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Written Submission from the Canadian Coalition for Nuclear Responsibility

Mémoire du Regroupement pour la surveillance du nucléaire

In the matter of the

À l'égard des

Canadian Nuclear Laboratories

Laboratoires Nucléaires Canadiens

Application to amend the licence and licensing basis for the Gentilly-1 Waste Facility

Demande concernant la modification de leur permis et du fondement d'autorisation pour l'installation de gestion des déchets de Gentilly-1

Hearing in writing based on written submissions

Audience par écrit fondée sur des mémoires

July 2026

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Canada

Cultivating Trust:

Inform, Engage, Protect

a submission from

The Canadian Coalition for Nuclear Responsibility

to

The Canadian Nuclear Safety Commission

regarding

The proposed dismantling of the core of the Gentilly-1 reactor

by means of

an amendment to the G1 WFDL

requested by

Canadian Nuclear Laboratories

June 17 2026

RECOMMENDATIONS

Recommendation 1.
That the Canadian Nuclear Safety Commission (CNSC) be cognizant of the fact that, for the Canadian public and for the Indigenous peoples of Canada, the Age of Nuclear Waste is just beginning and therefore all major decisions related to the storage, packaging, transport and disposal of post-fission radioactive waste must be treated with full transparency and opennness if public trust is to be expected and valued.

Recommendation 2.
That the Gentilly-1 Waste Facility (G1WF) licence, set to expire on December 31 2034, not be amended and extended to 2041 as requested by the licencee Canadian Nuclear Laboratories (CNL), without a full face-to-face hearing before CNSC Commissioners as is the established practice for extending power reactor operating licences and granting previous detailed decommissioning licenses such as that for the Douglas Point reactor.

Recommendation 3.
That the terms of the G1WF licence not be amended to authorize CNL “to proceed with the execution of decommissioning involving the removal of all buildings and structures from the Gentilly-1 Waste Facility (G1WF) site”, without a full face-to-face hearing before CNSC Commissioners, as this will be the first time in Canada that a power reactor has ever been fully dismantled and important precedents may be set for future activities of this nature.

Recommendation 4.
That during the the existing unamended licence period, CNL be tasked by CNSC to prepare a report to be made fully available to the public, providing a more detailed and accurate radiological characterization of each major component of the structures to be eventually dismantled, bearing in mind not just the requirements for worker safety and environmental protection during dismantling, but also the need to inform future generations as to the characteristics of all radionuclides present in the wastes, with particular attention to those that will endure for many generations and will become internal radioactive emitters if released.

Recommendation 5.
That as part of the report mentioned above, or otherwise, CNL discuss publicly options related to how cutting operations and other volume reduction methods such as melting, grinding, compressing, segmenting, or incinerating may be carried out, with special attention to the monitoring, containment and treatment of radioactive dust, gases, vapours and liquids that would result from this.

Recommendation 6.
That as part of the report mentioned above, or otherwise, CNL discuss publicly how municipal and provincial authorities will be engaged and consulted before deciding on whether or not any “clearance level” radioactive waste from G1WF is to be disposed of in non-radioactive municipal landfills, garbage dumps or scrapyards, and what kind of notification will be provided to those in charge of such waste faciltiies.

Recommendation 7.
That as part of the report mentioned above, or otherwise, CNL discuss publicly how residual radioactive contamination of the G1WF site will be monitored and removed, with special attention to soil, subsoil and ground water.

Recommendation 8
That when CNL eventually completes the decommissioning of the G1 reactor core under a new licence, the radioactive decommissioning wastes be stored on the reactor site (as has been done up until now for all radioactive reactor refurbishment waste in Canada) until a suitable final destination for intermediate level raduoactive waste has declared to be available by NWMO.

Background

Gentilly-1 (G1) is a federally-owned power reactor located at Bécancour Québec, right beside the Gentilly-2 reactor that is owned by Hydro Quebec. Gentilly-1 is a prototype CANDU “boiling water” reactor design using light water as a primary coolant and heavy water as a neutron moderator. It has 380 vertical fuel channels inside a cylindrical vessel called a calandria, in lieu of the horizontal fuel channels used in all other CANDU reactors (including Gentilly-2).

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

The Gentilly-1 reactor operated for only 183 days over a period of 6 years (1972-1978), without ever contributing a single kilowatt-hour of electricity to the Quebec grid. It was defueled in 1984 and the site was converted into a waste management facility (G1WF). Decades later, in December 2012, the neighbouring Gentilly-2 reactor (owned by Hydro Quebec) was shut down after 30 years of successful operation, having achieved a 76.4 percent lifetime capacity factor.

Atomic Energy of Canada Limited (AECL) is the sole owner of the Gentilly-1 facility, but Canadian Nuclear Laboratories (CNL) is the licensee. CNL is run by a consortium of US-based multinational corporations that receive lavish funding from the federal government through AECL to manage all federally-owned nuclear facilities (including G1) and the associated radioactive wastes. The current 20-year GoCo (Government owned, contractor operated) contract provides for $24 billion in federal funding to CNL – an average of $1,200 million per year. It is the largest federal contract ever awarded.

CNL is currently requesting the Canadian Nuclear Safety Commission (CNSC) to grant an amendment to the Gentilly-1 (G1) Waste Facility Decommissioning Licence (WFDL). The current 15-year licence, granted in February 2019, is set to expire on December 31, 2034. It only authorizes the licensee to conduct “Storage with Surveillance” activities. CNL is asking for an amendment to the licence to allow it “to proceed with the execution of decommissioning involving the removal of all buildings and structures from the Gentilly-1 Waste Facility (G1WF) site”, CNL also wants the amended licence to extend for 15 years onwards from the date of the amendment – presumably from 2026 until 2041. That’s almost double the time remaining on the current licence.

Cultivating Distrust

In September 2025, CNSC announced that it will hold a “hearing in writing” in July 2026 to decide whether or not to grant CNL its requested amendment to the Gentilly-1 Nuclear Waste Facility Decommissioning Licence. CNSC invited public interventions on the dossier. However, the CNSC announcement made no mention of the fact that if granted, the amendment would authorize the first ever complete dismantling of the radioactive core of a nuclear power reactor in Canada. Nor was it mentioned that the requested amendment would grant a substantial extension of time for the amended licence and entail hundreds of truckloads of radioactive waste over public roads for years to come. The CNSC announcement is linked below

www.cnsc-ccsn.gc.ca/eng/the-commission/participant-funding-program/opportunities/2025-07-cnl-gentilly-1-waste-facility/

The Canadian Coalition for Nuclear Responsibility (CCNR) soon discovered that most individuals and organizations in Canada, long active in the nuclear field, were completely unaware of the unprecedented nature of the proposed amendment. Given the bland wording of the CNSC announcement, and the low priority the amendment request seemed to be afforded by the Commission – not meriting a normal CNSC face-to-face public hearing but only a "hearing in writing" – most presumed that the proposed amendment was a routine matter of little importance to the CNSC or to the public.

The language in the CNSC announcement was disarming, obscure and misleading. Small wonder that it caused no excitement. The phrase "Gentilly-1 Waste Facility" did not even hint at the existence of a defunct nuclear power reactor. The phrase "waste facility decommissioning licence" did not suggest that it encompassed the complete radioactive demolition of the most highly contaminated portions of that reactor. The phrase "authorize CNL to proceed with activities" did not convey the consortium's intent to package and ship hundreds of truckloads of radioactive debris over public roads to some unspecified destination. The language used by CNL in its licence amendment request was equally obscure: CNL asks for authorization "to proceed with execution of decommissioning involving the removal of all buildings and structures from the Gentilly-1 Waste Facility (G1WF) site." The word "radioactivity" is conspicuously absent.

Alarm bells went off, metaphorically, when it was revealed that CNL had already – over a period of several months, from December 2024 to June 2025 – quietly moved all of the irradiated nuclear fuel stored at the Gentilly-1 reactor to the Chalk River Nuclear Laboratories site in Ontario. This activity was carried out with no licence amendment at all, and without a murmur to the public; that is to say, without any hearing or public process of any kind – not even a hearing in writing – and with no clear public notification that such a puzzling relocation of high-level radioactive waste was even in the offing.

This smoothly executed and secretive move by CNL was surprising for several reasons:

(1) The existing Gentilly-1 Waste Management licence (WFDL) allows only for "storage with surveillance" activities. That phrase does not suggest that

high-level radioactive wastes could be rolling over public roads and bridges to an entirely different location operating under an entirely different CNSC licence, all within the rubric of “storage with surveillance”.

(2) The Nuclear Waste Management Organization (NWMO), legally responsible for the final dispositioning of all of Canada’s solid high-level radioactive waste, clearly indicates that used nuclear fuel shipments in Canada are not expected to begin before 2040.
https://www.nwmo.ca/-/media/Reports-MASTER/Corporate-reports/2021-Preliminary-transportation-plan.ashx

(3) Moving used nuclear fuel is costly – it cost the Canadian taxpayer $42.2 million for relocating 3123 used fuel bundles over a distance of about 500 kilometres. Even from a monetary point of view, moving high level radioactive waste should not be done more often than necessary. To this day, no explanation has been offered to justify the relocation of used fuel from G1 to Chalk River, given the fact that it will sooner or later have to be moved again at public expense anyway.
answer to parliamentary question re. Gentlly-1 used fuel
www.ccnr.org/G1_used_fuel_HofC_Dec_2025.pdf

CNL is a private company. It is not a government agency. It is a contractor. The consortium that currently runs CNL is Nuclear Laboratory Partners of Canada (NLPC). It is a joint venture of three US-based multinational corporations: BWXT, Amentum, and Kinetics, all with ties to the nuclear weapons industry. As previously noted, NLPC recently signed a 20-year contract worth $24 billion of federal taxpayers’ money. The money is transferred to CNL from AECL, a long-standing crown corporation that in turn is wholly owned and funded by the federal government. CNL is paid by AECL for services rendered, including the phrase “reducing Canada’s nuclear liability”.

Those services sometimes seem inscrutable. In 2024-2025, for example, when 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. The United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) asserts that no storage or disposal of toxic materials of any kind shall take place on the land of Indigenous people without their "free, prior and informed consent." Consent was not given, and was apparently 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 and/or (b) moved from one place to another. The transport of highly radiotoxic material from G-1 to Chalk River cost over 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 radioactive liability has not been eliminated or even reduced, it has just been relocated further upstream. On unceded Algonquin lands.

The hazardous nature of these high-level radioactive 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 the security of the shipments. During the relocation of the waste, support was obtained by CNL from CSIS, the RCMP, and Quebec police. The costs and risks will be doubled since 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 years hence.

Under the existing G-1 licence, CNL was authorized to manage radioactive wastes at the G-1 site under conditions of "storage with surveillance". Members of the public, including CCNR and its supporting organizations, were shocked to learn that that term "storage with surveillance", as interpreted by CNSC, also allows CNL to "transfer" radioactive wastes to an entirely different location. It seems a very deceptive choice of words, as most people would never guess that "storage with surveillance" may actually mean "transport. One gets the impression that neither CNL nor CNSC really wants the public to grasp what is actually going on, by using words in highly unusual ways.

But what about the role of CNSC as a licensing agency in all of this? Chalk River and Gentilly-1 operate under completely different licences. Having relocated the used nuclear fuel from Gentilly-1 to Chalk River, does that not entail a change of licensing? Does it not mean that this highly radiotoxic material is now bound by an entirely different licence with entirely different conditions? Should there not have been a CNSC hearing to deal with such a "change of licence" – passing from the G1 Waste Facility licence to the Chalk River Nuclear Laboratories licence? Is that not a kind of licence amendment?

Moving the G1 used nuclear fuel was not an easy matter. It required opening up the steel-and-concrete silos where the Gentilly-1 used fuel had been stored for decades, hoisting the sealed waste packages into transport containers using an indoor overhead crane, and then driving dozens of truckloads of irradiated nuclear fuel in specially designed containers to Chalk River over public roads and bridges for seven months. Upon arrival, the wastes had to be transferred by crane once again into new silos built at Chalk River for that very purpose (in Waste Area G) at a cost of $14.7 million.

As noted, this was done without the free prior and informed consent of the Kebaowek First Nation (KFN). Yet during the same period of time that the waste was being moved, CNSC was hit with an adverse decision from a federal judicial review, based precisely on the Commission's previous failure to adequately consult KFN on the question of storing radioactive waste on their unceded traditional territory – which includes the Chalk River site. The federal court's decision was announced February 19, 2025.

CCNR believes that such complicated and clandestine manoeuvres do not strengthen public trust. Indeed, they can and do cultivate distrust in the regulatory system. It's not just the use of misleading terminology (i.e. "storage with surveillance"). It's not just the absence of any explanation in plain language of the true meaning of a regulatory procedure (i.e. dismantling a nuclear reactor core). It's not just the failure to translate all relevant documents into French and to reach out to solicit the views of the French-speaking population of Quebec. It's more than that.

It's the apparent disregard, on the part of both the industry and the regulator, for the public's genuine anxiety about the nature of the toxic radioactive legacy of the nuclear age – a legacy that is already costing billions of taxpayers' dollars, a legacy that will be passed on to future generations for hundreds of thousands, even millions of years to come. It's quite a lot of fuss for an industry that claims to be providing "clean energy".

The Age of Nuclear Waste

To those within the nuclear establishment, nuclear waste is an everyday fact of life. To those outside the nuclear establishment, the age of nuclear waste is only just beginning, and it seems to stretch out until the very crack of doom. That's because nuclear waste is only now emerging from the shadows of the industry into the public arena.

Canada has been producing post-fission nuclear wastes since 1945, when the ZEEP (Zero Energy Experimental Pile) reactor started up at Chalk River on September 5 of that year. So the creation of human-made radionuclides in Canada is only 81 years old. Nevertheless, these radioactive wastes will remain a matter of concern for hundreds of thousands, even millions of years to come. Public awareness and concern applies first and foremost to the so-called high-level radioactive waste, in the form of used nuclear fuel, but it applies also to the more voluminous radioactive materials that have been dubbed "low level" and "intermediate level" waste by the industry and its regulators.

Some radioactive materials that are harmless when properly packaged can be extremely dangerous when inhaled, ingested or otherwise absorbed into the body. For example, because alpha radiation cannot penetrate a sheet of paper, alpha emitters are generally harmless outside the body – yet some of the deadliest radionuclides known to sciences are alpha emitters. For, once inside the body, an alpha-emitter can be hundreds or thousands of times more biologically damaging than a non alpha-emitter with the same degree of radioactivity. Radium, radon gas, plutonium, and polonium are all highly toxic alpha emitters. In a similar way, beta emitters that pose no risk to workers when well packaged can be exceedingly dangerous as internal emitters. In this sense,

radioactive materials labelled as “low-level” waste can turn out to be very harmful indeed under adverse circumstances. “Low level” does not mean “safe”.

Until recently, most human-made radioactive waste materials have been kept out of the public eye, safely contained at the nuclear facilities where they were created. The occasional nuclear accident, such as the meltdowns at Three Mile Island, Chernobyl, and Fukushima Daiichi, have served to remind people of the very real danger posed by these materials when they do manage to escape from containment. But on the whole, nuclear waste has been regarded by the industry and by the regulator as an industry problem, and not so much a problem for the public to be concerned with. CCNR believes that this attitude must change, or distrust will be the order of the day. People must be informed about, engaged with, and also protected from radioactive risks.

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Some years ago, in Ontario, the Anishinabek Nation and the Iroquois Caucus formed an Alliance on the transport and disposal of radioactive waste. They issued a declaration with the following five starting points:

ANISHINABEK/IROQUOIS ALLIANCE

Joint Declaration *[May 2017]*

1. **No Abandonment:** Radioactive waste materials are damaging to living things. Many of these materials remain dangerous for tens of thousands of years or even longer. They must be kept out of the food we eat, the water we drink, the air we breathe, and the land we live on for many generations to come. The forces of Mother Earth are powerful and unpredictable and no human-made structures can be counted on to resist those forces forever. Such dangerous materials cannot be abandoned and forgotten.
2. **Monitored and Retrievable Storage:** Continuous guardianship of nuclear waste material is needed. This means long-term monitoring and retrievable storage. Information and resources must be passed on from one generation to the next so that our grandchildren's grandchildren will be able to detect any signs of leakage of radioactive waste materials and protect themselves. They need to know how to fix such leaks as soon as they happen.
3. **Better Containment, More Packaging:** Cost and profit must never be the basis for long-term radioactive waste management. Paying a higher price for better containment today will help prevent much greater costs in the future when containment fails. Such failure will include irreparable environmental damage and radiation-induced diseases. The right kinds of packaging should be designed to make it easier to monitor, retrieve, and repackage insecure portions of the waste inventory as needed, for centuries to come.
4. **Away from Major Water Bodies:** Rivers and lakes are the blood and the lungs of Mother Earth. When we contaminate our waterways, we are poisoning life itself. That is why radioactive waste must not be stored beside major water bodies for the long-term. Yet this is exactly what is being planned at five locations in Canada: Kincardine on Lake Huron, Port Hope near Lake Ontario, Pinawa beside the Winnipeg River, and Chalk River and Rolphton beside the Ottawa River.
5. **No Imports or Exports:** The import and export of nuclear wastes over public roads and bridges should be forbidden except in truly exceptional cases after full consultation with all whose lands and waters are being put at risk. In particular, the planned shipment of highly radioactive liquid from Chalk River to South Carolina should not be allowed because it can be down-blended and solidified on site at Chalk River. Transport of nuclear waste should be strictly limited and decided on a case-by-case basis with full consultation with all those affected.

We will now address the specifics of reactor decommissioning as it affects a reactor core.

Radioactive Waste and Decommissioning

During the normal operation of a nuclear reactor, hundreds of varieties of newly created radioactive elements (radionuclides) are produced as unintended toxic byproducts. Of nuclear fission. These include (a) fission products (broken pieces of fissile atoms that have been "split", such as iodine-131, ruthenium-103 and strontium-90), (b) transuranic

actinides (radioactive elements that are heavier than uranium, such as plutonium, neptunium, and americium), and (c) activation products (non-radioactive atoms that have become radioactive after absorbing one or more stray neutrons, such as cobalt-60, nickel-59, and chlorine-36).

Collectively, these radioactive byproducts of nuclear fission are millions of times more radioactive than fresh nuclear fuel. The gamma radiation alone that is given off by a freshly discharged used fuel assembly would kill any human being in less than a minute at a distance of one metre. Used fuel remains intensely gamma-radioactive for centuries, and highly radiotoxic for hundreds of thousands of years thereafter (i.e. toxic following inhalation, ingestion or absorption, often due to alpha or beta radiation.)

Even after used nuclear fuel has been removed from the reactor and placed in wet or dry storage, or taken off site, the core area of the reactor remains intensely radioactive. This is due primarily to neutron activation of impurities in the structural materials. In addition, radioactive contamination of surfaces occurs wherever circulating water deposits sediments containing fission products, transuranic actinides and activated corrosion products. Much of this radioactive material has leaked out of irradiated fuel assemblies during normal operation due to tiny cracks, pin-holes or other imperfections in the outer metal cladding of the fuel.

For example, deposited in the inner “tube bundles” of used steam generators (boilers) that were removed from Bruce units 1 and 2 during refurbishment, there are fission products and actinides that could only have originated from irradiated nuclear fuel. They were carried to the steam generators by the primary coolant, and deposited there. See Annex 1 for a partial list of radioactive contaminants identified in two of those Bruce steam generators. The core components of the reactor are far more radioactive because they experience direct neutron activation and not just by contamination.

Because of the unavoidable long-lived radioactivity of structural components in the core area and equipment connected to the core by pipes carrying the primary coolant, all of

this material has to be isolated from the environment of living things for thousands of years, It has all become radioactive waste. Most of it is dubbed intermediate level waste. It is generally referred to as “decommissioning waste”.

Addressing the Core

The dismantling of the core components of the Gentilly-1 reactor was written about 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 2. 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 the radioactive hulks of old reactors can be shielded from the intense gamma radiation (and occasional neutron 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, and those filters themselves become radioactive waste.

The main reason why these core components are so radioactive is “neutron activation”. Neutrons are subatomic projectiles without any electrical charge that normally pass through steel easily. They are released in enormous quantities by fissioning atoms during the normal operation of a nuclear reactor. But 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 unstable – that is, radioactive. It has become “activated” by the neutron, and it has now become a radioactive “activation product”.

Activation products, in most cases, are not found in nature, although some (like tritium and carbon-14) are produced routinely in the upper atmosphere due to cosmic radiation from outer space and exist in trace amounts all over the Earth. But within the core area of a nuclear reactor, stray neutrons create copious amounts of 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 relatively long-lived activation products, namely those 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 immediately after shutdown were 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, were 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

Every radioactive atom eventually disintegrates, giving off a kind of subatomic shrapnel called “atomic radiation”. Atomic radiation can refer to an electrically charged fast-moving particle – an alpha particle or a 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; all are classified as human carcinogens by the IARC – the 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 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 would give a lethal dose in 28 minutes. The same publication indicates a gamma dose from the thermal shield of a shut-down Pickering reactor as 260,000 rems per hour – giving a lethal exposure in 5 $^{1}/_{2}$ seconds. [Note: a “sievert” is equal to 100 rems]

The Gentilly-1 thermal shield (immediately after shut down) would be far less radioactive than that, but still potentially deadly. So, back in 1984, Robert S. Vogt

recommended underwater cutting techniques be used on the G1 thermal shield. Since then, 42 years have past. By 2026, the gamma radiation fields would be further reduced by a factor of 100 – but even so, the thermal shield remains a highly radioactive object.

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. Exposure of skin to beta emitters can cause radiation burns and provoke cataracts. Beta emitters are however most 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 delivered very slowly, from inside the body. That is damaging to living cells, some of which may be able to reproduce with damaged genetic instructions, eventually leading to cancers of various kinds.

Radiotoxicity is the term used to express the biological damage that is done by radioactive materials that are 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 internal emitters.

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 at any time. They are not just a hazard for workers, but can pose 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, these human-made radioactive poisons will not find their way back to the surface to cause harm.

That is an important consideration, for many of these beta-emitting radionuclides are very mobile in the environment. 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 which migrate and diffuse unimpeded. Some very long-lived solids, like technetium-99 (213,000 year half-life), are particularly mobile. As another example, the extremely long-lived iodine-129 (17 million year half-life) is one of the more problematic radionuclides, and it can "sublimate" from a solid to a gas.

Reactor decommissioning

It is important to bear in mind that the complete dismantling of a nuclear power reactor of any kind has very seldom been accomplished.

A 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 the German Institute for Economic Research (DIW Berlin)
https://www.econstor.eu/bitstream/10419/268719/1/1833051734.pdf

The term “radiologically decommissioned” is used by the authors to indicate that the plant is completely dismantled, including the most radioactive portions of the reactor core. It is worth noting that only two of the six countries listed in Table 1-3 above – Germany and the USA – had radiologically decommissioned any commercial power reactors by 2022. In fact, while it is not apparent from the table alone, in each of those two countries there were only two commercial facilities that had been fully dismantled.

The extra 15 decommissioned reactors in the USA indicated in the table above, are all non-commercial reactors. Somewhat surprisingly, France had no “radiological decommissioning” experience as of 2022. 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 extraordinary cost overruns and schedule delays. Without careful advance planning, it may be the same with reactor dismantling.

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 Canada 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-1, even at the advanced planning stage, based on a disciplined and well-thought-out approach, opportunities for Canada 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. Under the existing licence for Gentilly-1, such a radiological characterization can and should be carried out by CNL and documented in a publicly available report that describes the methodologies used in detail and records the error bands (with discussion of how they are arrived at) along with all radiological measures and estimates.

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 be vital information for future generations to know exactly what human-made toxic materials are in this radioactive legacy that we are leaving them.

The International Atomic Energy Agency (IEAE) 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 (NEA) 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 bench-marking exercise performed at the activated biological shield of 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 m^3 … 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 exercise and a challenging task 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 itself but for the very long term transmission of knowledge to future generations.

Recommendation 4.

That during the the existing licence period, CNL be tasked by CNSC to prepare a report that is fully available to the public, providing a more detailed and accurate radiological characterization of each major component of the structures to be eventually dismantled, bearing in mind not just the requirements for worker safety and environmental protection during dismantling, but also the need to inform future generations as to the characteristics of the radionuclides present in the wastes, with particular attention to those that will endure for many generations and that will become internal radioactive emitters if released.

Recommendation 5.

That as part of the report mentioned above, or otherwise, CNL discuss publicly options related to how cutting operations and other volume reduction methods such as melting, grinding, compressing, segmenting, or incinerating may be carried out, with special attention to the monitoring, containment and treatment of radioactive dust, gases, vapours and liquids.

Recommendation 6.

That as part of the report mentioned above, or otherwise, CNL discuss publicly how municipal and provincial authorities will be engaged and consulted before deciding on whether or not any “clearance level” radioactive waste from G1WF is to be disposed of in non-radioactive municipal landfills, garbage dumps or scrapyards, and what kind of notification will be provided to those in charge of such waste facilities.

Recommendation 7.

That as part of the report mentioned above, or otherwise, CNL discuss publicly how residual radioactive contamination of the G1WF site will be monitored and removed, with special attention to soil, subsoil and ground water.

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), including all federally-owned used nuclear fuel.

Such a site has already been selected by NWMO, in northwestern Ontario, near the small village of Ignace. Ignace 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 indicated 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.

NWMO is now searching for a willing host community for a second DGR, this one to be used for intermediate level radioactive waste that will include most reactor refurbishment waste and reactor decommissioning waste.

Recommendation 8

That when CNL completes the decommissioning of the G1 reactor core under a new licence, the decommissioning wastes be stored on site (as has been done for all reactor refurbishment waste in Canada) until a suitable final destination is made available by NWMO.

Annex 1

List of radionuclides in Bruce steam generators

Plutonium in the Bruce "A" nuclear steam generators

Here is a partial list of radioactive contaminants inside a single used steam generator from each one of the two reactors (Units 1 and 2 of Bruce A), according to CNSC (document CMD-10-H19B). The mass (in grams) of each of the radioactive materials listed is estimated by CNSC staff.

RADIONUCLIDE		***MASS***	
Name of Isotope (with Atomic Mass)	Half-Life (years)	Unit 1 (grams radioactive material)	Unit 2 (grams radioactive material)
Americium-241	430 y	0.103412	0.102412
Americium-243	7 400 y	0.002162	0.002432
Carbon-14	5 700 y	0.009065	0.072501
Curium-244	18 y	0.002644	0/000347
Cobalt-60	5.3 y	0.001781	0/000881
Cesium-137	30 y	0/000249	0.000238
Europium-154	8.8 y	0.000027	0.000290
Iron-55	2.7 y	0.000272	0.000290
Hydrogen-3 (Tritium)	13.0 y	0.000057	0.000051
Hafnium-181	2.7 y	0.000001	0.000001
Iodine-129	17 000 000 y	0.000060	0.000060
Niobium-94	20 000 y	0.002159	0.002158
Nickel-59	75 000 y	0.173601	0.036723
Nickel-63	96 y	0.030194	0.006526
Neptunium-237	2 100 000 y	0.028703	0.033295
Plutonium-238	*88 y*	*0.007507*	*0.004703*
Plutonium-239	*24 000 y*	*2.124977*	*2.471769*
Plutonium-240	*6 500 y*	*0.827304*	*0.957105*
Plutonium-241	*14 y*	*0.021309*	*0.030809*
Plutonium-242	*380 000 y*	*0.048762*	*0.056317*
Antimony-125	2.8 y	0.000001	0.000001
Strontium-90	29 y	0.009097	0.007581
Technetium-99	210 000 y	0.000143	0.000092
TOTALS			
Long-lived (> one year half-life)		**3.416108**	**3.787315**
Mass of plutonium isotopes only		**3.029859**	**3.520703**
Percent plutonium		**88.7%**	**93.0%**
TOTAL MASS			

(Source: CNSC)

There are 5 plutonium isotopes present in the steam generators.
In addition there are 18 other long-lived isotopes listed.

In the 16 Bruce A steam generators (8 from Unit 1 and 8 from Unit 2), the total mass of radioactive material is estimated to be about 57.6 grams, of which 52.4 grams is plutonium. So plutonium makes up 91.0 percent of the mass of radioactive material in the steam generators.

Plutonium is extremely dangerous even in minute quantities. The maximum permissible "body burden" of plutonium-239 for an atomic worker (for instance, someone working in the nuclear weapons industry) is 0.7 micrograms. Inside the steam generators there are 36.8 grams of this one particular isotope – enough, in principle, to give over 52 million atomic workers their maximum permissible body burden of plutonium-239. If we include all five isotopes of plutonium, the number of atomic workers who could be overdosed, in principle, is just about doubled.

Plutonium isotopes also have very long half-lives, ranging from decades to hundreds of thousands of years. This means that any accident which resulted in a spill could pose long-lasting dangers.

- Gordon Edwards, Ph.D., November 8, 2010

Annex 2

G-1 Reactor Dismantling Proposal

(Canadian Nuclear Society, 1984)

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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 also 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

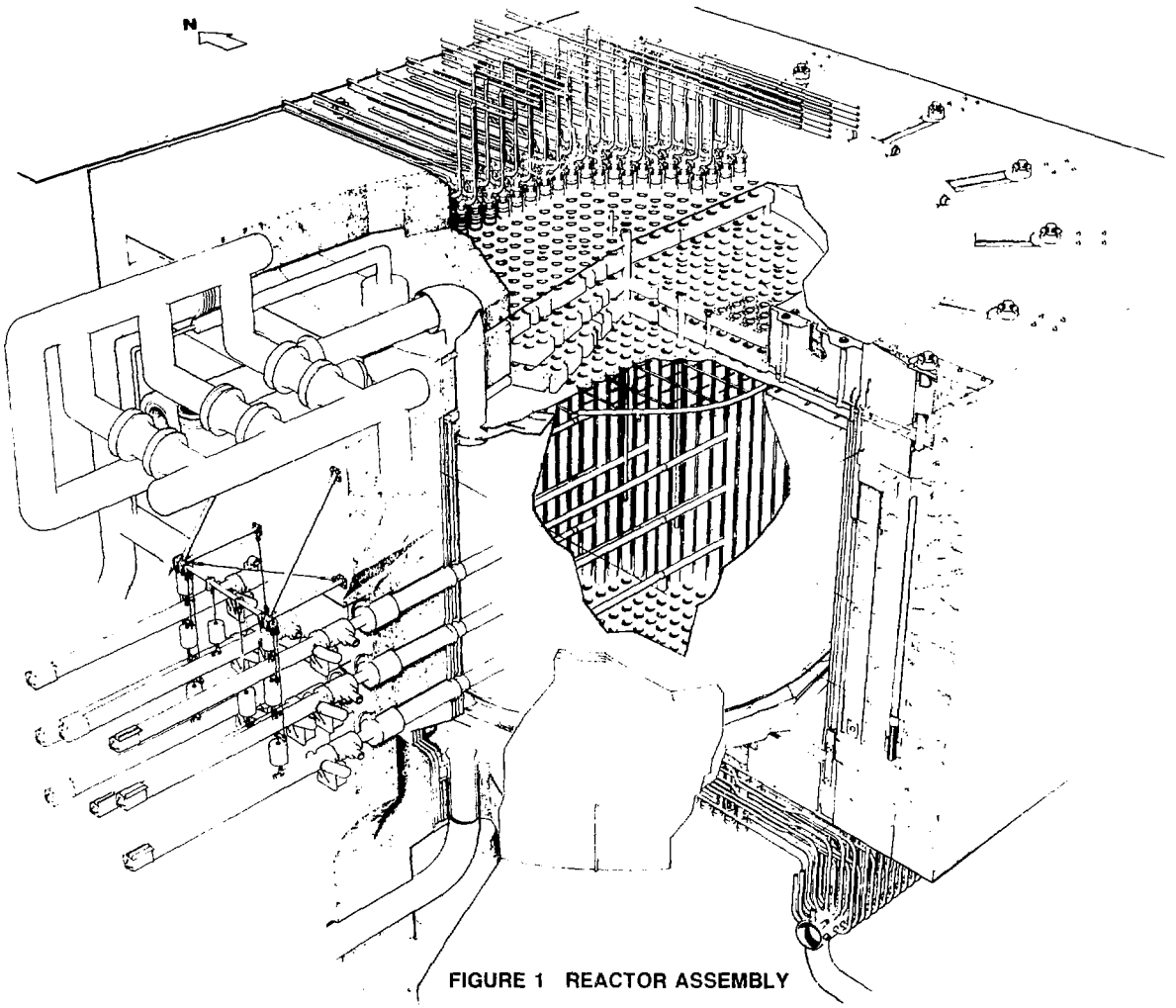

FIGURE 1 REACTOR ASSEMBLY

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

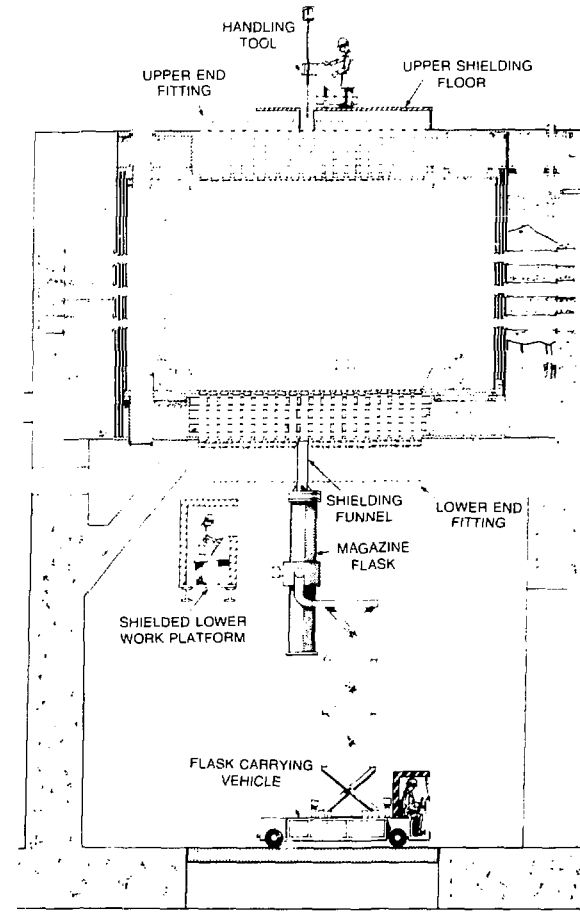

FIGURE 2 FUEL CHANNEL REMOVAL

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.

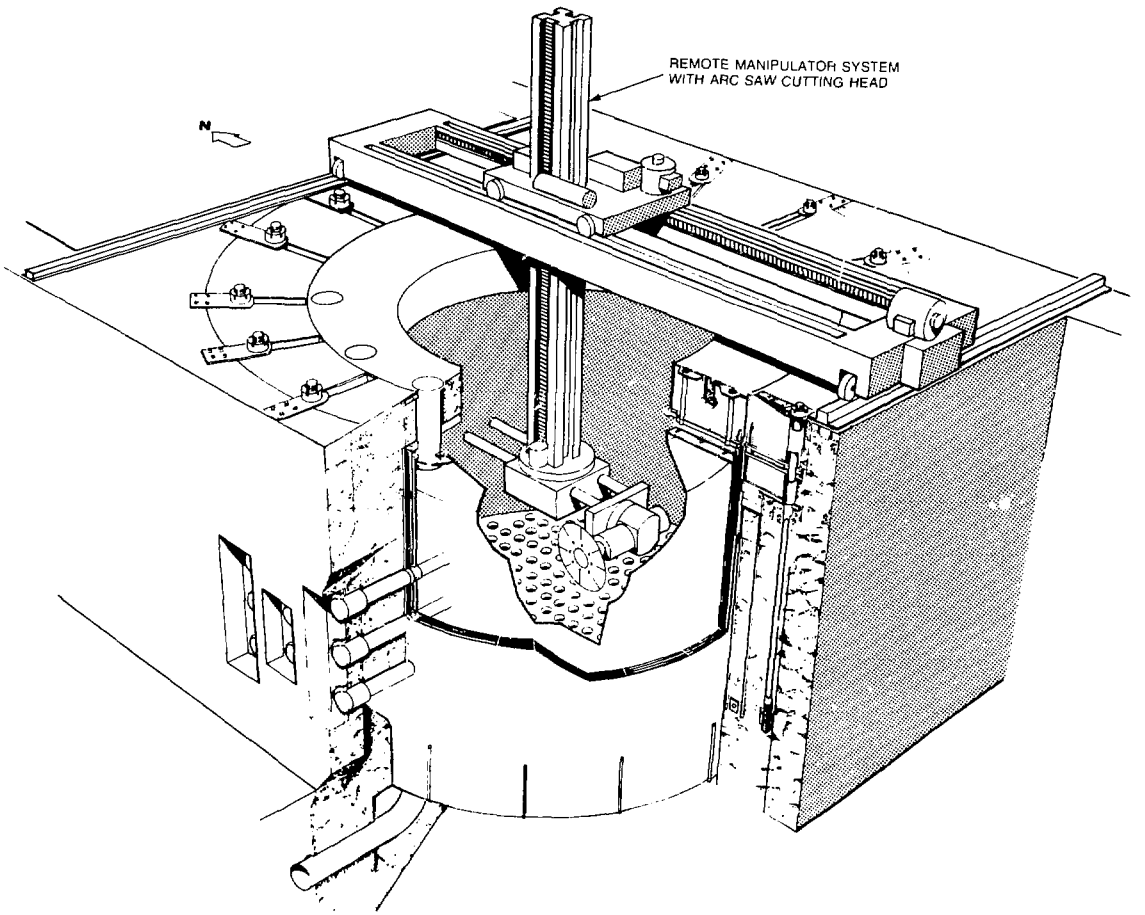

FIGURE 3 CALANDRIA AND THERMAL SHIELD VESSEL SECTIONING

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

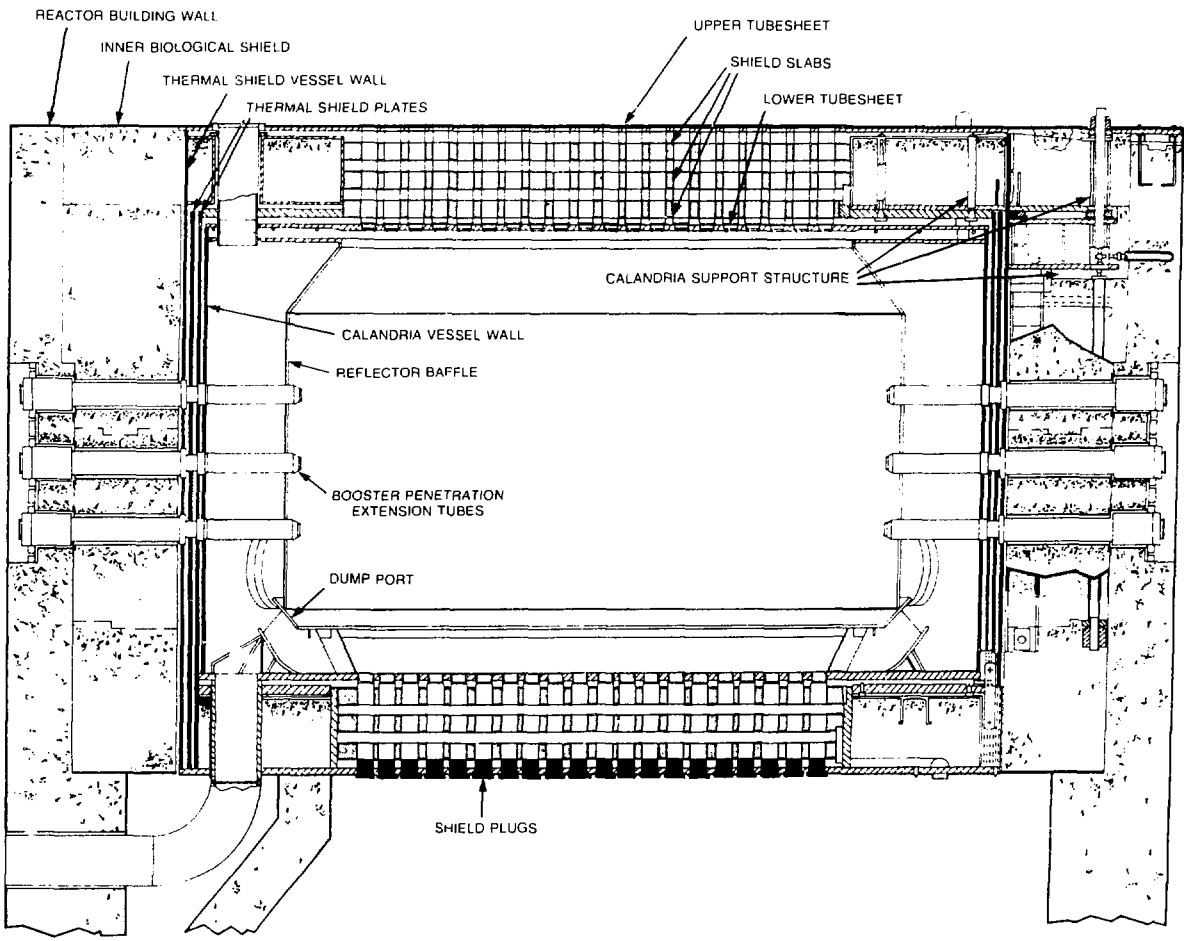

FIGURE 4 REACTOR WITH REACTIVITY MECHANISMS, FUEL CHANNELS, CALANDRIA TUBES AND EXTENSION TUBES REMOVED

accumulated 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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