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Nuclear reactor pressure tubes are deteriorating faster than expected. Critics warn regulators are ‘breaking their own rules’

The Canadian Nuclear Safety Commission has allowed utilities to operate tubes beyond licensing limits, a crucial concession for the nation’s aging reactors

MATTHEW MCCLEARN, Globe and Mail Investigation
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Canada has four functioning nuclear power plants, clockwise from top left: The Pickering, Darlington and Bruce Power facilities in Ontario, and the Point Lepreau generating station in New Brunswick.

THE GLOBE AND MAIL, THE CANADIAN PRESS, HANDOUTS

Early in the summer of 2021, Canada’s nuclear safety regulator received alarming news.

Inspections had revealed that two pressure tubes from different reactors at Canada’s largest nuclear power plant, the Bruce Nuclear Generating Station, had deteriorated far more quickly than expected. This meant the station’s operator, Bruce Power, had violated the terms of its operating licence. The revelation put the Canadian Nuclear Safety Commission in a tight spot. How were its leaders to respond?

Pressure tubes are commonly described as the heart of the CANDU reactor, Canada’s homegrown nuclear reactor design. The tubes contain uranium fuel bundles and heavy water,

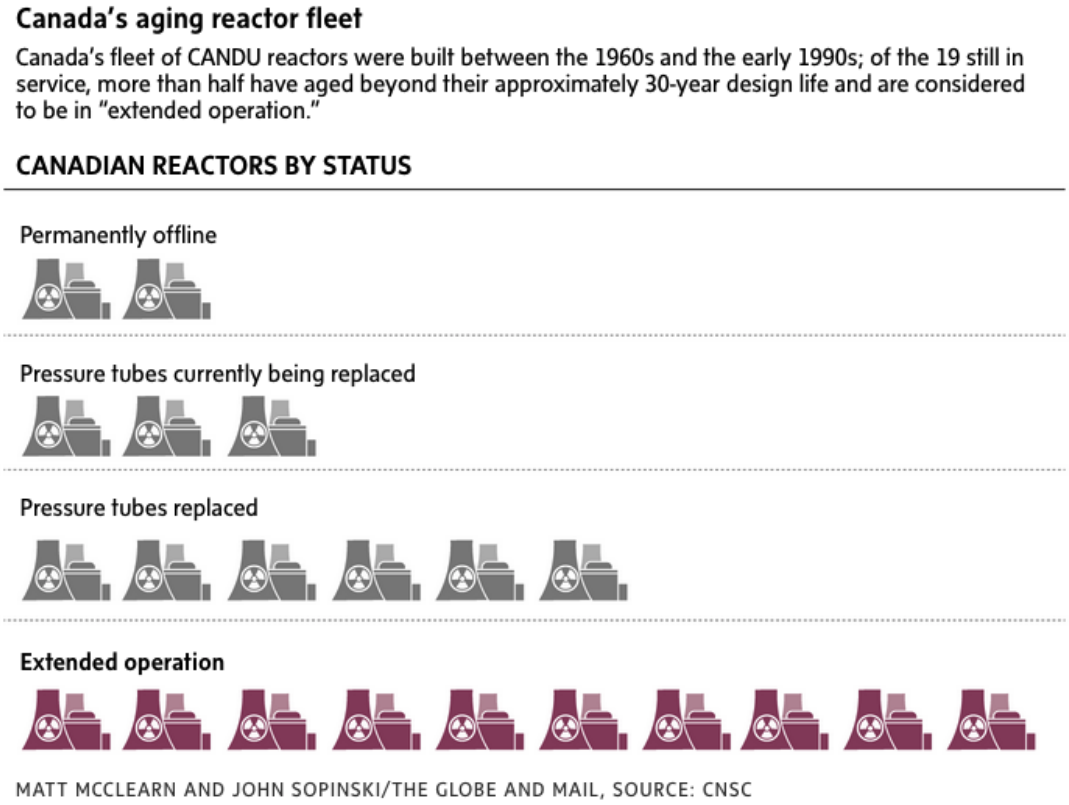
which serves as coolant.

Each of Canada's 19 operating CANDU reactors – including the eight at Bruce – contains several hundred pressure tubes. They deteriorate as they age, gradually increasing their propensity to fracture. So the industry has developed elaborate systems to monitor that deterioration, and mathematical models to predict when tubes will no longer be fit for service. CNSC officials have reassured outsiders that this approach is systematic and thorough.

But the news from Bruce Power revealed that the system had broken down. In an e-mail to colleagues written shortly after the discovery, Vali Tavasoli, director of the CNSC's operational engineering assessment division, noted that the regulator already knew pressure tubes absorb deuterium (an isotope of hydrogen) more quickly as they near the end of their lives, making them brittle and more prone to failure.

"But the rate of increase was not expected to be this much," he wrote.

Inquiries from elected officials and the media soon followed. This was a delicate matter: More than half of Canada's CANDUs had already exceeded their original 30-year design lives.



A federal election campaign was under way. Involvement was required from the highest levels: CNSC president Rumina Velshi was placed in charge of the team responding to the regulatory violations.

Documents obtained by The Globe and Mail under the federal Access to Information Act reveal how the CNSC, confronted by these serious violations, effectively set aside its previous requirements. The episode demonstrates that regulatory limits for Canada's nuclear industry can be remarkably elastic when it comes to facilitating the continued operation of Canada's aging reactor fleet.

"They are breaking their own rules," Frank Greening, who worked in Ontario Power Generation's pressure tube group for a decade before retiring in 2000, said in an interview.

"It was always everyone's understanding that these limits … were there for a reason," he added. "There was a hard limit for years and years and years. And now all of a sudden they're saying it's not really that important. And that worries me."

Ever since the 1983 incident at the Pickering Nuclear Generating Station, in which a pressure tube at the Unit 2 reactor had begun leaking, Canada's nuclear industry and its regulator have sought to manage the problem, with mixed results.

FRANK GUNN/THE CANADIAN PRESS

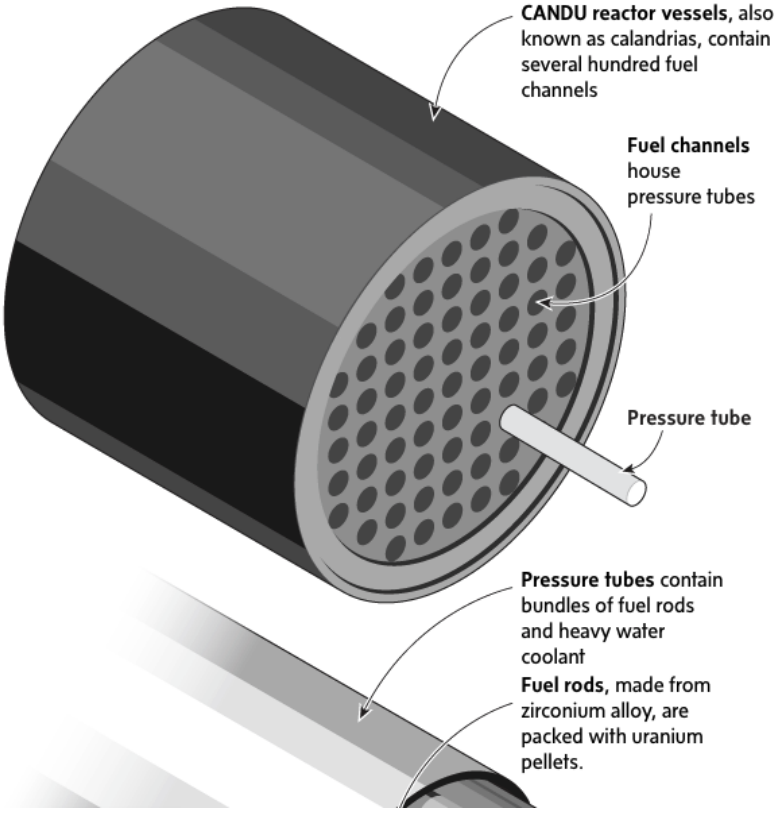
The CANDU's congenital disease

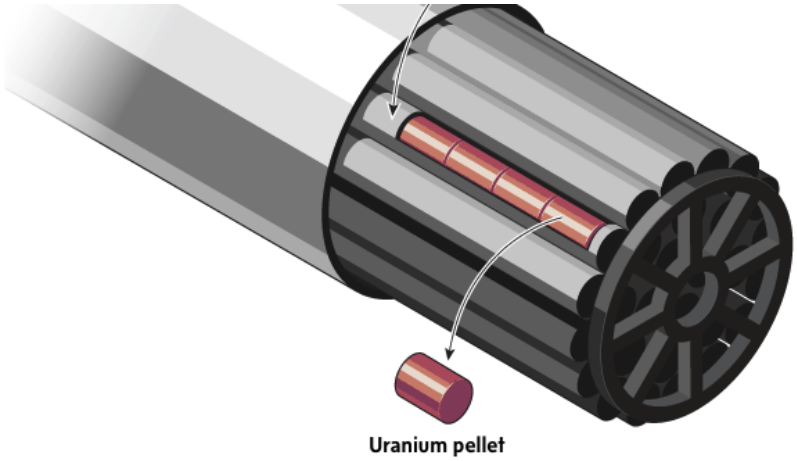
On Aug. 1, 1983, alarms sounded in the control room of the Pickering Nuclear Generating Station. A pressure tube at the Unit 2 reactor there had begun leaking 17 kilograms of heavy water a second. Operators safely shut the reactor down.

Lab testing found several circular blisters in the metal surface of the tube, through which a 20-millimetre crack had formed. The culprit: Deuterium levels at the tube's outlet end were more than three times higher than expected.

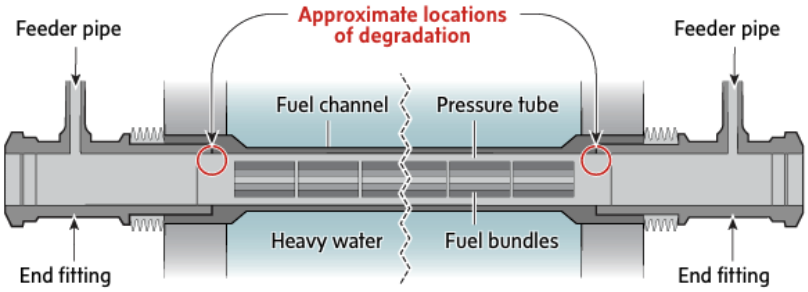
In the hearts of CANDU reactors, a congenital defect

Pressure tubes are crucial components of CANDU reactors that contain fuel bundles and coolant. Subjected to intense radiation, heat and pressure, they deteriorate over time. In particular, they accumulate deuterium (an isotope of hydrogen), rendering them more vulnerable to fracturing.





Side view of a pressure tube inside a calandria



Note: diagrams are not to scale.

MURAT YÜKSELIR / THE GLOBE AND MAIL, SOURCE: CANADIAN NUCLEAR SAFETY COMMISSION

Subsequent inspections found blisters in the outlet ends of other tubes as well.

Canada's nuclear industry had stumbled onto a congenital defect in the CANDU design. Subjected to high temperatures, pressures and intense radiation, over time pressure tubes absorb deuterium.

The 1983 incident prompted a review. Ontario Hydro (Ontario Power Generation's predecessor company) opted to replace all the tubes in Pickering Units 1 and 2 with new ones made of a more damage-resistant material – an expensive undertaking. All tubes currently operating in CANDU reactors were made using the more resilient material.

Ever since the incident at Pickering, Canada's nuclear industry and its regulator have sought to manage the problem, with mixed results.

Deuterium ingress is measured in parts per million (ppm) of hydrogen equivalent concentration. When the CNSC renewed the Bruce station's licence in 2018, it insisted that, should readings from any of the station's tubes exceed 120 ppm, Bruce Power would either have to shut down the reactor or demonstrate that its tubes were safe to operate with hydrogen concentrations above that level.

In the summer of 2021, when Bruce Power disclosed the unexpected deterioration, it was in the midst of a major overhaul of its Unit 6 reactor at the Bruce station, which is located in Kincardine, Ont. It removed tubes and sent some for lab testing. One of the oldest tubes, it turned out, had exceeded the 120 ppm limit.

Around the same time, the utility discovered that another tube, this one from Unit 3, was also offside. Both violations were found in the same segment of each of the six-metre tubes, near the outlet end.

The picture grew more alarming as the magnitude of the exceedances became apparent. The hydrogen levels in the Unit 6 tube were as high as 212 ppm, while the Unit 3 tube reading was 131 ppm.

Though CNSC staff members accepted that the violations had been inadvertent, they had no idea what had caused them. They didn't know how many other tubes at the station might contain elevated hydrogen levels. They didn't know whether CANDUs at other stations in Ontario and New Brunswick might suffer from the same problem. And they didn't know how such high levels would affect the probability of tube failures, nor how much that might increase the likelihood of severe accidents.

A way forward

Here's one thing CNSC staff members were confident about: There was no imminent safety threat to workers, the public or the environment.

This certainty stemmed from several long-standing beliefs. CNSC staff believed high hydrogen levels alone wouldn't cause a tube to rupture, and that pre-existing damage was required to initiate a crack. They also thought cracks wouldn't form while a reactor was operating. Rather, they believed, the risk was that a tube might fracture while it was starting up or shutting down.

And, even if a tube did rupture, they assumed the reactor would shut down safely. "In other words, it is safe to continue operating the units, but if a unit shuts down, it may not be safe to restart," concluded Alexandre Viktorov, the CNSC's director general of power reactor regulation, in an e-mail to colleagues written soon after the problem's discovery.

At first, senior CNSC officials seemed prepared to take a hard line with reactor-operating utilities. "No restart will be allowed without obtaining the facts on what the values are for the other units," Ramzi Jammal, the CNSC's chief regulatory operations officer, wrote in an e-mail.

Any impediment to restarting reactors can have far-ranging consequences. Three major Canadian utilities (Ontario Power Generation, Bruce Power and New Brunswick Power) rely heavily on CANDU reactors to generate electricity. Reactors are routinely shut down, often for regular maintenance and inspections, but also during unforeseen incidents such as equipment failures.

The Bruce station, which generates nearly a third of Ontario's electricity, had several outages planned over coming months. So did other stations. Utilities were seeking quick approvals for

restarts, placing CNSC staff members under significant pressure.

On the other hand, a tube fracture, however unlikely, could also have extreme consequences. If a tube failed, the CNSC's leadership, politicians and the public "would likely demand shutdown of all of the units in extended operation," one internal CNSC document speculated. All but six of Canada's 19 reactors in service are in extended operation, meaning they are operating beyond their 30-year design lives. Shutting them down could compromise energy security in Ontario and New Brunswick.

Agnes Robert, a CNSC regulatory program officer, recommended that the regulator insist utilities inspect at least 30 per cent of the tubes in each reactor. Some colleagues dismissed that suggestion as neither achievable nor reasonable.

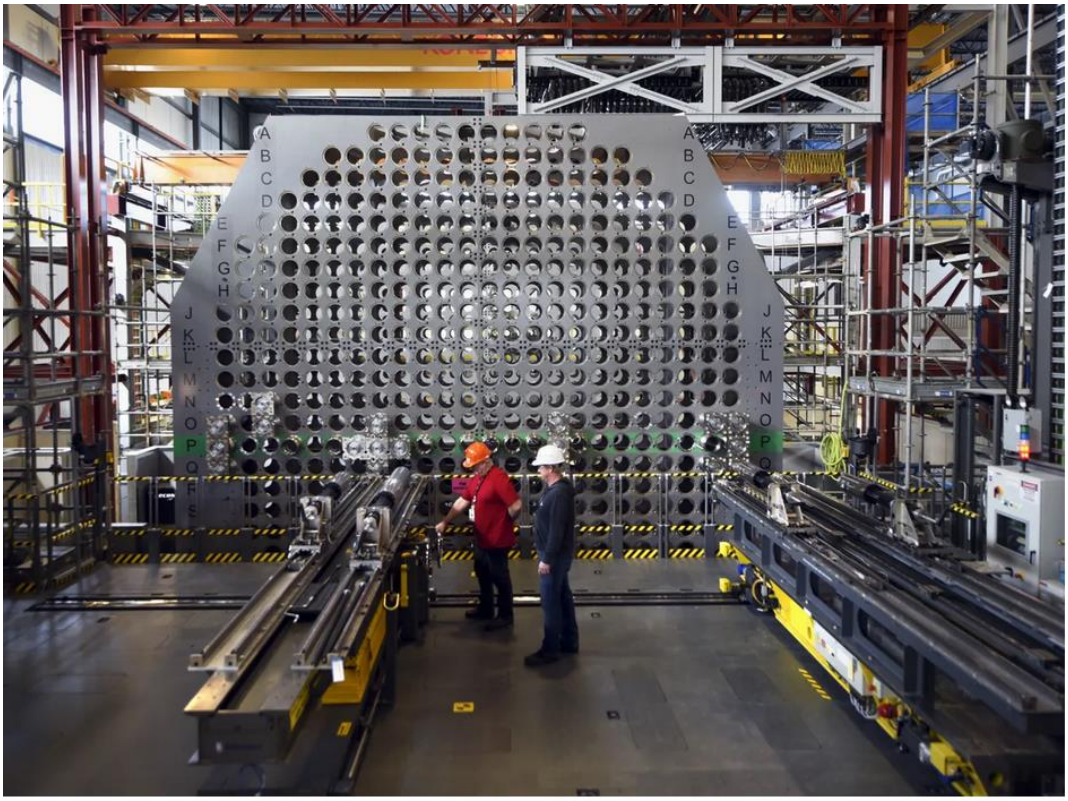
Blair Carroll, a specialist in the CNSC's operational engineering assessment division, noted in an e-mail that, in most reactors at the Pickering and Darlington stations, barely half that number had been examined. Inspecting so many additional tubes, he said, "would involve a very significant effort."

Anticipating pushback from utilities on any new requirements, Mr. Jammal urged staff members to communicate with them as clearly as possible. "We will be challenged," he wrote. "I have no issue being challenged by the licensees."

It was Mr. Carroll who struck on a way forward. Since the high readings were found in the same small part of each tube, he wrote in an e-mail to colleagues a couple of weeks after the discovery, "an argument can be made" that, if Bruce Power could prove flaws that might lead to cracking weren't likely to exist in this part of the tubes, then the tubes remained fit for service.

And Mr. Carroll noted that the rules didn't actually require Bruce Power to prove that its pressure tubes could resist fractures above 120 ppm. All the utility needed in order to keep operating above that limit was the CNSC's permission. "I don't think there is anything in the [licence] that would be violated with a shift to demonstrating that cracking is not a concern" in that part of the tubes, he wrote.

His suggestion prevailed. Days later, the CNSC issued an order to Bruce Power and other utilities offering two paths to restarting reactors: They could either prove that their pressure tubes met the licence requirements, or they could show "with a high degree of confidence that no flaws are present" in the specific part of the tubes where the high readings had been found.



A full-scale mockup of a reactor was built for workers at the Darlington Nuclear Generating Station to rehearse repairs before starting actual work on the offline reactor.
FRED LUM/THE GLOBE AND MAIL

Managing the message

The CNSC and the nuclear industry have long promoted a concept called “defence in depth.” Its organizing principle is that nuclear power plants have multiple, overlapping methods of preventing accidents. This is intended to allow failures to be detected and corrected before they result in serious incidents.

One of the CNSC’s promotional videos reassures the public that pressure tubes “must meet operational fitness standards,” and that licensees are required to “demonstrate that each pressure tube is able to continue to safely operate into the future.” Another video says that “if an operator is not following the rules, we take immediate action to correct the situation.”

As they struggled to understand what had happened to the Bruce station’s pressure tubes, CNSC staff members needed to figure out what to tell outsiders.

The Ontario Clean Air Alliance, an activist group opposed to nuclear power generation, seized on the problems at Bruce as evidence of “the precarious state of Ontario’s aging nuclear reactors.” It launched a letter-writing campaign, and repeated its long-standing calls for the immediate shutdown of aging stations.

With public interest piqued, senior CNSC officials offered reassurances to officials at all levels

of government. A short letter was drafted to Deputy Prime Minister Chrystia Freeland. It said there was no risk to public safety or the environment, and offered to brief her about the situation. But not everyone thought the letter should be sent.

“One concern would be that us proactively offering a direct brief to that level of government would tend to signal a high degree of alarm about this file,” wrote one CNSC staff member, who suggested contacting the less prominent Privy Council Office instead.

The CNSC also asked Scott Feschuk, a communications consultant and former journalist with the crisis public-relations firm Feschuk Reid, to “validate our communications approach.” He warned the CNSC that the looming federal election could complicate matters.

“We don’t want to be the ones to inflame the situation,” he wrote in an e-mail. “So we don’t want to go out in a way that makes people detect any level of real concern. … I wouldn’t care too much about the general public at this point unless the story begins to take off. I definitely wouldn’t do anything that draws their attention to the story if they’ve happened to miss it to this point.”

Back to Square One

By the time the CNSC gathered in February to consider whether Bruce Power should be granted a blanket approval to restart Unit 3, Mr. Carroll’s solution seemed to be working. Bruce Power had amassed inspections data for nearly 500 tubes, and found no flaws near the problem area.

Gradually, utilities won back the privilege of restarting reactors. In October, 2021, the CNSC told Bruce Power it could restart Unit 3 once. By March, 2022, it was comfortable granting the privilege for all restarts of that unit. CNSC staff recommended the same privilege for Ontario Power Generation, in part because its Darlington and Pickering stations still complied with regulations.

Meanwhile, another problem surfaced.

In December, 2021, Bruce Power reported a fresh regulatory violation from the same Unit 6 tube that had touched off the crisis. This time, the offending reading came from the tube’s opposite end, the inlet. This was bad news: Mr. Carroll’s “no flaws” solution couldn’t apply, since flaws had previously been found in this area of the inlet ends of tubes at the Bruce and Darlington stations.

The Pickering Nuclear Power Generating Station is Canada's oldest operating nuclear power plant and is scheduled to close in 2024.
CARLOS OSORIO/REUTERS

The revelations didn't sit well with Indra Maharaj, one of three commissioners on the CNSC panel that had authorized Bruce Power to restart Unit 3.

"This feels like we're starting from the very beginning again, after all of our work," she observed at a hearing in March.

Bruce Power's chief engineer, Gary Newman, said the presence of flaws wasn't anything to worry about; the company had "concluded that there might be some slight changes, but really nothing that would substantiate any kind of concern."

At the same hearing, Ms. Velshi, the CNSC president, said the exceedances showed the industry's models for estimating hydrogen concentrations weren't valid. That being the case, she wondered, "how can we be confident that we do have fitness for service?"

At a public hearing on Nov. 3, CNSC staff members acknowledged that they couldn't be confident – at least, not concerning tubes at the Darlington and Bruce stations. But they believed that, if a single tube failed, automatic shutdown systems at Canada's nuclear power plants would function properly and protect the public.

"CANDU reactors are designed to accommodate a pressure tube failure," Mr. Carroll told commissioners at the Nov. 3 hearing. "It has happened in the past. And they've safely shut down."

"The increase in risk is negligible for continued operations in the short term, which provides

industry time to complete the required work," Dr. Viktorov said.

The CNSC has decided the risk is acceptable for up to three years, while research into the problem continues. By then, many of Canada's oldest pressure tubes may already have been retired.

The Pickering station, Canada's oldest operating nuclear power plant, is scheduled to close in 2024. (Recently, Ontario's government announced it intends to run the plant until September, 2026, a plan that will require CNSC approval.) Bruce's Unit 3 is expected to shut down for a major overhaul this year, which will include replacement of all its tubes. Other reactors have newer pressure tubes, and are considered to be less at risk of violating regulatory limits.

Industry officials, the CNSC and outside experts continue to debate what caused the Bruce tubes to deteriorate. Though some have offered theories, the CNSC maintains that more evidence is needed to support them.

Dr. Greening, the retired pressure tube expert, said understanding the problem's cause is crucial.

"Until we know what's causing this, they can't really say, 'Well, we think everything else is okay.'"

And not everyone thinks it's wise to rely on plant safety systems.

Sunil Nijhawan, a reactor safety consultant, warned that pressure tubes can fail in a variety of ways. In more severe scenarios, a ruptured tube could cause adjacent channels to fail. Even a single tube failure could damage the calandria, the large cylindrical structure that houses all of the tubes. A particularly serious accident could result in a power plant's host community being "written off," he said.

"You don't depend on safety systems, or your analytical capabilities, to save the day," Dr. Nijhawan added. "Once an accident happens, there are so many unknowns. ... Once you violate the fitness of service, you cannot know what the accident will look like, and what your safety systems are going to do."

Even a single pressure tube failure could cause billions of dollars in damage to a reactor, he noted.

"There's one more thing we always forget: Who is going to pay for the damage caused by this?" he said. "The people of Ontario are going to pay for that."

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