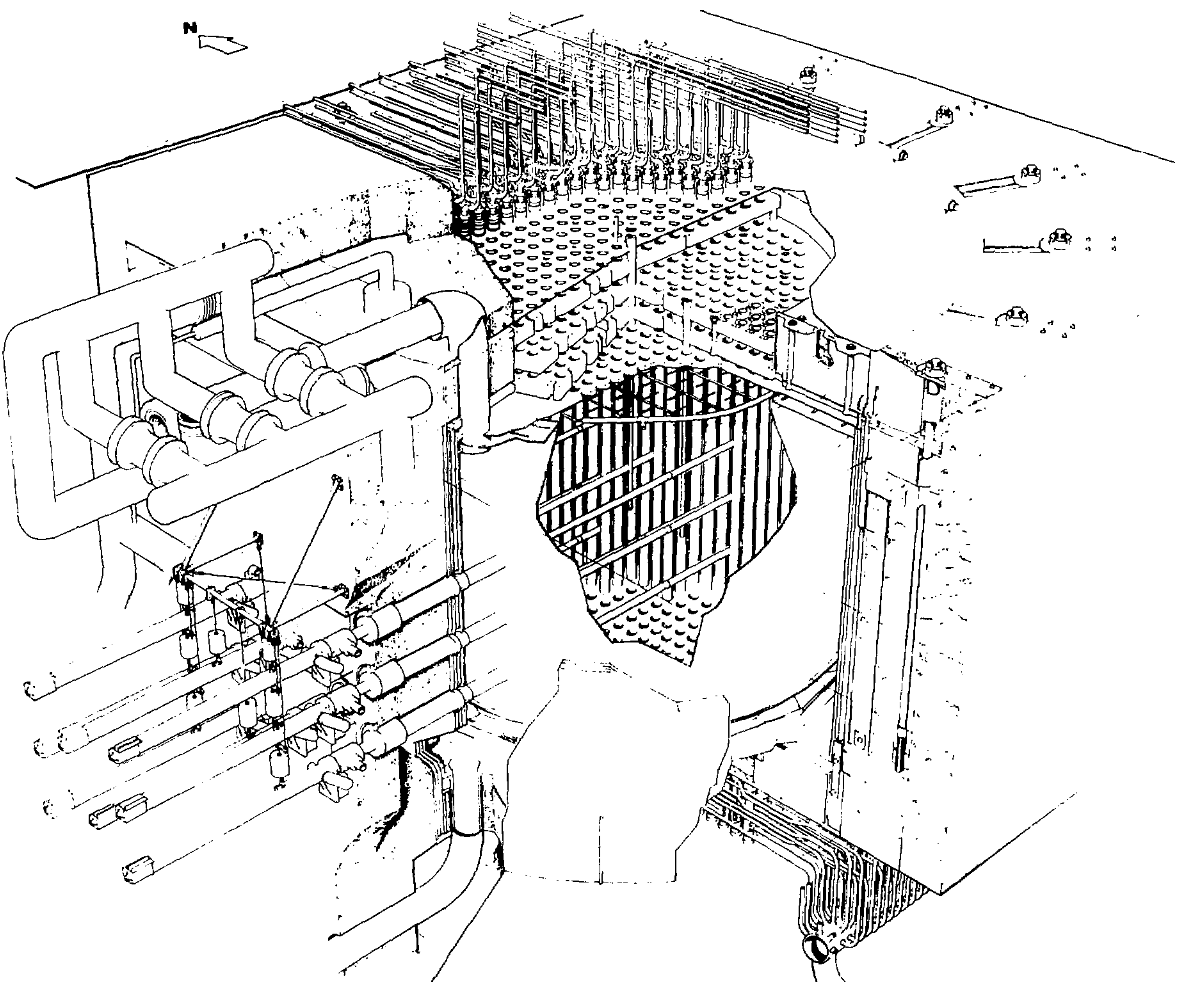

FIGURE 1 REACTOR ASSEMBLY

where it can be cut in half and loaded into appropriate transport sleeves.

The radiation protection approach to be taken during removal of the reactivity mechanisms is that the exposure of personnel in the vicinity of the reactor should not exceed the maximum existing "background" dose rate from the building in this area of 0.2 mSv/h. All operations can be easily shielded to keep exposure targets near this level.

Removal of the reactivity mechanisms shall proceed in three substages. The horizontal reactivity mechanisms, including 3 ion chambers and 8 booster flow tubes, shall be flasked and removed by working from the floor at elevation 59'-6". The drives of the vertical reactivity mechanisms shall be conventionally removed from the grating above the outlet feeders. The elements, guide tubes, shield plugs, cabling and piping of the vertical reactivity mechanisms shall be removed and/or flasked by working from a shielding floor above the reactor.

Fuel Channel, Calandria Tube and Extension Tube Tube Removal

There are 308 fuel channels consisting of an upper end fitting, a pressure tube and a lower end fitting. The end fittings are made of 403 stainless steel and the pressure tube is made of a heat treated zirconium - 2.5% niobium alloy. The upper end fitting is 51" long and 4.340" outside diameter. The lower end fitting is 87.75" long and 6.75" outside diameter. The pressure tube is about 18' long, 4.267" inside diameter with a .095" wall thickness. The pressure tube is rolled into the end of the lower end fitting and is sandwich rolled onto the upper end fitting. The fuel channel is held in the reactor axially by a bolted split ring connection to the bottom of the lower extension tube.

Each fuel channel is surrounded by a calandria tube in the core and an upper and lower extension tube in the upper and lower axial shield respectively. The calandria tubes are rolled into the inboard ends of the upper and lower extension tubes with calandria tube inserts.

The 308 fuel channels of the Gentilly-1 reactor were designed to be removed and replaced as a one piece assembly consisting of an upper end fitting, a pressure tube and a lower end fitting. This factor greatly simplifies the dismantling procedure, and since both the biological and axial shields will be intact at the time of fuel channel dismantling, the occupational radiation exposure resulting from this work can be effective minimized.

With this in mind, the approach selected for fuel channel dismantling is a manually controlled method utilizing simple tools and handling equipment. This approach shall benefit from the design engineering, site experience and laboratory development work associated with fuel channel replacements done at Douglas Point, NPD, Pickering A and Bruce A.

The anticipated crew configuration for most of the operations in this stage is two single man crews working above the reactor, two double man crews working below the reactor and one driver of the flask carrier vehicle. Also an operator for the 30 ton reactor building polar crane will be required for part of the time.

Due to the repetitive nature of the work, the provision of shielding and specialized tools is a cost effective means of reducing radiation exposure. Thus, it is proposed that a movable shielding platform which would rest on the upper tubesheet of the uper axial shield be used for all operations performed from the top of the reactor. Preliminary studies show that a thick steel floor, handled by the reactor building polar crane would be suitable.

Currently there exists underneath the lower end fittings a movable platform which was used for fuel channel installation. This platform would need to be modified such that it could carry the necessary shielding materials. Additionally, since most of the tools would need to be lifted and held from below, tool handling and holding fixtures would need to be mounted on the work platform. Fuel channel removal is depicted in Figure 2.

Removal of the fuel channels, calandria tubes and rextension tubes would consist of four substages: upper end fittings and shield plug removal, pressure tube and lower end fitting removal, calandria tube and lower extension tube removal, and upper extension

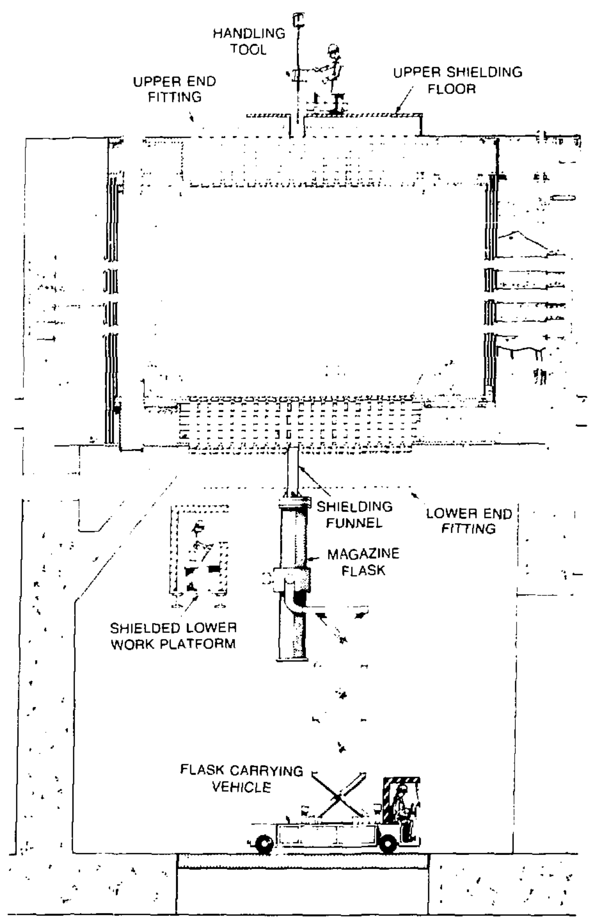

FIGURE 2 FUEL CHANNEL REMOVAL

tube removal.

The removal of the upper end fitting and shield plug would proceed as follows: Using an external tube cutter, cut the upper extension tube above the upper tubesheet. Insert a chipless tube cutter into the fuel channel from the bottom and cut the pressure tube just above the lower end fitting, again at mid-length and lastly just below the upper shield plug "top Stop". Position a flask above the channel site and withdraw the upper end fitting and shield plug together. Remove the flask to the hot waste laydown areas.

The removal of the lower end fitting and the pressure tube would proceed as follows: Insert a handling tool through the top of the reactor. Undo the six bolts of the split ring connection between the lower end fitting and the lower extension tube. Position the three barrel, magazine flask with pedestal attached below the channel site. Using the handling tool, lower the end fitting and the two pressure tube pieces into the three barrels of the magazine flask. Remove the flask to the hot cutting room. Shield the fuel channel opening with a 6" thick lead plug by bolting it to the lower extension tube. Repeat until all of the lower end fittings and pressure tubes are removed.

Once all of the fuel channels have been removed, the work platform below the reactor would be modified such that the floor of the platform would be raised to 7' below the lower tubesheet of the lower axial shield (elevation 48'-6").

The removal of the calandria tubes and the lower extension tubes would proceed as follows: Insert a tube cutting saw through the top of the reactor and cut the calandria tube at the inboard edge of the calandria tube insert. Insert a handling tool through the top of the reactor to hold the calandria tube and extension tube. Install a calandria tube insert removal tool which would split, collapse and remove the lower calandria tube insert. Flask the calandria tube insert. Using a chipless tube cutter inserted from the bottom, cut the calandria tube and lower extension tube just above the lower calandria tube insert. Cut the bolting flange from the lower extension tube. Sever the tubesheet to extension tube weld. Slit the lower extension tube rolled joint and collapse it. Position the magazine flask with an external chipless tube cutting attachment below the lattice site. Via the handling tool pus the lower extension tube into one barrel of the magazine flask. Lower 9' of the calandria tube into one of the chambers of the flask. Remove the flask to the hot cutting room. Replug the opening in the tubesheet and seal weld it. Repeat this process for all 308 fuel channel sites.

Once the lower extension tubes have been removed from the lower axial shield, the lower tubesheet of the lower axial shield will only be supported by its weld to the lower axial shield shell. This is not enough to carry the weight of the two 8" thick shielding slabs which will lowered onto it as well as 20' of hydrostatic head. To provide additional support three WF beams at 6' centres must be installed below the reactor. These beams would stay in place through completion of the removal of the calandria and thermal shield assembly.

The removal of the upper extension tubes and shielding sleeves would proceed as follows: Insert a chipless tube cutter through the top of the reactor and cut the upper extension tube just above the lower tubesheet of the lower axial shield. Insert the handling tool from the top of the reactor. Sever the upper extension tube to upper tubesheet weld. Slit and collapse the upper extension tube rolled joint. Withdraw the upper extension tube and its shielding sleeve through the upper axial shield as a unit into a flask. Remove the flask to the hot waste laydown area. Repeat these operations until all of the upper extension tubes and shielding sleeves are removed.

Calandria and Thermal Shield Vessel Removal

The dominant factor influencing the dismantling procedure for the calandria and thermal shield vessel is the potential for high occupational radiation exposure. Currently, the outermost layers of steel shield personnel from the fields emitted by the innermost plates. Once the outer layers are peeled off, the fields will increase 100 fold unless measures are taken to provide alternative shielding. One way to shield personnel is to fill the entire vessel with water. In this way the radiation exposure target of 0.05 mSv/h can be achieved.

The remote manipulator system would be installed at this step. The system would consist of a gantry crane running on rails on top of the concrete, with a polar manipulator attached. (Figure 3) The system would be controlled remotely from a dedicated control room. Closed circuit television cameras would let the operators see their work areas.

The upper axial shield (with extension tubes removed) consist of 5 plates each about 20' in diameter. The top is a 1-1/2" thick carbon steel plate called the upper tubesheet of the upper axial shield. Under this are three 8" thick carbon steel shielding slabs. The bottom of the shield is a 3-1/2" thick 304L stainless steel plate called the lower tubesheet of the upper axial shield. Each plate has 308, 8" diameter holes on an 11" square pitch.

The sectioning operations shall proceed as follows: The upper tubesheet is to be cut in-situ into 2' x 4' pieces of parts thereof. The pieces would then be lifted out of the pool, using a shielding cover which would shield each piece on its way to a transport sleeve which could sit near the work area. Once a transport sleeve is full it would be moved in a flask to a shielded storage area to await shipment.

Each plate would be handled similarly, with some allowance for removing miscellaneous support bolts, etc.

The calandria consists of the reflector baffle, the dump port, the booster penetration extension tubes, the D_2O spray cooling supply pipes and the calandria vessel wall. The reflector baffle is a 304L stainless steel plate cylinder separating the reflector region and the dump annulus. It is welded to the 1.375" thick annular plate at the top and to the dump port at the bottom. The reflector baffle is .75" thick in its main cylindrical section which is 23'-4" in diameter and 13'-3" high and is 1.0" thick in its conical at section. The dump port is an annular nozzle welded to the bottom of the calandria vessel made up of pieces of 1" thick stainless steel plate. The 16 booster penetration extension tubes are 3' long, 9" diameter, 1-1/4" thick stainless steel tubes, welded to the inside of the calandria vessel wall at one end and to the reflector baffle at the other. The D_2O spray cooling supply pipes are 2 stainless steel 6" schedule 40 pipes vertically traversing the dump annulus to supply the spray cooling headers. The calandria vessel wall is a stainless steel right cylinder with 17'6-1/2" height, 30'-0" diameter and 1" plate thickness.

The dismantling of the calandria shall be carried out with the work platform at elevation 80'5". The resulting waste shall be lifted out of the calandria by the reactor building polar crane, lowered through the hatch ways and then removed to the hot waste packaging area. The dismantling shall proceed in five steps corresponding to reflector baffle, dump port, booster penetration extension tubes, D_2O spray cooling supply pipes and calandria vessel wall.

The first step shall be the sectioning and removal of the reflector baffle. This would proceed from the top to bottom, cutting out 2' x 4' pieces at a time. The pieces would be lifted out in an onsite flask and removed to the hot waste packaging area.

The second step shall be sectioning and removal of the dump port. This would proceed by working around the annulus, sectioning off a 2' wide piece at a time, lifting it out in an onsite flask and removing it to the hot waste packaging area.

The third step shall be removal of the booster penetration extension tubes. Since the reflector baffle has already been removed, the tube would only need to be cut at the calandria vessel wall and removed using an onsite flask to the hot waste packaging area.

The fourth step shall be removal of the D_2O spray cooling supply piping. The pipe would be cut into 2' lengths which would be loaded into an onsite flask and then removed to the hot waste packaging area.

The fifth step shall be sectioning and removal of the calandria vessel wall, including the upper annular plate. This would proceed by working from top to bottom sectioning off 2' x 4" pieces at a time, loading them onto an onsite flask and removing them to the service building for transfer to a transport sleeve.

For the purpose of this paper the lower axial shield shall consist of the upper tubesheet, and three shielding slabs. The lower tubesheet is not included here since it must remain intact so long as the calandria cavity is water filled.

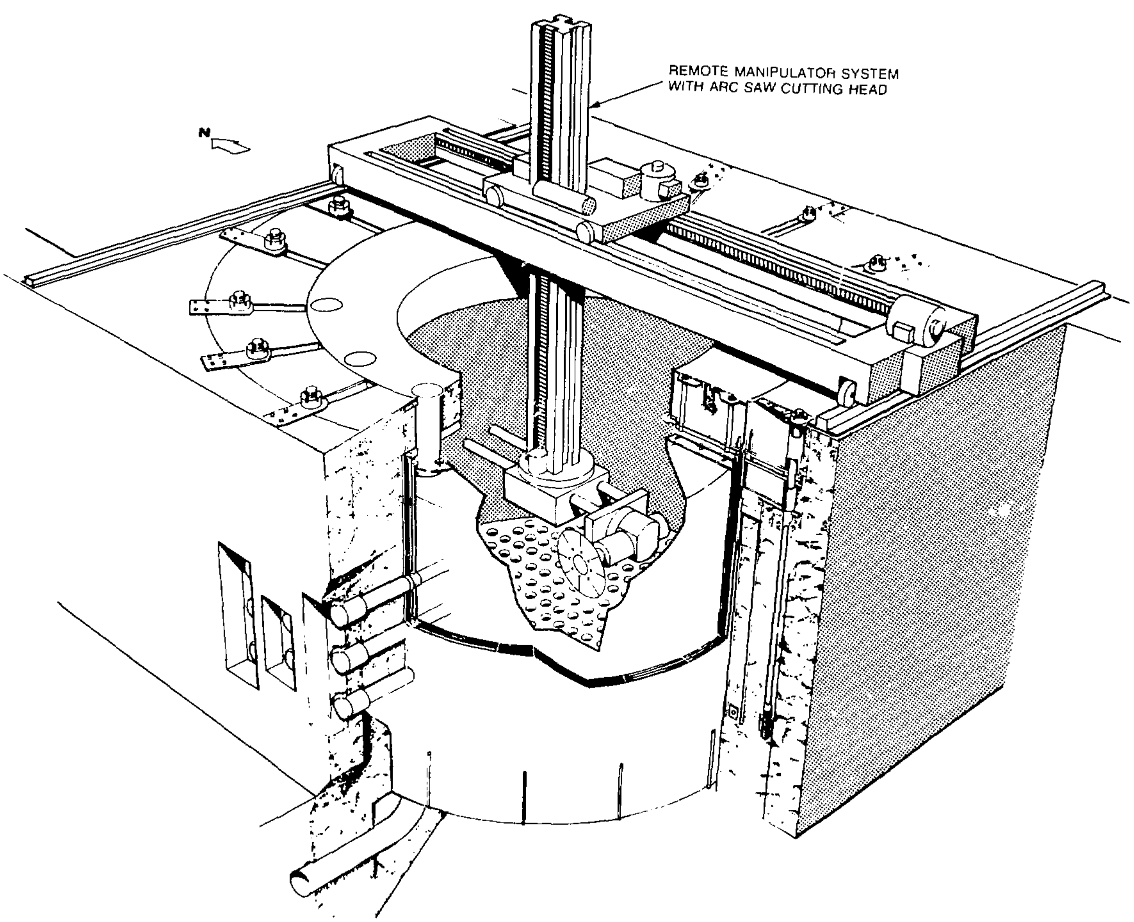

FIGURE 3 CALANDRIA AND THERMAL SHIELD VESSEL SECTIONING

The upper tubesheet is a 3-1/2" thick 304L stainless steel plate 30' in diameter with 308 7" holes on 11" square pitch. It weights about 94,000 lb. Each shielding slab is an 8" thick carbon steel plate 20' in diameter with 308 8" holes on an 11" square pitch.

The cutting and handling operations would continue to be controlled from the same platform as the calandria sectioning. The sectioning and removal of the lower axial shield shall be executed in 4 steps, with sectioning and removal of each plate comprising a step. The first step would be the sectioning and removal of the upper tubesheet. It would be cut into 2' x 4' pieces which would be moved via onsite flask to the hot waste packaging area.

The second step would be the removal of the three shielding slabs. Each slab would be sectioned into 2' x 4' pieces which would be carried via onsite flask to the hot packaging area.

The thermal shield consist of two layers of carbon steel. Each layer is constructed in segments arcing through 22°-30'. Together, the segments form a double walled tube about 30' in diameter and 17'-6-1/2" in height. The plates are 1-1/2" thick carbon steel.

The cutting and handling of the thermal shield would continue to use the work platform at elevation 80'-5". The sectioning and removal of the thermal shield plates would proceed as follows: Cut off 2' x 4' pieces of thermal shield and load them onto an onsite flask. Lift out the onsite flask and remove it to the hot waste packaging area.

At this point the water in the calandria cavity must be drained. As well, any debris or swarf

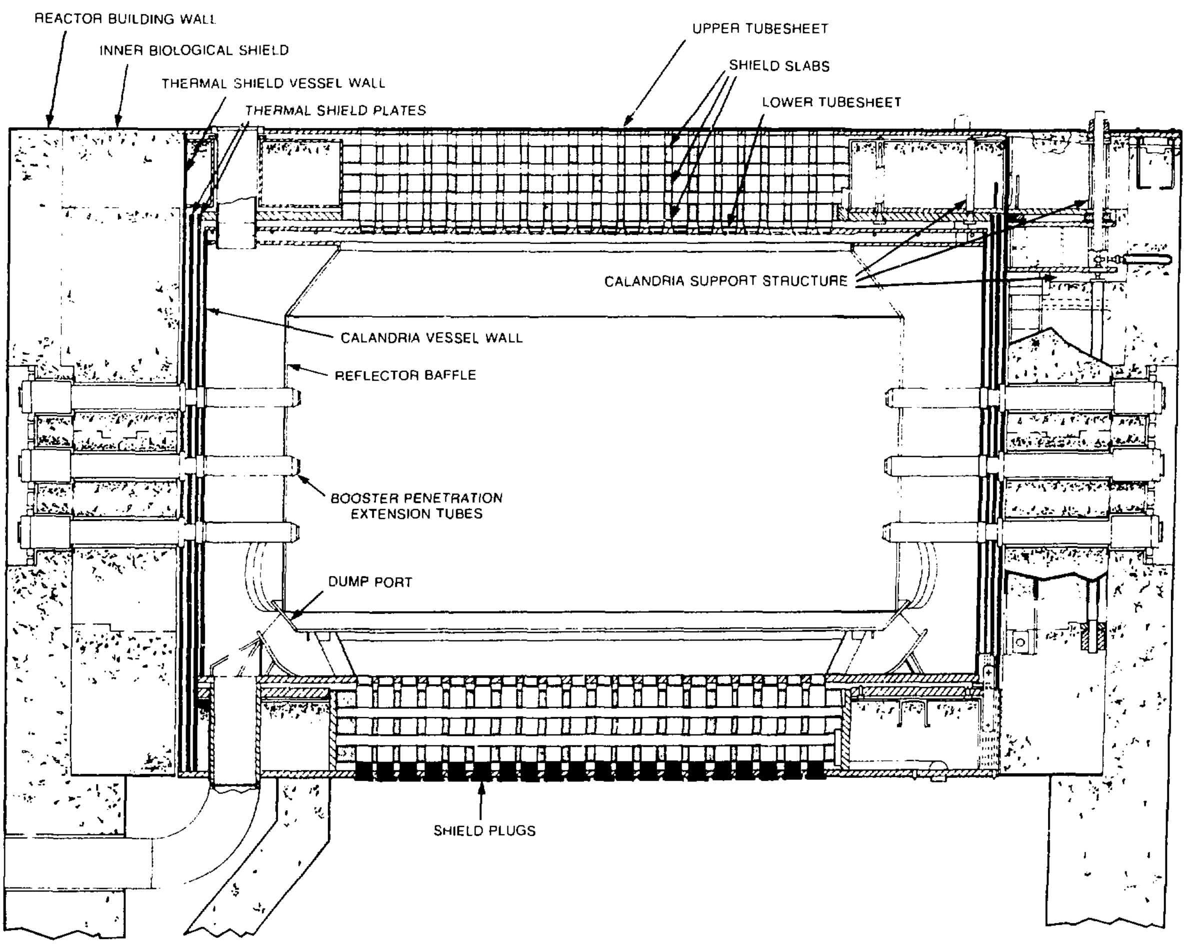

FIGURE 4 REACTOR WITH REACTIVITY MECHANISMS, FUEL CHANNELS, CALANDRIA TUBES AND EXTENSION TUBES REMOVED

accumulateo in the cavity must be vacuumed out since it is much more active than the outer water boundary.

The removal of the outer water boundary shall be carried out in air, with a polyethylene tent erected to contain the dust and fumes generated by the cutting processes. Initially, remotely controlled cutting of the most active plates is feasible but then the breaking away of concrete and the cutting of the calandria support sturcture will need to be done manually by workers wearing dust masks, since the component geometry is too complex.

Removal of the outer water boundary and the calandria support structure would proceed as follows: Using remotely controlled cutting, section the axial shield shell, the thermal shield vessel wall and the lower tubesheet of the lower axial shield into 2' x 4' pieces. Grapple and flask the pieces and then remove the flask to the hot waste packaging area. Manually break away the concrete in the calandria support structure and then uisng oxy-acetylene cutting, remove the exposed steel work. Flask the debris and move the flask to the hot waste packaging area.

Inner Biological Shield Removal

By this step the upper and lower support structure will have been removed. The remaining inner biological shield is a steel reinforced concrete annulus with many other carbon steel embedments. The inside diameter of the annulus is 31'-6", and it is 4' thick and 25' high. Embedments in the concrete include 16 vertical support beams, 16 cooling coil loops, penetrations for the booster and ion chambers, and anchoring hardware for the support structure. The reinforcing steel consists of 5 concentric grids of rebar, with rebar sizes from .75" to 1.325" in diameter.

TABLE 1 - ESTIMATED EFFORT AND EXPOSUE FOR GENTILLY-1 REACTOR DISMANTLING ON REACTOR WORK

	EFFORT (PERSON HOURS)	EXPOSURE (PERSON SIEVERTS)
1. Reactivity, Mechanism Removal	350	0.061
2. Fuel Channel, Calandria Tube and Extension Tube Removal	10782	0.527
3. Calandria and Thermal Shield Assembly Removal	9032	0.555
4. Inner Biological Shield Removal	5696	0.570
TOTAL	25860	171.3

Due to the variety of geometries present and the relatively activation of components, the most efficient way to remove the calandria support structure and the inner biological shield is by controlled blasting and manual cutting of the exposed steel.

The removal of the inner biological shield would proceed as follows: Drill a series of charge holes just inboard of the second layer of rebar. Place appropriately sized charges in the holes. Position blasting mats to contain missiles. Blast away a layer of concrete. Clear away the concrete rubble. Using oxy-acteylene cutting equipment, cut off the expose steel. Flask the steel and move it to the hot waste packaging area. Repeat this sequence until all of the inner biological shield is removed.

The estimated effort and exposure for all reactor dismantling work is summarized in Table 1.

CONCLUSION

The dismantling of the Gentilly-1 reactor is technically elegant and can be performed safely with reasonable radiation exposure cost. Reactor repair technology developed at AECL can be easily adapted to dismanting techniques. Remote, underwater plate cutting technology can be developed to meet the needs of reactor dismantling projects.

The same design features which were introduced to ease manufacture and operation of a CANDU reactor also result in a simple dismantling procedure. This includes the accessibility of components and the removability of major assemblies such as the fuel channels.

Upon consideration of the Gentilly-1 reactor dismantling proposal, it can be concluded that CANDU reactors can be dismantled, if so decided, making use of conventional technology and tools to keep radiation exposure as low as reasonably achievable.

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