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**Docket:** NRC-2014-0137  
Technical Basis for Regulatory Guidance on the Alternate PTS Rule

**Comment On:** NRC-2014-0137-0001  
Draft Guidance Regarding the Alternate Pressurized Thermal Shock Rule

**Document:** NRC-2014-0137-DRAFT-0010  
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## General Comment

Dear NRC,

Please see the attached files:

1. NUCLEAR REACTOR PRESSURE VESSEL CRISIS: GREENPEACE BRIEFING (dated Feb. 15, 2015; 10 pages);
2. Greenpeace press release, "Thousands more cracks found in Belgian nuclear reactors, Belgian regulatory head warns of global implications," dateline Brussels, Feb. 17, 2015 (2 pages).

As revealed in this report from Greenpeace Belgium, micro-cracking in Belgian atomic reactor pressure vessels (RPVs) due to hydrogen flaking could be a global problem -- including in the U.S. -- going undiagnosed, simply because nuclear utilities and government regulators (such as NRC) haven't done, or haven't required, the needed testing. Belgium's nuclear regulatory agency has issued "a statement confirming that the additional tests conducted in 2014 revealed 13,047 cracks in Doel 3 and 3,149 in Tihange 2," as reported in Greenpeace Belgium's press release.

Embrittlement can lead to RPV failure due to pressurized thermal shock (PTS) in pressurized water reactors (PWRs). Beyond Nuclear, in coalition with Don't Waste MI, MI Safe Energy Future, and Nuclear Energy

SUNSI Review Complete  
Template = ADM-013

E-RFDS = ADM-03  
Add = To: Steven (qesh) - M. Kirk (mtk) -  
S. Pouton (SXB3)

Information Service, has challenged the continued operation of Entergy Nuclear's Palisades atomic reactor in s.w. MI on the Lake Michigan shore, due to its worst embrittled RPV in the U.S. As reported by Greenpeace Belgium, a RPV breach due to PTS could cause a Loss-of-Coolant-Accident (LOCA), core meltdown, containment failure, and catastrophic radioactivity release.

Greenpeace Belgium's experts call for comprehensive testing of all atomic reactors worldwide, a position echoed by Belgium's top nuclear regulator. Belgium's two suspect reactors are currently shut; Greenpeace demands they remain so till the concern is addressed.

Meanwhile, Palisades -- the worst embrittled atomic reactor in the U.S. -- operates at full power. So too do other badly embrittled U.S. atomic reactors, such as Point Beach Unit 2 in WI, also located on the Lake Michigan shore, as is Palisades.

Lake Michigan, wedged between the two worst-embrittled RPVs in the U.S., is a headwaters of the Great Lakes -- 20% of the world's surface fresh water; nearly 90% of North America's surface fresh water; drinking water supply for 40 million people in 8 U.S. states, 2 Canadian provinces, and a large number of Native American First Nations downstream; and lifeblood for one of the world's largest regional economies.

Given the high risks (the consequences to Lake Michigan and the Great Lakes downstream) of a RPV through-wall crack, 10CFR50.61a's increased risks, as compared to 10CFR50.61's, cannot be allowed to stand in NRC regulations, regulatory guides, and supporting technical documents, such as DG-1299 and NUREG-2163.

The Greenpeace Belgium report, and press release, focus on the global risk implications (including in the U.S.) of widespread, sub-surface, micro-cracking revealed under Ultrasonic Testing (UT) at the troubled Doel-2 and Tihange-3 atomic reactors in Belgium. Initially, in 2012-2013, the cracking was thought to be related to defective manufacturing processes at Rotterdam Drydock Company. However, materials scientists now hypothesize that hydrogen flake corrosion cracking is involved -- and are concerned this could impact reactor pressure vessels worldwide (including in the U.S.). They call for precautionary testing of all RPVs globally, a warning currently being rejected by the nuclear power industry and its regulators internationally -- including in the U.S. by NRC. Such an unacceptable NRC response, under direct questioning by myself, occurred on Feb. 19, 2015, during a day-long NRC meeting about RPV risks which I attended by phone.

Entergy Nuclear Palisades' exhaustively documented RPV embrittlement/PTS risks, in combination with synergistic RPV fabrication or operationally-induced (and worsening with time) flaws -- as from hydrogen flaking -- represent unknown, and very likely unacceptable, risk levels. These synergistic risks are completely unaddressed in 10CFR50.61a, and its associated DG-1299 and NUREG-2163. These synergistic risks must be comprehensively understood, and addressed. DG-1299, NUREG-2163, and 10CFR50.61a do not accomplish this.

Previously undetected, widespread micro-cracking revealed in Belgian RPVs is deeply relevant to the DG-1299/NUREG-2163 proceeding. After all, flaws in the RPV are an essential contributor to PTS through-wall fracture risks (the others being RPV embrittlement, as well as a PTS disaster sequence). Entergy Nuclear at Palisades, and other nuclear utilities with dangerously embrittled RPVs, must comprehensively understand, and address, the number of flaws in RPVs (including micro-cracks), as well as their size, significance, and vulnerability to embrittlement induced PTS risks.

The place to start is UT testing of all RPVs, as carried out at the two troubled Belgian reactors. Top priorities for such testing are at Palisades and Point Beach Unit 2. NRC's DG-1299/NUREG-2163/10CFR50.61a should require this.

## Attachments

3 9 15 Greenpeace cracking report

20150215\_CLEAN -- FINAL IPR cracks story

# NUCLEAR REACTOR PRESSURE VESSEL CRISIS

## GREENPEACE BRIEFING

***"This may be a global problem for the entire nuclear industry."***  
*Belgian Nuclear Regulator, FANC, Director General, Jan Bens, February 13<sup>th</sup> 2015.<sup>1</sup>*

***WENRA recommends "Examination of the base material of the vessels if considered necessary."***<sup>2</sup>  
*Western European Nuclear Regulators Association, December 2014.*

***"Failure of the pressure vessel of a PWR or a BWR constitutes an accident beyond the design basis for which there is no safety system - inevitably leading to a catastrophic release of radioactive material to the environment."*** *Nuclear Reactor Hazards Greenpeace, 2005.<sup>3</sup>*

***FEBRUARY 15<sup>th</sup> 2015***

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<sup>1</sup> <http://deredactie.be/cm/vrtnieuws/binnenland/1.2238955>, accessed February 14<sup>th</sup> 2015.

<sup>2</sup> Report Activities in WENRA countries following the Recommendation regarding flaw indications found in Belgian reactors December 17 2014

[http://www.wenra.org/media/filer\\_public/2014/12/26/flaws\\_in\\_rpv\\_feedback\\_2014-12-19.pdf](http://www.wenra.org/media/filer_public/2014/12/26/flaws_in_rpv_feedback_2014-12-19.pdf), accessed February 2014.

<sup>3</sup> Nuclear Reactor Hazards Ongoing Dangers of Operating Nuclear Technology in the 21st Century Report. Greenpeace International, Helmut Hirsch, Oda Becker, Mycle Schneider, Antony Froggatt April 2005, <http://www.greenpeace.org/seasia/th/PageFiles/106897/nuclearreactorhazards.pdf>, accessed February 2015.

## Introduction

On February 13<sup>th</sup> 2015, the Director General of the Federal Agency for Nuclear Control (FANC) responsible for nuclear safety in Belgium revealed that the problems found in two nuclear reactors had implications for nuclear safety worldwide. FANC later posted a statement on its website announcing that thousands “flaw indications” had been found during investigations in the Doel 3 and Tihange 2 nuclear reactor pressure vessels. The ‘flaw indications’ are in reality microscopic cracks. The disclosures became headline news across Belgian media.

At the same time, two senior scientists – Professor MacDonald from the University of California, Berkeley and Professor Bogaerts from the University of Leuven stated that based on their research, corrosion effects could aggravated the thousands of cracks found in the Doel 3 and Tihange 2 reactors and could even have severe safety impact on every reactor in the world.

*“The importance of this could range from inconsequential to being so severe that it would shut down all the reactors. My advice is that all reactor operators, under the guidance of the regulatory commissions should be required to do an ultrasonic survey of the pressure vessels. All of them.” Professor Digby MacDonald, February 13<sup>th</sup> 2015.<sup>4</sup>*

This briefing explains some of the background to the nuclear safety crisis in Belgium and some of the implications globally for every commercial reactor currently operating.

## Shutdown reactors inspection reveals problem

In June 2012 during regular maintenance shutdown of the thirty three year old<sup>5</sup> Doel 3 nuclear reactor operated by Electrabel (a company of the GdF-SUEZ Group) an ultrasonic (UT) inspection was performed on the steel Reactor Pressure Vessel (RPV). During normal power operation the reactor pressure vessel is not accessible for inspections. As a result defects may remain undetected for longer periods of time. In contrast to previous tests, which only assessed several pre-prepared parts of the vessel surface, the welding zones on the vessel and “dummies” that are hanging inside the vessel, the new scan inspected a much larger area of the vessel.

Reactor pressure vessels, which contain the highly radioactive nuclear fuel in nuclear power plants, are made of steel plates that are welded together. Neutrons from the fuel in the reactor irradiate the vessel as the reactor is operated. This can embrittle the steel, or make it less tough, which has significant safety implications for the integrity of the pressure vessel.

The ultrasonic inspection found a large number of “flaw indications” or micro cracks in the lower and upper reactor core shells of the Doel 3 pressure vessel.<sup>6</sup> Electrabel performed inspections of the full thickness of the vessel wall using the UT, and approximately 8,000 quasi-laminar (Q-L) micro cracks were detected in the base metal (remote from the welds) with a through-wall depth extending from several millimeters (mm) beyond the clad-base metal interface (CBMI) to about 60% of the wall thickness from the inner surface.

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<sup>4</sup> Interview with Belgian national state broadcaster.

<http://dereductie.be/cm/vrtnieuws/videozone/programmas/terzake/2.37612>. Digby Macdonald, is Professor in Residence, Department of Materials Science and Engineering, UC Berkeley, <https://www.nuc.berkeley.edu/people/digby-macdonald>, accessed February 14<sup>th</sup> 2015.

<sup>5</sup> IAEA Power Reactor Information System; <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=12>, accessed February 14<sup>th</sup> 2015.

<sup>6</sup> These are described as quasi-laminar indications in the belt line ring forgings.

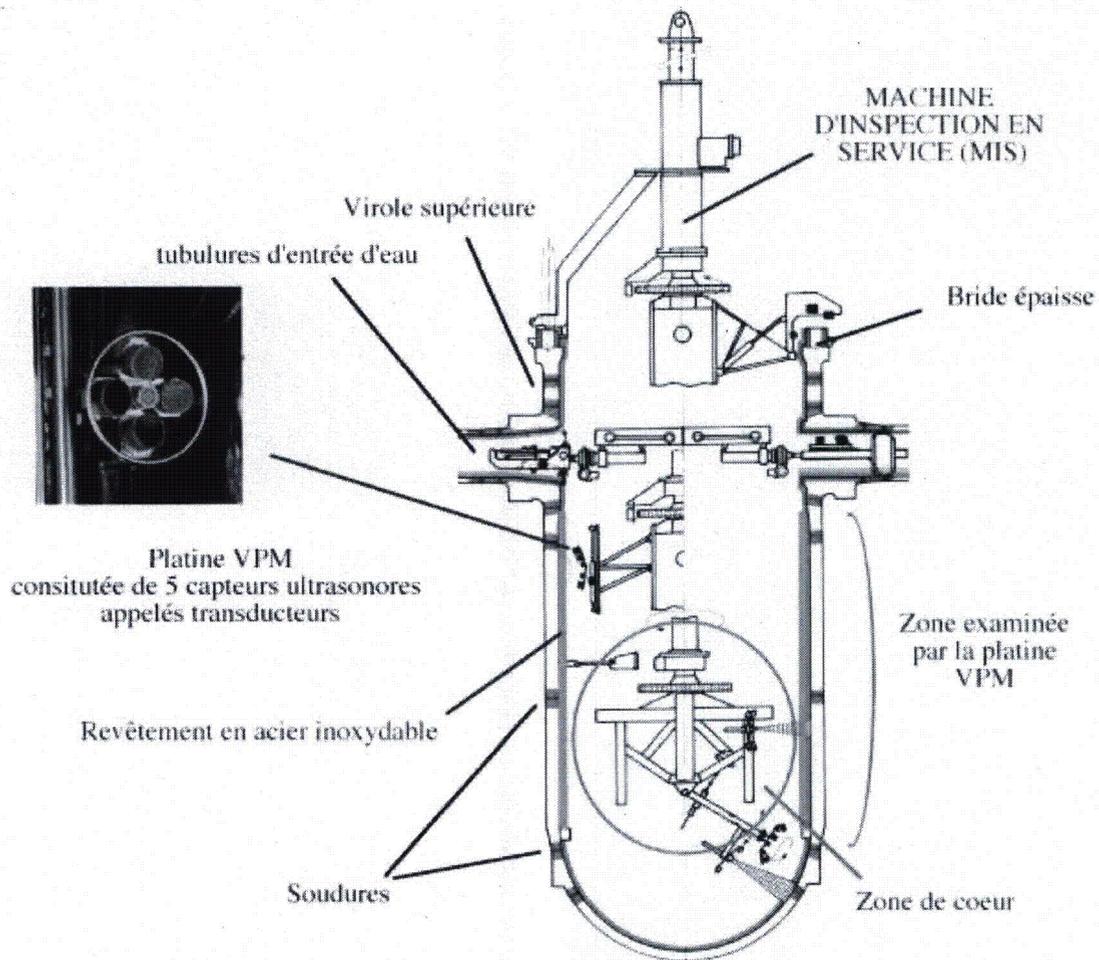


Figure 1 : Mise en place de la MIS dans la cuve, et détails de la platine à ultrasons  
 Institut de Radioprotection et de Sureté Nucleaire IRSN

The micro cracks found were circular in shape and most have diameter length of 10 mm or less, with a maximum diameter length of 70 mm.<sup>7</sup> A further test found a large number of such flaws deeper inside the material. A similar inspection performed in September 2012 at the thirty two year old<sup>8</sup> Tihange 2 reactor pressure vessel showed similar micro cracks but less than at Doel – just under 2000 in total.

### Hydrogen flakes and manufacturing cause

The explanation provided by FANC and Electrabel between 2012 and 2013 for the thousands of micro cracks was due to the presence of hydrogen flakes within the steel, and that they were likely to have been present during the forging manufacture of the steel vessels. The presence of hydrogen flakes was a result of small ruptures in the carbon steel material produced by the release of high-pressure hydrogen gas, which was trapped in the metal during the steel making process, according

<sup>7</sup> “Materials Reliability Program: Evaluation of the Reactor Vessel Beltline Shell Forgings of Operating U.S. PWRs for Quasi-Laminar Indications”, (MRP-367) 3002000647 FINAL Report, October 2013 Non-Privileged/Confidential Version for NRC(Privileged & Confidential Version submitted to NRC under Affidavit), US Nuclear Regulatory Commission, <http://pbadupws.nrc.gov/docs/ML1406/ML14064A411.pdf>, accessed February 14<sup>th</sup> 2015.

<sup>8</sup> IAEA Power Reactor Information System, <https://pris.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=13>, accessed February 14<sup>th</sup> 2015.

to the investigations. European nuclear regulators along with their partner agencies world wide concluded that *“according to current knowledge hydrogen flakes may only form during manufacturing of the base metal.”*<sup>9</sup>

As a result, the focus turned to the vessel manufacturer - Rotterdam Drydock Company (Rotterdamsche Droogdok Maatschappij, RDM). The conclusion of the investigations was that pressure vessel construction code inspections either did not detect or did not adequately document the existence of these indications.<sup>10</sup>

Twenty two reactor pressure vessels are installed in nuclear reactors worldwide made by RDM.<sup>11</sup> The response from regulators ranged from requiring additional inspections, to assurances that no similar flaws had been identified in the reactors concerned.<sup>12</sup> In addition to assessing the vessels manufactured by RDM, regulators also asked for assessments of the specific type of manufacturing used by RDM – so called beltline ring forgings.<sup>13</sup> In the United States for example fabrication data found that twenty-one operating U.S. PWRs and no BWRs have beltline ring forgings.

In 2013 and 2014 the non-governmental European regulatory body WENRA, recommended that inspections be made of the original manufacturing and inspection records of all European nuclear reactor pressure vessels<sup>14</sup>, and,

*“Examination of the base material of the vessels if considered necessary.”*<sup>15</sup>

However, they continued to focus on the origin of the problem being manufacturing.

The general conclusion from national regulators and following reports from reactor operators was that the type of micro-cracks found in Doel 3 and Tihange 2 reactors did not exist in their nuclear power plants.<sup>16</sup>

<sup>9</sup> World Nuclear Association, Safety checks on reactor vessels, August 28<sup>th</sup> 2012, [http://www.world-nuclear-news.org/rs-safety\\_checks\\_on\\_reactor\\_vessels-2808124.html](http://www.world-nuclear-news.org/rs-safety_checks_on_reactor_vessels-2808124.html), accessed February 14<sup>th</sup> 2015.

<sup>10</sup> Nuclear reactor vessels are inspected at time of fabrication according to applicable construction codes, and the inspection records are required to be retained for the life of the plant.

<sup>11</sup> In addition to the two pressure vessels in Doel 3 and Tihange 2 manufactured by RDM, vessels were also supplied to Argentina (1), Germany (2), Spain (2), USA (10), Sweden (1) and Switzerland (2), the Netherlands (1). Soupçons sur les cuves de 22 réacteurs nucléaires, Le Monde, August 8<sup>th</sup> 2012, [http://www.lemonde.fr/planete/article/2012/08/09/soupcons-sur-les-cuves-de-22-reacteurs-nucleaires\\_1744086\\_3244.html](http://www.lemonde.fr/planete/article/2012/08/09/soupcons-sur-les-cuves-de-22-reacteurs-nucleaires_1744086_3244.html), accessed February 15<sup>th</sup> 2015.

<sup>12</sup> World Nuclear Association, Safety checks on reactor vessels, August 28<sup>th</sup> 2012, [http://www.world-nuclear-news.org/rs-safety\\_checks\\_on\\_reactor\\_vessels-2808124.html](http://www.world-nuclear-news.org/rs-safety_checks_on_reactor_vessels-2808124.html), accessed February 14<sup>th</sup> 2015.

<sup>13</sup> Large pressure vessels are fabricated by two methods. In the first method, rolled and welded plates are used to form separate steel courses. Such a vessel has both longitudinal and circumferential weld seams. In some older vessels designed before 1972, the longitudinal welds are of particular concern with regard to vessel integrity because they contain high levels of copper and phosphorous. In the second method, large ring forgings are used. This method is intended to improve component reliability because of the lack of longitudinal welds. Weld seams are located to avoid intersection with nozzle penetration weldments. Traditionally the part of the vessel of primary concern with regard to age-related degradation is the core beltline — the region of shell material directly surrounding the effective height of the fuel element assemblies, plus an additional volume of shell material both below and above the active reactor core.

<sup>14</sup> WENRA recommends reactor vessel checks, World Nuclear Association, August 30<sup>th</sup> 2013, [http://www.world-nuclear-news.org/RS-WENRA\\_recommends\\_reactor\\_vessel\\_checks-3008134.html](http://www.world-nuclear-news.org/RS-WENRA_recommends_reactor_vessel_checks-3008134.html), accessed February 14<sup>th</sup> 2015.

<sup>15</sup> Report Activities in WENRA countries following the Recommendation regarding flaw indications found in Belgian reactors December 17 2014 [http://www.wenra.org/media/filer\\_public/2014/12/26/flaws\\_in\\_rpv\\_feedback\\_2014-12-19.pdf](http://www.wenra.org/media/filer_public/2014/12/26/flaws_in_rpv_feedback_2014-12-19.pdf), accessed February 2014.

<sup>16</sup> “Report Activities in WENRA countries following the Recommendation regarding flaw indications found in Belgian reactors”, December 17<sup>th</sup> 2014, [http://www.wenra.org/media/filer\\_public/2014/12/26/flaws\\_in\\_rpv\\_feedback\\_2014-12-19.pdf](http://www.wenra.org/media/filer_public/2014/12/26/flaws_in_rpv_feedback_2014-12-19.pdf), accessed February 14<sup>th</sup> 2015.

Since the inspection results revealed a potential safety concern, the Doel 3 and Tihange 2 NPPs remained in cold shutdown while the licensee performed a safety evaluation to determine if they could safely be returned to service. This safety case was presented to the Belgian safety authorities in two separate documents at the end of 2012. FANC confirmed that at that time it was not possible to confirm the exact root cause of the hydrogen flaking.<sup>17</sup> However without understanding the root cause of the problem, FANC and other national nuclear regulators should not have communicated that the problem was due to manufacturing limited to those pressure vessels produced in the Netherlands.

After the conclusion of a safety report, FANC approved the reactors for safety and they were restarted in May 2013.

But FANC in its final safety report also left open the possibility that the cause was not manufacturing ***“However, it is not possible to guarantee this assumption with absolute certainty without performing destructive testing on the reactor pressure vessels, which is not an option.”***<sup>18</sup>

### **New tests – new doubts**

The uncertainties in the conclusions of their 2013 assessments and independent critical analysis<sup>19</sup> led FANC to require Electrabel to conduct a series of materials tests conducted at the BR2 research reactor by SCK in Mol from 2013-2014. These tests involved bombarding a sample of steel to neutron radiation to simulate 40 years of operation. Although these test results have not been made public, the indications during 2014 were that they discovered serious problems. As Electrabel informed the regulator on 25<sup>th</sup> March 2014,

***“the tests...had produced some unexpected results.”***<sup>20</sup>

On the same day, Electrabel/GDF-Suez announced the immediate shutdown of the Doel-3 and Tihange-2 reactors.<sup>21</sup>

The decision was taken after one of the tests ***“related to the mechanical strength of a sample analogue to the composition of the concerned vessels did not deliver results in line with experts expectations”***. Additional testing confirmed the unexpected behaviour of the hydrogen flaked material, Electrabel started a second irradiation campaign in April 2014 at the BR2 research reactor to answer the various questions raised by this issue and to confirm or discount some potential explanations. “This second irradiation campaign again confirmed the unexpected behaviour but did not provide a clear explanation of the non-hardening embrittlement phenomenon observed in the VB395 flaked material.”<sup>22</sup>

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<sup>17</sup> “Doel 3 and Tihange 2 Reactor Pressure Vessels Final Evaluation Report”, May 2013, Federal Agency for Nuclear Control (FANC), Belgium, <http://fanc.fgov.be/GED/00000000/3400/3429.pdf>, accessed February 15<sup>th</sup> 2015.

<sup>18</sup> “Doel 3 and Tihange 2 Reactor Pressure Vessels Final Evaluation Report”, May 2013, Federal Agency for Nuclear Control (FANC), Belgium, <http://fanc.fgov.be/GED/00000000/3400/3429.pdf>, accessed February 15<sup>th</sup> 2015.

<sup>19</sup> “Flawed Reactor Pressure Vessels in Belgian Nuclear Plants Doel-3 and Tihange-2”, Ilse Tweer, Materials Scientist, Consultant. Report commissioned by the Greens/EFA Group in the European Parliament. March 2013, see <http://www.greens-efa.eu/fileadmin/dam/Documents/Studies/Flawed%20Reactor%20Pressure%20Vessels.pdf>, accessed February 14<sup>th</sup> 2015.

<sup>20</sup> “Flaw indications in the reactor pressure vessels of Doel 3 and Tihange 2”, Progress Report 2014, FANC, <http://www.fanc.be/GED/00000000/3700/3751.pdf>

<sup>21</sup> Electrabel/GDF-Suez, “Anticipating planned outages of Doel 3 and Tihange 2 reactors”, 25 March 2014, see <https://www.electrabel.com/en/corporate/article?article=14-03-25-anticipating-planned-outages-doe13-tihange2-reactors>,

<sup>22</sup> “Flaw indications in the reactor pressure vessels of Doel 3 and Tihange 2”, Progress report 2014, FANC, <http://www.fanc.fgov.be/GED/00000000/3700/3751.pdf>, accessed February 14<sup>th</sup> 2015.

FANC reported that ***“the material’s embrittlement appears to be greater than one would expect based on the trend curves reported in the existing literature”***.<sup>23</sup>

At the same time Electrabel reported that following shutdown of Doel and Tihange ultrasonic inspections, showed that a comparison with the new 2014 data with those from 2012-2013, applying the same detection and sizing procedure, has shown that the flaw indications did not evolve during operation from May 2013 to March 2014.<sup>24</sup>

As materials scientist Ilse Tweer concluded, ***“No experimental data exist on radiation embrittlement of reactor materials with hydrogen flaking. Irradiation programs in the future would require high-flux irradiation in order to get results in reasonable time periods. Due to a possible dose rate effect high-flux irradiation results might underestimate the real embrittlement. It has to be kept in mind that no RPV specific material exists for such an irradiation program. The specimens from the AREVA material – a rejected steam generator ring - cannot be considered to be representative.”***<sup>25</sup>

As a result of the materials testing results which have been conducted at the BR2 research reactor in Mol it appeared in 2014 that FANC was considering that the problem is not limited to the 21 pressure vessels that were manufactured in the Netherlands but potentially is a problem for nuclear reactors world wide. This was included as a possibility in their 2013 final report, but was not highlighted in their communication at the time, and given the implications was also not communicated by the nuclear industry and regulators globally.

## **New disclosures**

Two materials scientists disclosed on February 13th 2015 that the problem with the Belgian reactor vessels could be the migration of hydrogen atoms into the steel pressure vessel. As Professor MacDonald explained, the phenomenon is the entry of hydrogen from water which is on the inside of the pressure vessel, the water is in contact with stainless steel sheet, but hydrogen can go through the stainless steel sheet. ***“What happens if hydrogen is injected as hydrogen atoms and they are small and easily move through the lattice...It is like having a marble move between billiard balls”***.<sup>26</sup>

***“The importance...could range from inconsequential to being so severe that it would shut down all the reactors. My advice is that all reactor operators, under the guidance of the regulatory commissions should be required to do an ultrasonic survey of the pressure vessels. All of them.”***  
*Professor Digby MacDonald, February 13<sup>th</sup> 2015.*<sup>27</sup>

It was explained, that until now, analysis has only taken a mechanical viewpoint of what is happening. ***“But the fundamental root cause of this is most likely a corrosion problem. And unless we deal with the root cause, we are never likely to understand the phenomenon.”***

<sup>23</sup> “Flaw indications in the reactor pressure vessels of Doel 3 and Tihange 2”, Progress report 2014, FANC, <http://www.fanc.fgov.be/GED/00000000/3700/3751.pdf>, accessed February 14th 2015.

<sup>24</sup> <http://www.fanc.fgov.be/GED/00000000/3700/3751.pdf>

<sup>25</sup> Ilse Tweer, “Flawed Reactor Pressure Vessels in Belgian Nuclear Plants Doel-3 and Tihange-2”, Materials Scientist, Consultant, Report commissioned by the Greens/EFA Group in the European Parliament, March 2013, see <http://www.greens-efa.eu/fileadmin/dam/Documents/Studies/Flawed%20Reactor%20Pressure%20Vessels.pdf>, accessed February 14<sup>th</sup> 2015.

<sup>26</sup> Interview with Belgian national state broadcaster, <http://deredactie.be/cm/vrtnieuws/videozone/programmas/terzake/2.37612>.

<sup>27</sup> Interview with Belgian national state broadcaster, <http://deredactie.be/cm/vrtnieuws/videozone/programmas/terzake/2.37612>. Digby Macdonald, is Professor in Residence, Department of Materials Science and Engineering, UC Berkeley, <https://www.nuc.berkeley.edu/people/digby-macdonald>, accessed February 14<sup>th</sup> 2015.

***“The consequences could be very severe...Like fracturing the pressure vessel. Loss of coolant accident. This would be a leak before break scenario. In which case before a fracture of a pipe occurred... you would see a jet of steam coming out through the insulation. My advice is that all reactor operators, under the guidance of the regulatory commissions should be required to do an ultrasonic survey of the pressure vessels. All of them.”***

If confirmed during the coming weeks and months the implications are profound.

Belgium professor and a specialist in nuclear material corrosion, Walter Bogaerts,<sup>28</sup> stated on February 13<sup>th</sup> 2015, that, ***“If I had to estimate, I would really be surprised if it ... had occurred nowhere else.”*** and that,

***“I am afraid that the corrosion aspects have been underestimated.”***

Electrabel in response to the latest development has stated that it is prepared to conduct further tests as demanded by FANC.<sup>29</sup>

### **Safety implications and ageing nuclear reactors**

***“This may be a global problem for the entire nuclear industry.***  
*Belgian Nuclear Regulator, FANC, Director General, Jan Bens, February 13<sup>th</sup> 2015.<sup>30</sup>*

The inside of nuclear reactor pressure contains cooling water, made up of hydrogen and oxygen. Hydrogen dissolves in metals as an atom or screened proton rather than as a hydrogen molecule.<sup>31</sup> The most damaging effect of hydrogen in structural materials is hydrogen embrittlement. Materials susceptible to this process exhibit a marked decrease in their energy absorption ability before fracture in the presence of hydrogen. This phenomenon is also known as hydrogen-assisted cracking, hydrogen-induced blister cracking. The embrittlement is enhanced by slow strain rates and low temperatures, near room temperature.

Prior to the latest developments in Belgium, nuclear regulators worldwide generally concluded that based on inspections conducted so far the micro cracks found in the two Belgian reactors is unlikely to exist in other reactors. The U.S. Nuclear Regulatory Commission view is representative,

***“It is concluded that the condition observed at Doel 3 is unlikely to exist in U.S. PWRs, and it would not have structural significance even if it did.”***

However this conclusion is not consistent with the latest warnings from the Director General of FANC and the analysis of Professors Bogaerts and MacDonald.

Failure of a reactor pressure vessel is a beyond-design-basis event, and acceptable margins against pressure vessel failure must be maintained throughout its operational life. In reactor pressure vessel integrity regulations, propagation of a flaw through the vessel wall is conservatively assumed to cause reactor pressure vessel failure. Pressurised Water Reactors (PWRs) are more vulnerable to pressure vessel embrittlement because PWRs may experience pressurized thermal shock (PTS).

<sup>28</sup> BNEN, the Belgian Nuclear Higher Education Network, [http://bnen.sckcen.be/en/Courses/Nuclear\\_materials](http://bnen.sckcen.be/en/Courses/Nuclear_materials), accessed February 14<sup>th</sup> 2015.

<sup>29</sup> <http://deredactie.be/cm/vrtnieuws/francais/videotheque/1.2239770>, accessed February 14<sup>th</sup> 2015.

<sup>30</sup> <http://deredactie.be/cm/vrtnieuws/binnenland/1.2238955>, accessed February 14<sup>th</sup> 2015.

<sup>31</sup> Hydrogen Embrittlement of Metals: A Primer for the Failure Analyst, WSRC-STI-2008-00062 M. R. Louthan, Jr. Materials Science and Technology Savannah River National Laboratory Aiken, South Carolina 29808, <http://sti.srs.gov/fulltext/WSRC-STI-2008-00062.pdf>, accessed February 14<sup>th</sup> 2015.

PTS can occur under some accident scenarios that introduce cold water into the reactor vessel while the vessel is pressurized. Introduction of cold water in this manner can cause the vessel to cool rapidly, resulting in large thermal stresses in the steel. These thermal stresses, along with the high internal pressure and an embrittled vessel, could lead to cracking and even failure of the vessel. The presence of cracks in the Belgian PWR's raises the question of the fundamental safety of the reactors.

As described earlier, the principal communication from the nuclear industry and regulators in Europe, North America and Asia during the past two years has been that the manufacturing of the Doel and Tihange pressure vessels was the likely reason for the discovery of hydrogen flakes. But as noted, FANC could not confirm the root cause of the problem. Without a root cause analysis the reason for an engineering failure cannot be assured.

The evidence from the two scientists disclosed on February 13<sup>th</sup> 2015, is that there is problem of the migration of hydrogen atoms into the steel pressure vessel. If confirmed the implications are profound. The fact that the Director General of FANC has stated that hundreds of nuclear reactors worldwide should be examined suggests that there is indeed a potentially generic safety problem.

Greenpeace has long questioned the safety of ageing nuclear reactors. For more than two decades we have warned that the ageing process is leading to the gradual weakening of materials that could lead to catastrophic failures of components with subsequent severe radioactive releases. In particular,

***“Most notable among these is the embrittlement of the reactor pressure vessel, which increases the risk of the vessel bursting. Failure of the pressure vessel of a PWR or a BWR constitutes an accident beyond the design basis for which there is no safety system - inevitably leading to a catastrophic release of radioactive material to the environment.”<sup>32</sup>***

Embrittlement under neutron radiation is of special importance for old reactors. At the time of their construction, knowledge of neutron-induced embrittlement was limited, so sometimes unsuitable materials were used.

The challenge presented to the world nuclear reactor operators and regulators of these new disclosure in Belgium is that replacement of the reactor pressure vessel is impossible for economic and practical reasons.<sup>33</sup> Consequently, if ageing mechanisms prevent further safe operation of these components, the reactor will have to be shut down. The risk of loss of reactor pressure vessel integrity increases under accident conditions, as the International Atomic Energy Agency (IAEA) explains:

***“If an embrittled RPV were to have a flaw of critical size and certain severe system transients were to occur, the flaw could propagate very rapidly through the vessel, possibly resulting in a through-wall crack and challenging the integrity of the RPV.”***

The IAEA identifies such severe transients as:

› Pressurized thermal shocks (PTS), characterized by rapid cooling of the downcomer and

<sup>32</sup> “Nuclear Reactor Hazards Ongoing Dangers of Operating Nuclear Technology in the 21st Century Report”, Greenpeace International, Helmut Hirsch, Oda Becker, Mycle Schneider, Antony Froggatt April 2005, <http://www.greenpeace.org/seasia/th/PageFiles/106897/nuclearreactorhazards.pdf>, accessed February 2015;

“Lifetime extension of ageing nuclear power plants: Entering a new era of risk” Report commissioned by Greenpeace, 2014, [http://out-of-age.eu/wp-content/uploads/2014/02/20140228\\_Briefing\\_Ageing\\_english.pdf](http://out-of-age.eu/wp-content/uploads/2014/02/20140228_Briefing_Ageing_english.pdf)

<sup>33</sup> IAEA. 2008. Heavy component replacement in nuclear power plants: experience and guidelines. IAEA Nuclear Energy Series, Technical Reports, No. NP-T-3.2. IAEA, Vienna.

internal RPV surface, followed sometimes by repressurization of the RPV (PWR reactor types)

- ) Cold overpressure (high pressure at low temperature) for example at the end of shutdown situations.

So the unidentified degradation of reactor pressure vessels, such as cracks and flaws, therefore has the potential to escalate an incident into an uncontrollable accident, even though it does not cause problems during normal operation.

There are conflicting scientific opinions concerning the current significance and further progression of ageing. Huge uncertainties are involved in estimating and predicting the progression of ageing and the long-term behaviour of materials, especially under accident conditions.

The average age of the global nuclear reactor fleet was 28.5 years in mid 2014, with 170 reactors (44 percent of the total) operating for 30 years or more and 39 reactors have operated for over 40 years.<sup>34</sup>

As the world's nuclear power plants get older, there are efforts to play down the role of ageing. Those efforts include conveniently narrowing the definition of ageing. Furthermore, the most basic and severe shortcoming of international regulatory norms resides in the fact that no country has a comprehensive set of technical criteria for deciding when further operation of a nuclear power plant is no longer permitted. As a consequence reactors are being allowed to operate longer.

As a result of ageing the risk of a nuclear accident grows significantly each year, once a nuclear power plant has been in operation for about two decades.<sup>35</sup>

If the problems identified by the two scientists announced during the last few days are confirmed with further assessments in Belgium including that the micro cracks are found to be a generic issue related to the effects of radiation over years of operation and exposure to radiation, the implications for all commercial nuclear power could be devastating. The risk is that rather than take up the call of the Director General of FANC, national regulators worldwide and the nuclear reactor operators will continue to downplay the significance of these important developments. Given the uncertainties and the potential catastrophic risk of a reactor pressure vessel failure this is not acceptable from a public safety perspective.

## **Conclusion**

As we approach the fourth anniversary of the March 2011 Fukushima-daiichi nuclear disaster, evidence has emerged from that demands immediate action to prevent another possible catastrophe. Thousands of previously unknown cracks in critical components of two reactors point to a potentially endemic and significant safety problem for reactors globally. Continuing to operate any reactor with such cracking would be an unacceptable risk to public safety. Greenpeace demands detailed inspections of all nuclear reactors worldwide, as conducted in Belgium, and the public release and scrutiny of the results. Any reactor with such cracking must be kept offline, until and unless the cracking is understood and safety is guaranteed. Anything less would be insane given the risk of a severe nuclear accident.

<sup>34</sup> World Nuclear Industry Status Report, Mycle Schneider, Anthony Froggatt, July 2014. <http://www.worldnuclearreport.org/IMG/pdf/201408msc-worldnuclearreport2014-hr-v4.pdf>, accessed February 15<sup>th</sup> 2015.

<sup>35</sup> Nuclear Reactor Hazards Ongoing Dangers of Operating Nuclear Technology in the 21st Century Report. Greenpeace International, Helmut Hirsch, Oda Becker, Mycle Schneider, Antony Froggatt April 2005, <http://www.greenpeace.org/seasia/th/PageFiles/106897/nuclearreactorhazards.pdf>, accessed February 2015.

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## **Thousands more cracks found in Belgian nuclear reactors, Belgian regulatory head warns of global implications**

**Brussels, 17 February 2015** – Following the discovery of thousands of additional cracks in critical components of two Belgian nuclear reactors, Greenpeace today called for immediate checks of nuclear power plants worldwide.

The cracks were found in the steel nuclear reactor pressure vessels in nuclear reactors Doel 3 and Tihange 2. The vessels contain the highly radioactive nuclear fuel core. Failure of this component can cause a catastrophic nuclear accident. On February 13<sup>th</sup>, two leading material scientists announced that the pervasive and unexpected cracking could be related to corrosion from normal operation, with potential implications for reactors worldwide.

In a reaction to this, the Director General of the Belgian nuclear regulator, The Federal Agency for Nuclear Control (FANC), stated that, *"This may be a global problem for the entire nuclear industry. The solution is to implement worldwide, accurate inspections of all 430 nuclear power plants."* (1)

Greenpeace Belgium nuclear campaigner, Eloi Glorieux, said:

"What we are seeing in Belgium is potentially devastating for nuclear reactors globally due to the increased risk of a catastrophic failure. Nuclear regulators worldwide must require reactor inspections as soon as possible, and no later than the next scheduled maintenance shutdown. If damage is discovered, the reactors must remain shut down until and unless safety and pressure vessel integrity can be guaranteed. The nuclear industry, already in crisis, is faced with an ageing nuclear reactor fleet at increasing risk of severe disaster."

The problem was initially discovered in the summer of 2012. Both the Doel 3 and Tihange 2 reactors have been shutdown since March 24<sup>th</sup> 2014 after additional tests revealed an unexplained advanced embrittlement of the steel of the test sample. The integrity of the pressure vessel is required to be guaranteed due to the severe accident and radioactive releases that would result if this component were to fail.

As nuclear reactors age, radiation causes pressure vessel damage, or embrittlement, of the steel. According to the statements of the two materials scientists on Feb 13<sup>th</sup>, the damage in the Belgian reactors may be partially caused by a problem resulting from the migration of hydrogen into cracks in the steel of the vessel – exacerbating and expanding that cracking. The phenomenon is like a road in winter where water trickles into tiny cracks, freezes, and expands, breaking up the road; it appears that hydrogen from the water within the vessel that cools the reactor core is getting inside the steel, reacting, and destroying the pressure vessel from within.

FANC has subsequently issued a statement confirming that the additional tests conducted in 2014 revealed 13,047 cracks in Doel 3 and 3,149 in Tihange 2. On February 15<sup>th</sup> the nuclear reactor operator, Electrabel (GDF/Suez parent company) announced that it would be prepared to 'sacrifice' one of its reactors to conduct further destructive tests of the reactor pressure vessel in order to study this poorly understood and extremely concerning damage phenomenon. (2)

In 2012, the operator of the reactors, Electrabel, dismissed the cracks as due to manufacturing problems done in the late 1970's in the Netherlands, but still failed to table evidence for this

assumption. The Belgium regulator also stated that the most likely cause was manufacturing – but also that it could not prove this and that it may be due other causes.

The recent announcements of the materials scientists, which were echoed in the concerns of the head of the Belgian nuclear regulator, indicate that this problem could be far beyond manufacturing. If confirmed, it means that the safety of every nuclear reactor on the planet could be significantly compromised.

There are 435 commercial nuclear reactors world wide, with an average age of 28.5 years in mid 2014. Of these 170 reactors (44 percent of the total) have been operating for 30 years or more and 39 reactors have operated for over 40 years.

As of 2015, Doel 3 has been operating for 33 years; Tihange 2 for 32 years.

“As we approach the fourth anniversary of the Fukushima-daiichi nuclear disaster, evidence has emerged that demands immediate action to prevent another catastrophe. Thousands of previously unknown cracks in critical components of two reactor reactors point to a potentially endemic and significant safety problem for reactors globally. Continuing to operate any reactor with such cracking would be a wholly unacceptable risk to public safety. Greenpeace demands detailed inspection of all nuclear reactors worldwide, as conducted in Belgium, and the public release and scrutiny of the results. Any reactor with such cracking must be kept offline, until and unless the cracking is understood and safety guaranteed. Anything less would be insane given the risk of a severe nuclear accident,” said Glorieux.

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Notes

1 - Belgium Director General of the Federal Agency for Nuclear Control (FANC) Jan Bens as reported on Belgian national tv broadcaster,  
<http://derefactie.be/cm/vrtnieuws/binnenland/1.2238955>

2 – Electrabel statement  
<http://derefactie.be/cm/vrtnieuws/videozone/programmas/journaal/2.37616?video=1.2239411>

3 - Professor Digby MacDonald, “The consequences could be very severe...Like fracturing the pressure vessel. Loss of coolant accident. This would be a leak before break scenario. In which case before a fracture of a pipe occurred... you would see a jet of steam coming out through the insulation. My advice is that all reactor operators, under the guidance of the regulatory commissions should be required to do an ultrasonic survey of the pressure vessels. All of them.” Interview with Belgian national state broadcaster,  
<http://derefactie.be/cm/vrtnieuws/videozone/programmas/terzake/2.37612>.

Professor Walter Bogaerts, stated on February 13<sup>th</sup> 2015, that, “If I had to estimate, I would really be surprised if it ... had occurred nowhere else.” and that “I am afraid that the corrosion aspects have been underestimated.” as reported Belgian national state broadcaster,  
<http://derefactie.be/cm/vrtnieuws/videozone/programmas/terzake/2.37612>.