

Defecten in de reactordrukvaten van Doel 3 en Tihange 2

Rapport



The Greens | European Free Alliance
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Table of Contents

1 Samenvatting.....	4
2 Introduction.....	8
2.1 Conference Order.....	8
2.2 Involved Persons.....	8
2.2.1 Participants of the Conference.....	8
2.2.2 Further Participants.....	10
2.2.3 Advisors and Peer Reviewer.....	10
2.3 Documents.....	10
3 Caveats.....	12
4 Lack of Conservatism.....	13
5 Superfluous tests.....	15
6 Selection of Investigated Details.....	16
6.1 Defects.....	16
6.1.1 Classification.....	16
6.1.2 Finding.....	16
6.1.3 Localizing.....	16
6.1.4 Form and Size.....	17
6.1.5 Origin.....	17
6.1.6 Search for Representative Sample Material.....	19
6.2 Structural Integrity.....	21
6.2.1 Loads.....	21
6.2.1.1 Cold Tongues (Plume Effect).....	21
6.2.1.2 Earthquake and Paleoseismologie.....	22
6.2.1.3 Design Basis Accidents during Shutdown.....	22
6.2.2 Grouping of Defect.....	23
6.2.3 Material Properties.....	24
6.3 Core Damage Frequency.....	26

6.4 Manufacturing Documentation.....	28
6.4.1 Missing Documentation.....	28
6.4.2 Contradictory Documentation.....	29
6.5 Necessary conditions for restarting.....	30
6.5.1 Preparatory Work of the Operator.....	30
6.5.2 Requirements of FANC.....	30
6.5.2.1 A complete reactor-inspection after any significant deviation from the normal operation.....	30
6.5.2.2 FANC Requirements 1 – 16.....	31
7 Appendix.....	33
7.1 Questions to FANC.....	33
7.2 Requirement of FANC for restarting.....	37
7.3 Source Directory.....	40
7.4 Index.....	42

1 Samenvatting

Tijdens de zomer van 2012 werden in het reactordrukvat (RDV) van de Belgische kerncentrales Doel 3 en Tihange 2 een tot dan toe onbekend aantal defecten vastgesteld. Op grond daarvan werden de twee reactoren tijdelijk buiten werking gesteld. De defecten zijn gemiddeld 1,0 cm en maximaal 2,4 cm groot. In het reactorvat van Doel 3 werden meer dan 8.000 en in dat van Tihange 2 meer dan 2.000 defecten vastgesteld [04]. Het FANC, de Belgische toezichthouder op de kerncentrales, eiste een onderzoek door de exploitant. Dat onderzoek werd door het FANC beoordeeld en afgesloten met een eindrapport [14]. In mei 2013 gaf het FANC de toelating om de twee reactoren weer in gebruik te nemen.

Het reactordrukvat is het centrale deel van een kernreactor. Daarin bevinden zich de brandstofstaven en gebeurt de kernsplijting. Het RDV wordt gemaakt van afzonderlijke stalen ringen, die aan elkaar worden gelast. Het RDV wordt blootgesteld aan zware belastingen. Tijdens de werking heerst in het drukvat een temperatuur van circa 300 °C en een druk van ongeveer 160 bar. Het opstarten en stilleggen, maar ook snelle uitschakelingen van de reactor betekenen een bijzonder belasting voor het RDV. Tijdens de werking is de wand van het drukvat blootgesteld aan het neutronenbombardement dat ontstaat bij de kernsplijting. Door al die processen wordt het staal bros.

Bij alle onderzoeken van nucleaire installaties moet men er bij het bekijken van ontwerpongevallen van uitgaan dat het reactordrukvat niet mag falen (jaarlijkse kans op voorval kleiner dan 10⁻⁷). Het lekken of barsten van het RDV moet in alle gevallen vermeden worden, omdat dit onvermijdelijk zou leiden tot een kernsmelt.

Door het grote aantal defecten in de reactorvaten verhoogt het risico dat het reactordrukvat spontaan zou falen, waardoor de atoomkern zou smelten en grote hoeveelheden radioactieve stoffen zouden vrijkomen. In dat geval zou er geen tijd zijn voor waarschuwingen en om evacuatiemaatregelen op te starten. Een dergelijk ongeval zou erger uitvallen dan dat van Fukushima en eventueel zelfs – omwille van de grote bevolkingsdichtheid – Tsjernobyl.

Uitgaande van het gevaar dat deze defecten kunnen veroorzaken, organiseerden het 'Aachener Aktionsbündnis gegen Atomenergie' en de groene fractie in het Europees Parlement in januari 2014 een conferentie, waarvan dit rapport het verslag is. Er werden deskundigen uitgenodigd om na te gaan of het verantwoord was de werking van Doel 3 en Tihange 2 ook met deze aanwezige defecten voort te zetten. Als basis voor de beoordeling dienden de door het FANC gepubliceerde documenten.

Op basis van de openbaar gemaakte documenten kwam de conferentie tot drie categorieën van kritiek: methodische fouten, gebrekkige productdocumentatie en fouten in onderzoeksdetails.

Uiteindelijk bleek uit de beoordeling dat een verdere werking van de installaties volgens de erkende internationale normen niet is toegestaan. Naast de punten van kritiek stuiten de deskundigen ook telkens weer op vragen die niet te beantwoorden zijn op basis van de gepubliceerde documenten. Daarom werd een vragenlijst voor het FANC opgesteld (zie pagina 33).

De **methodische fouten** hebben betrekking op de volgende punten:

- de noodzakelijke **conservativiteit** bij het inschatten en berekenen ontbreekt
- de **oorsprong van de defecten** kan niet worden geïdentificeerd
- de uitbater en het FANC kennen de **werkelijke kenmerken van het materiaal** in het RDV niet.

Conservativiteit is een principe uit de ingenieurwetenschappen. Veronderstellingen worden altijd zo geformuleerd dat ze voorzien zijn op het meest ongunstige geval. Als het op basis van die veronderstellingen lukt om de deugdelijkheid te bewijzen, geldt de benadering als conservatief. Zij houdt dan rekening met onzekerheden en onnauwkeurigheden in de veronderstellingen. In dit geval speelt men 'op veilig'. In belangrijke delen van de door het FANC aanvaarde onderzoeken ontbreekt die conservativiteit. Conservatieve uitgangspunten van de door het FANC bijeengeroepen internationale commissie van deskundigen (International Expert Review Board – IERB) worden zelfs genegeerd. Een van de aanbevelingen van die commissie had onmiddellijk kunnen leiden tot de conclusie dat de twee reactoren niet meer geschikt waren om te werken [05].

De **oorsprong van de defecten** is niet opgehelderd. En toch volgt het FANC de verklaring van de exploitant Electrabel dat ze zijn ontstaan bij de productie van het RDV. De exploitant baseert zich voor die hypothese op het feit dat er geen ander verklaringspatroon zou zijn [01], [14]. Een dergelijke veronderstelling kan niet als conservatief worden aanvaard. De conclusie is dat deze defecten op het moment dat het RDV werd gemaakt – ook met de toen beschikbare techniek – hadden moeten worden vastgesteld [05]. Ten minste één ring van het RDV van Tihange 2 werd bij de oplevering geweigerd omdat er te veel defecten aan waren [04]. Het afgewezen deel werd niet gemonteerd, maar vervangen door een ander. Bij een conservatieve benadering moet men daaruit besluiten dat de defecten die nu bekend zijn geworden niet zijn ontstaan bij de productie van het drukvat, maar tijdens de werking. Als dat echter het geval is, moet een toezichthoudende instantie de verdere werking van deze twee reactoren verbieden.

Het is niet mogelijk om de **werkelijke kenmerken van het materiaal** te bepalen. Nochtans vormen die de basis die nodig is voor alle verdere beschouwingen. Er bestaat geen representatief staal van het materiaal, waarmee het mogelijk zou zijn om de huidige kenmerken van het materiaal vast te stellen. Omdat het technisch gezien niet mogelijk is om een staal te nemen van het materiaal uit het reactordrukvat, moet er representatief

staalmateriaal beschikbaar zijn. Representatief betekent in dit verband dat er materiaal beschikbaar moet zijn dat ten eerste voortkomt uit hetzelfde productieproces als het RDV en ten tweede een vergelijkbaar verouderingsproces heeft gekend. Met veroudering bedoelen we hier een vergelijkbare belasting door de werking, met name het neutronenbombardement en het opstarten en stilleggen van de reactor (grote veranderingen in druk en temperatuur). Electrabel gebruikt als zagezegd representatief materiaal een afgewezen stuk uit de stoomgenerator van een Franse kerncentrale en ook een restant van delen die zijn uitgesneden voor aanleg van de leidingen van de primaire koelkring van Doel 3 [21]. De beide monsters hebben geen vergelijkbaar verouderingsproces gekend en zijn niet blootgesteld geweest aan straling of aan wisselende temperaturen en druk. De uitsnede van Doel 3 vertoont geen vergelijkbare defecten. Het monster van de stoomgenerator kan noch op basis van de specificatie of van de productie als representatief materiaal worden omschreven. De stoomgenerator werd in het jaar 2012 geproduceerd [20], dat wil zeggen 30 jaar na de twee reactordrukvaten. Het valt nauwelijks aan te nemen dat de stoomgenerator ook maar onder bij benadering vergelijkbare voorwaarden is geproduceerd. Het is niet mogelijk om te bewijzen dat de defecten in het monsterstuk van de Franse stoomgenerator vergelijkbaar zijn. Het kan niet als conservatief worden beschouwd om deze twee monsters als representatief staal te erkennen.

Deze drie basisvariabelen moeten absoluut betrouwbaar zijn voor elke verdere deskundige analyse. In dat verband stelden de deelnemers aan de conferentie vast dat de betrouwbaarheid van de basisvariabelen tot dusver niet gegarandeerd is. Om die reden is er geen enkele ernstige wetenschappelijk analyse meer mogelijk. Normaal gezien moet elke verdere discussie hier worden stopgezet.

Zolang de exploitant geen bijkomende geloofwaardiger basisvariabelen kan leveren, is de werking van beide reactoren niet te verantwoorden en zou een neutrale toezichhoudende instantie die moeten weigeren.

Ondanks die conclusie hebben de deelnemers aan de conferentie in overeenstemming met de opdracht toch de argumenten van het FANC, die hebben geleid tot de beslissing om de installaties voort te laten werken, geanalyseerd.

Het FANC heeft er meermaals op gewezen dat de beschikbare productdocumentatie tegenstrijdig en onvolledig is [14]. Om de kwaliteit van de afzonderlijke onderdelen van het RDV te kunnen beoordelen, is een documentatie zonder hiaten en zonder tegenstrijdigheden absoluut noodzakelijk. Tests tijdens de werking zijn belangrijk en nodig, maar kunnen op zich evenwel nooit volstaan om de kwaliteit van een onderdeel te beoordelen – dat kan enkel samen met de productiedocumentatie gebeuren.

Bij de meer gedetailleerde beschouwing lijken vooral de volgende punten relevant:

- **Ontwerpongevallen worden vereenvoudigd en klaarblijkelijk niet expliciet aangetoond met berekeningen.**

- **Aanbevolen veiligheidsmaatregelen** worden niet toegepast.

Uit de gepubliceerde documenten valt niet af te leiden met welke **ontwerpongevallen** (lekken en transiënten) rekening is gehouden. Met de hulp van deze beide punten worden de situaties vastgesteld die het RDV het meest belasten. Het FANC en de uitbater waren het er wel niet over eens welke situatie het meest belastend is [14]. Uit de documenten blijkt niet of de beide situaties wel expliciet zijn berekend.

De aanbevolen veiligheidsmaatregelen van de door het FANC bijeengeroepen internationale groep van deskundigen (IERB) worden niet toegepast. In het 'Final Report' van het FANC wordt die aanbeveling zonder verdere motivatie genegeerd. Het toepassen van die aanbeveling had moeten leiden tot het onmiddellijk stilleggen van beide reactoren (pagina 24).

2 Introduction

2.1 Conference Order

Due to the defects in the two reactors the anti-nuclear group from Aachen (Germany) “Aachener Aktionsbündnis gegen Atomenergie” together with the parliamentary group of the Greens in the European Parliament have invited to a conference on 24 and 25 January 2014 to Aachen.

The given task for the conference was to analyse the available documents on the reported defects in the reactor pressure vessels of Doel 3 and Tihange 2 reported by FANC in 2012 and to assess the decision to continue operation of two NPPs. Based on this analysis statements about the hazard potential should be made.

2.2 Involved Persons

The participants of the conference and consultants who support the results of the conference and have supplemented this report with their posts are listed below. The conference participants are divided into those who attended the conference due to their expertise and participants from the anti-nuclear movement who have dealt in detail with this issue (further participants). Some experts are kept anonymous to avoid conflicts of interest with customers.

2.2.1 Participants of the Conference

Prof. Dr. Wolfgang Kromp – Materials Science, Safety and Risk Sciences

Dipl.Ing. Dieter Majer – Nuclear Regulatory review, plant safety

Studied mechanical engineering at the university of Berlin.

Worked from 1973 to 2011 for various German regional and central authorities (ministries) in the field of nuclear safety. Worked from 1998 to 2011 for the Ministry of Environment, Nature Conservation and Nuclear Safety as a senior official, responsible with about 50 staff for the safety of nuclear installations in Germany. Also responsible for international affairs.

Since 2011 retired.

After retirement nuclear consultant for various domestic and international organizations.

Several studies on safety deficiencies in nuclear power plants in Europe published.

Dr. Rainer Moormann – Nuclear Safety

- 1976 PhD (physical chemistry) Technical University Braunschweig, FRG
- 1976-2012 Scientific employee at Forschungszentrum (Research Center) Juelich FZJ; safety analyses for nuclear systems as pebble bed reactors, fusion reactors and spallation neutron sources
- 2011 Whistleblower award for publication of safety problems of pebble bed reactors in spite of massive opposition in FZJ. These publications were one reason for the collapse of the unsafe pebble bed reactor project PBMR in South Africa.

M.Sc. Christian Steffens – engineering sciences in the energy sector

Dr. Ilse Tweer – Materials Science

- 1966 PhD Univ. of Vienna, Austria (Radiation damage in metals)
- 1966-1968 Assistant at the Univ. of Vienna, Inst. for Solid State Physics
- 1968-1970 Research Fellowships: Univ. of Delaware, Cath. Univ. of America, Washington D.C.
- since 1972 Documentation work for several Research Institutes (i.a. PTB Braunschweig, ZDE-Hannover, FIZ Energie/FIZ Karlsruhe, FIZ Werkstoffe, FIZ Technik, WTI-Frankfurt): materials science, solid state physics, reactor materials, nuclear medicine
- 1987-1994 Cooperation with Öko-Institut Darmstadt (NPP Obrigheim); Gruppe Ökologie (NPP Greifswald, NPP Stade): structural integrity of reactor pressure vessels
- since 1990 Cooperation with IRF (IRS)/Univ. of Vienna, member of Austrian Expert Teams (NPP Bohunice, NPP Krsko, NPP Mochovce, NPP Temelin, Trilateral Participation according to the Melk Protocol), special field: structural integrity of the reactor pressure vessel

*Dr. M. C.*¹ – Structural integrity and fracture mechanics

Dr. S. H. – Structural integrity and fracture mechanics

¹ Some experts are kept anonymous to avoid conflicts of interest with customers.

2.2.2 Further Participants

Eloi Glorieux – Greenpeace, Belgium

Jörg Schellenberg – Aachener Aktionsbündnis gegen Atomenergie, Germany

Walter Schumacher – Aachener Aktionsbündnis gegen Atomenergie, Germany

Leo Tubbax - nucléaire stop kernenergie, Belgium

2.2.3 Advisors and Peer Reviewer

Dr. Joe Hopenfeld – Peer reviewing and advises in the field of structural integrity and fracture mechanics

Dr. Hopenfeld has 50 years of experience in industry and government in the areas of steam generator performance, thermal-hydraulic, and material degradation and testing in nuclear and fossil power plants. While employed by the NRC (1982-2001) he has managed major international programs on steam generator performance in PWRs during accidents. His work at the US NRC led to the formulation of the current technical requirement specifications for steam generators. During the last 13 years Dr. Hopenfeld made several verbal and written presentations to the Atomic Safety and Licensing Board (ASLB) in connection with the life extension of the Vermont Yankee and the Indian Point Plants and the need for the shutdown of the San Onofre plant.

Dr Hopenfeld graduated from the Engineering School at the University of California, Los Angeles (BS 1960, MS 1962, Ph.D 1967). He has published many scientific articles and he holds eight patents.

http://www.stop-tihange.org/CV_Joe_Hopenfeld

2.3 Documents

This analysis is based on the documents published by FANC. All documents are listed in the source directory (page 40). A list of these documents is also published on the homepage of the supervisory authority and is accessible via the following link:

<http://fanc.fgov.be/nl/page/dossier-pressure-vessel-doel-3-tihange-2/1488.aspx?LG=2>

In addition, the Boiler and Pressure Vessel Code (BPVC) of the American Society of Mechanical Engineers (ASME) served as a source of information. According to this code, the two reactor pressure vessel were created and monitored. A request at the American Society of Mechanical Engineers to provide this standard to the conference free of costs remained unanswered. The necessary search of the conference participants took therefore place with publicly available copies of this standard for example in university libraries.

Basically all investigations, calculations and checks were performed exclusively by the operator Electrabel and its instructed experts.

All other documents of the bodies involved

- FANC - Nuclear Regulatory Authority
- Bel V – technical Subsidiary of FANC
- AIB-Vinçotte – performs inspections in the Belgian NPP.
- International Expert Review Board (IERB) – advisory group convened by FANC
- National Scientific Expert Group (NSEG) – advisory group convened by FANC

are based on these documentation provided by the operator without performing their own investigations, own calculations and evidences. Rather, these groups rely on the accuracy of the information in terms of calculations and experimental tests given by Electrabel [06].

The various groups transferred their reports to FANC. These individual reports are subsumed by the FANC and the relevant report was published. This contains the final evaluation and further conditions for operation.

The first series of reports published between the year 2012/2013 still contained many open issues. These issues had to be clarified by the operator prior to a the restart of the two reactors. For this reason, there was a second series of studies and reports in spring 2013. These reports led to the Final Report of FANC in May 2013. It may be noted that in the second series the judgement of the International Expert Review Board (IERB) is missing without any explanation.

3 Caveats

The participants of the conference agreed that a science-based evidence has failed for both issues: the current material properties and the origin of defects. Electrabel has not been able to provide representative samples.

In this respect all cost and time consuming analyses that were performed by Electrabel to demonstrate the structural integrity of the reactor pressure vessels and to give a justification for the continued operation of the facilities are not appropriate.

Despite these fundamental reservations, the conference participants decided to analyse and assess the further work of Electrabel and the decision of FANC for the re-start of the two reactors.

Motive of this decision is the high hazard potential of the defects:

The observed defects in the reactor pressure vessels increase the probability of a reactor pressure vessel failure without any advanced warning by orders of magnitude. Such an accident would exceed the events in Fukushima and could even surmount the accident at Chernobyl - due to the large population density, because local democratic rules exclude certain mandatory measures and because of the above already mentioned lack of warning time.

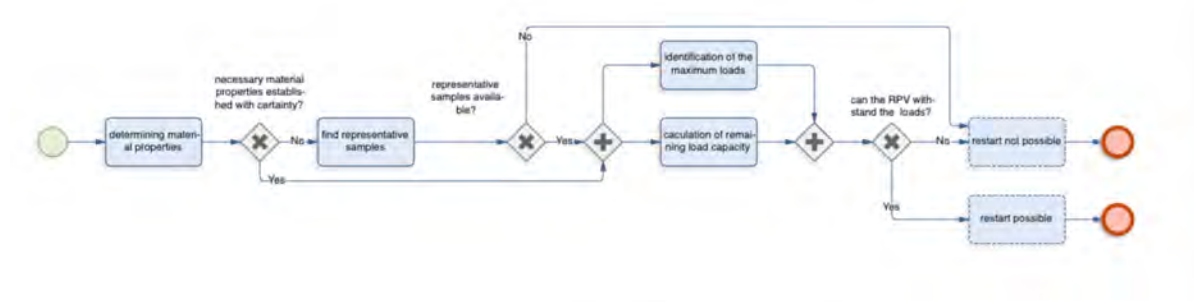


Figure 1 Workflow "Safety Validation"

4 Lack of Conservatism

The conference participants by consensus assume that for all aspects of reactor safety, a "conservative approach" has to be selected and would be chosen by all Nuclear Regulatory Authorities. Best Estimate approaches are to be rejected due to their lower reliability.

With respect to the structural integrity of the reactor pressure vessel a failure of the RPV must be avoided under all circumstances². For this reason, a conservative approach is imperative.

Important parts of the provided evidences of Electrabel do not show such a conservativeness. Nevertheless, FANC accepted them.

Exemplary examples of non-conservative approach:

- A pressure vessel with a density of fault indications as they were found in 2012 in both RPVs would not have been accepted at the time of construction (not even in accordance to the criteria of the manufacturer!) although the FANC approved the two reactors to re-start.
- FANC accepted verifications by experiments, obtained with non-representative samples.
- Electrabel uses a new, self-developed and not experimentally validated method (Grouping Method) for fracture mechanical analysis of large amounts of flaws. This became necessary because such a high density of defects is not foreseen in the ASME Code.
- FANC accepts the assumption that the defects in the RPVs are manufacture induced. This assumption is not based on scientific evidence.
- FANC accepted a RT_{NDT} -shift of 50 °C to cover all additional material property changes as recommended by Electrabel. This shift includes an assumed shift of 25 °C for hydrogen flaking, another 17 °C for the effect of macrosegregations, the remaining 8 °C are supposed to cover the unknown radiation effect on flawed material. In addition Electrabel does not use the FIS formula for the determination of RT_{NDT} shift, but the measured data from the radiation surveillance program. Taking into account the scatter of experimental data, which are not negligible especially in irradiated materials, the amount of 8 °C is not sufficiently conservative to cover the completely unknown processes

Further examples are given in the detailed chapter.

² Here damage probabilities of less than 10^{-7} (bis 10^{-9}) are required.

FANC itself claims that reactor pressure vessel failure has to be excluded under all circumstances. Electrabel's demonstration of structural integrity - as accepted by FANC - does not meet this requirement.

Question 1: Which assumptions in the reports of Electrabel are based on "best estimate" assumptions? Please list these in detail.

5 Superfluous tests

FANC demands experiments that in principle cannot lead to any meaningful results as long as no representative samples are available.

As a result data are produced with great effort that cannot answer the crucial questions and therefore these tests and the respective data are superfluous. For example, there is no way to determine the actual strength of the faulty material, unless by cutting samples from the RPV.

6 Selection of Investigated Details

The following sub-chapters are the result of individual subject areas of the conference. Each subject area deals with one aspect of the defects. The totality of the subject areas do not claim to be complete.

6.1 Defects

6.1.1 Classification

The defects in the RPVs of Doel 3 and Tihange 2 are the central conference issue. Defects are relevant because they are embedded in the steel and depending on size, shape, position and orientation they can have a significant impact on the structural integrity of the entire RPV. They were uniformly named as "flaws" in the public documents of Electrabel and FANC.

The shape, especially if they are cracks or round inclusions is essential. Since the characteristic of "Flaws" cannot be established beyond reasonable doubt by now, the conference participants have chosen the neutral term "defects".

6.1.2 Finding

Already during construction of Doel 3 and Tihange 2 in 1979 there were reports in the media and political disputes about defects in the RPVs [29]. A detailed overview of that newspaper reports was not available to the participants of the conference.

In summer 2012, studies on underclad cracking were carried out in the two RPVs. These tests were carried out because such cracks were found in the French NPP Tricastin. Aim of this test was to exclude such cracks in Belgian NPP. Underclad cracks were not found, but other lower lying defects. This result forced FANC to demand a full investigation of the wall thickness of the complete RPV. During this inspection the flaws discussed here were found.

6.1.3 Localizing

The exact localization of the defects is performed with an automated and robot-assisted ultrasound procedures. The investigation took place at completely discharged reactors using pulse-echo method in the summer of 2012. The study was carried out from the inside of the RPV throughout the entire wall thickness of the RPV. In addition to the accuracy this method has two fundamental limitations:

- The extension of the defects in radial direction is subjected to large inaccuracies.
- Hidden indications (defects behind defects) cannot be excluded and, if at all, detected only with very large uncertainties.

The necessary evidence that a detection especially with the two above-mentioned points is possible is carried out using rejected blocks VB395/1 of a French steam generator. [20] (page 19). This material cannot be considered to be representative for the RPVs.

The defects focus on individual shells of the RPV. Within these shells, the defects are focused on specific areas. The defects are located in the inner 10 cm of the cross section.

Question 2: How high is the inaccuracy in the determination of the radial component of the defects?

Question 3: How high is the probability that hidden defects are not detected?

Question 4: Why do you consider a calibration of UT on basis of the block VB395/1 as sufficient?

6.1.4 Form and Size

Shape, size, defect density (number of defects per volume unit) and orientation affect the structural integrity of the RPV. Defects with crack-like structure have a substantial safety hazard, since the behaviour of the large number of closely spaced defects in the case of severe transients is not known and thus the risk of spontaneous failure of the RPV cannot be excluded. The argument of the licensee, that the flaws are harmless due to their mostly parallel orientation to the inner surface is beyond comprehension. The behaviour of such defects during operation and in case of transients is completely unknown. Moreover, the radial part of individual defects and how this radial component may change in the case of thermo-mechanical influences is not known. Overall, the large number of defects weaken the RPV.

It must also be noted at this point must that the calibration of the UT is not performed on representative samples. In combination with the general limitations of UT an insufficient degree of conservatism must be stated here as well.

6.1.5 Origin

The origin of the defects is crucial. It must be clarified beyond doubt whether the defects caused during manufacture or during operation. Would the defects be caused during operation, a continued operation of the two reactors would in principle be no longer possible. In this case, it must be assumed that the RPV is not sufficiently able to withstand the loads during operation.

Currently, the licensee cannot demonstrate the origin of the defects. Nevertheless, the FANC follows Electrabel's explanation, that the defects are related to manufacturing. This hypothesis is supported by the operator to the fact that there are no other explanations „In the absence of any other explanation at this stage, the licensee supposes the presence of fabrication defects, but does not exclude other explanations.“ [01] and also in the Final Report FANC notes „The most likely origin of the indications identified in the Doel 3 and Tihange 2 reactor pressure vessels is hydrogen flaking due to the manufacturing process.“ [14]. Such a presumption is not sufficient and can under no circumstances be regarded as conservative. Rather, it must be assumed that the defects were not present after manufacturing because:

- At the time of manufacturing the technical options to detect these defects were available [05].
- At least one shell of the RPV of Tihange 2 were refused due to too many defects [04]. The amount of defects that lead to a refusal of acceptance at that time was significantly lower than the findings of 2012. Thus, there is no plausible explanation why these defects should not have been found if they had already been present at that time.

Consequently, it must be assumed that no defects existed at the start of operation of the reactors, but have evolved during operation. The participants of the conference emphasize at this point that the origin of the defects is also unclear to them. Due to the above-mentioned facts and in terms of a conservative approach, it must not be assumed that the formation of the defects occurred during manufacturing, it has to be assumed that the defects evolved or at least have grown during operation.

With respect the assumption of the licensee, that the defects are hydrogen-flakes it must be noted that in general hydrogen in steel is highly problematic, therefore dehydrogenation treatments of the steel have to be carried out during the manufacturing of an RPV.

Question 5: How can the claim of production-related origin of the defects be maintained even if during production control no defects have been found, although the technique for detection was available at that time and was used?

Question 6: How can the hydrogen flaking be explained by the H + S concentration of the ingots?

Question 7: What is the background for the note on page 16 (FANC, Final Report) [14] that in the samples with hydrogen flakes the carbon concentration is higher?

Question 8: How can it be explained that only shells of the RPVs of Doel 3 and Tihange 2 are affected?

Question 9: How can it be explained that the defects occur only at a certain depth from the inner surface?

Question 10: How can it be explained that the defects are not equally distributed throughout the volume?

Question 11: According FANC the pressure vessel would have been rejected during acceptance if affected with a defect density found in 2012. How can it be that the discovery of the defects in 2012 does not immediately lead to the same argument and an immediate and permanent closure of the reactors?

6.1.6 Search for Representative Sample Material

The current material properties of the RPV cannot be determined. For this reason, the operator has to rely on finding representative samples.

Representative means that material has to be available,

- which originates from the same manufacturing process
- that has undergone a similar ageing process
- that has comparable defects (defect type and defect density)

Using representative sample material further investigations can be carried out to assess the actual structural integrity of the RPV.

The operator presents two different samples that are representative to his point of view. These are

- a rejected piece from a **steam generator**, that includes hydrogen flakes and
- **nozzle cuts** from the RPV from Doel 3

The block of the **steam generator**, also often referred to in the documents with VB395, comes from a steam generator for a French NPP that was rejected due to too many defects. „Shell VB395 is a forged shell that was manufactured by AREVA as part of a steam generator for a 1300 MW-type power plant. It was rejected during manufacturing in 2012 due to the presence of a large number of hydrogen flakes.“ [20] The block VB395 cannot be assumed to be representative. The block was manufactured more than 30 years after the RPV of Doel 3 and Tihange 2. The specifications of the material for a pressure vessel and a steam generator are fundamentally different. It is hardly plausible that this block can be considered representative with respect to the material and the manufacturing process. VB395 was never exposed to neutron bombardment or comparable temperature/pressure cycles. Comparability of the defects of block VB395 with those of the RPV are mere speculation.

The **nozzle cut** of Doel 3 was also not exposed to similar ageing, neither thermomechanical nor by neutron bombardment. This specimen also has no similar defects. It can be assumed that special attention is laid on the manufacturing of the nozzle shell. This shell is due to the cut-outs for the cooling circuits, a particularly critical area.

Regulations require that for accelerated irradiation specimens only archive material may be used, that has the same production history as the RPV. The same applies of course also to the determination of the mechanical properties of the material without irradiation.

Question 12: How can it be that for the demonstration of the structural integrity of the RPV non-representative samples are used, neither comparable with respect to manufacturing nor with respect to specifications (AREVA block)?

Question 13: Why are the nozzle cuts considered as representative samples? Do they contain a comparable defect density? If not, then it is just sample material that would be assigned to a defect-free region of the RPV, in which case the operational loads and the irradiation history is still missing.

6.2 Structural Integrity

The proof of the structural integrity is in principle not possible, since a determination of the actual current material properties failed with the existing samples. The underlying samples are not representative (see also „Search for Representative Sample Material“ page 19). But this information is necessary for any assessing of the structural integrity of the RPVs.

Undoubtedly, the defects cause a weakening of the RPVs. Thus, it must be assumed that the two RPVs will no longer be able to withstand the same stresses as they did in the initial state. Basically a significant reduction of the wall thickness of the RPV must be assumed because such a wide variety of defects.

6.2.1 Loads

The RPV of an NPP has to withstand the loads occurring during operating and incidents in a way, that there are no exceeding of the limits of the release of radioactive nuclides. The following distinctions are made: "basic load" (normal operation), "transients" and "design basis accidents" (with values above the normal level).

Basically it has to be proofed that an RPV can withstand all forms of these loads. In the documentation published by FANC is not recognizable that a successful verification of all transient in normal operation and in the case of design basis accidents took place.

Question 14: Which design basis accidents and transients were used for the verification of structural integrity?

Question 15: Which design basis accidents and transients have been calculated explicitly?

Question 16: Why are the selected transients loads are limiting?

Question 17: Which pressure and thermal shock loads under normal and design basis accidents (DBAs) were used in the analysis.

Question 18: Which thermal hydraulic models and computer codes were used to generate thermal loads.

6.2.1.1 Cold Tongues (Plume Effect)

During reactor scram large quantities of cold water can be inserted into the reactor pressure vessel. Thus the cooling-down of the reactor pressure vessel wall cannot be accepted as symmetrical. Compared with the prevailing temperature there, the temperature differences

will arise here by around 250 °C. Internationally it is assumed that the "cold tongues" (plumes) represent a significant problem.

The licensee however assumes, that in the RPV of Doel 3 and Tihange 2 the symmetrical load is the most penalizing load case. The FANC accepts that explanation of Electrabel. In the documents FANC tells „*That issue leads to numerous exchanges with the licensee. Finally, in January 2013, the licensee provided Bel V with information allowing concluding that the "plume effect" may be neglected.*“ [14] From this sentence it is not visible, whether a calculation of this load-case ever took place.

Question 19: Does a calculation exist for the axially symmetrical and the asymmetrical load (plume effect) (cold tongues)?

6.2.1.2 Earthquake and Paleoseismologie

For assessing risks to equipment with regard to earthquake nowadays approaches of paleoseismology are also applied in addition to historical records. Paleoseismology investigates earthquakes on the basis of sediment deposits. That method can look extremely far into the past. This method is not based on human records of earthquakes, which allow only a very small look into the past. Thus the paleoseismology allows a more accurate assessment of the earthquake hazard in the respective regions.

In the documents of the FANC is not recognizable that earthquake load cases were applied for the demonstration of the structural integrity of the RPVs. Also the principle use of paleoseismology was not documented.

Nowadays, paleoseismology is state of science and technology. Therefore she must be considered at today's reviews of possible strains on a nuclear power plant.

Question 20: Which earthquake was chosen (probability and impact)?

Question 21: Which methods for the earthquake-calculations were carried out?

Question 22: Was the method "Paleoseismology" applied at all?

6.2.1.3 Design Basis Accidents during Shutdown

Recent studies have revealed that the probability of a meltdown during the plant shutdown lay in the same magnitude as during operation [30]. It is therefore essential to consider appropriate design basis accidents despite plant shutdowns and plant- revision of the system.

Question 23: Were design basis incidents considered during downtime, too?

Question 24: It was asked for earthquake loads in chapter 6.2.1.2. Were these loads also considered for plant shutdown?

6.2.2 Grouping of Defect

Because the ASME XI Code only provides guidance for fracture mechanical evaluation for cracks that have evolved during operation (single or a few) in the present case it is difficult to conclude the ASME Code can be applied for such a large number of defects that are supposed to have developed during manufacturing (according to the licensee). It must be assumed that in the case of transients during operation an interaction of neighbouring flaws can take place, which could then lead to a sudden increase of the relevant defect size. For computational evaluation of such processes Electrabel has proposed in accordance with the ASME Code a Grouping method in which by appropriate grouping of the observed defects a common defect size is defined in order to perform the fracture mechanical analysis [04].

Such a method is not envisaged by the regulations. The standards also do not discuss such a large number of manufacturing-related defects, shape and location of defects, as observed, are not addressed. The application of an approach like the grouping method has to be validated by experimental studies. Because no representative sample material is present, a reliable validation in principle cannot be performed.

Question 25: How can it be that in the case of such a large number of supposedly manufacturing induced defects which should have led (in accordance with the criteria for acceptance) to a rejection of the component, the safety of the component is now demonstrated using non-validated computational methods?

Question 26: Which experimental validation of the method exist?

Question 27: Which material was used for possible test block?

Question 28: How was the number of defects simulated?

Question 29: How was the spatial distribution of the defects, as observed in the real component simulated in the test block?

Question 30: How is the unexplained nature of the defects in the real component in the test block considered?

Question 31: Please show the fracture mechanics calculations that demonstrate that the integrity of the RPV is given for all design basis accidents, stating the scientific sources.

Question 32: Provide comparisons of crack propagation predictions from the "Grouping Model" with the appropriate experimental data.

Question 33: How does the Grouping Model accounts for interaction between fatigue and embrittlement?

Question 34: Which uncertainties in the input data used to calculating crack propagation are assumed?

Question 35: How does uncertainties in crack depth measurements affect crack growth predictions?

Question 36: Has a sensitivity study on the effect of crack size, stress and reduction in fracture toughness on RPV failure risk be performed?

6.2.3 Material Properties

Due to the continuous neutron bombardment of the RPV there is a progressive embrittlement of the steel. Thus, the nil-ductility transition temperature temperature (RT_{NDT}) moves further and further into higher temperature ranges.

The International Expert Review Board IERB has recommended to add a safety margin of 100 °C to the by the licensee calculated value of the (RT_{NDT}) [05]. Electrabel itself had only suggested a value of 50 °C. However, already 42 °C from this value are ascribed by the determined influences of Hydrogen Flaking and macro-segregation as reported by Electrabel. Thus, only 8 °C remain to cover the radiation effect on the material afflicted with so many defects. About the radiation effect on material with such a density and type of defects no literature data are available. This value therefore cannot be considered as conservative. In addition, Electrabel does not apply the RT_{NDT} shift calculated using the FIS formula, but uses the experimental data from the surveillance program, which is certainly a further reduction of conservatism. Therefore the IERB has demanded a value of 100 °C. However, this requirement does not enter into the final report of the FANC. According to Electrabel RT_{NDT} must be below 132 °C [09]. The value of Electrabel including the proposed 50 °C was 106,9 °C. Thus, the allowable upper limit was not reached. But in case the 100 °C proposed by IERB are taken into account, the value would be 156.9 °C thus over the permissible value of 132 °C. Further operation of the two reactors would then not be permissible.

Question 37: What became out of the demand of the IERB to carry out a sensitivity analysis and why was it not included in the Final Report anymore?

Question 38: Has the proposal of IERB to use 100 °C instead of the by Electrabel additionally proposed 50 °C to cover the possible radiation effects in sensitivity analyses, not implemented because this would immediately lead to an exceeding of the limit value of the RT_{NDT} of 132 °C?

Question 39: If according to Electrabel 25 °C of the 50 °C shift should cover the toughness decrease by existing hydrogen flakes (these are data from non-representative samples) and additional 17 °C covers embrittlement and macro-segregation, where is a safety margin for covering the uncertainty of irradiation effect on hydrogen flakes?

Question 40: Why does the licensee claims to perform a "very conservative" approach, although the used RT_{NDT} values are not calculated using the FIS formula but are replaced by less conservative values from the surveillance program?

6.3 Core Damage Frequency

The core damage frequency CDF is of central importance for the safety assessment of light water reactors, as all serious accidents include a core damage. The CDF is not the same as the probability of a catastrophic accident, there is a certain probability that despite core damage the effects are limited to the plant and do not reach the environment. (see, for example TMI accident). For newer systems (EPR), a CDF of $10^{-5}/y$ to $10^{-6}/y$ is expected, while an uncontrolled meltdown is assumed with $10^{-7}/y$. These values are significantly higher for older plant, since they contain no explicit design against meltdown in contrast to the EPR. More important than the CDF itself is even the mechanism leading to core damage: While a low-pressure core melt is considered to be easier to control and runs relatively slowly (i.e. possibly provides opportunities to counter-measures and disaster preparedness), leads the so-called high-pressure core melt under certain circumstances to a large vessel failure due to the melting. Under high pressure the failing vessel is torn from its anchorage. This would result in an immediate destruction of all safety facilities and safety barriers and thus represents in the safety analyses the most severe impacts of a meltdown. However, there is still a period of several hours between accident start and vessel failure for counter measures and initiation of civil protection measures such as evacuations.

Excluded in usual safety considerations is a serious core damage due to material related vessel failure, the so-called "catastrophic vessel failure". It is similar to the high-pressure core melt: Triggering event is a sudden crack induced by material failure in the vessel which - without any advance warning - leads to extensive destruction of the reactor. As thereby a complete loss of coolant takes place, it results in a rapid meltdown with very high levels of radioactivity release into the environment. For this case there is no sufficient time span for counter-measures and disaster prevention, so that the consequences of this event would even far exceed a high-pressure core melt. In Germany the catastrophic vessel failure is virtually eliminated in reactors by the concept of so-called basic safety. Its probability is assumed to be less than $10^{-9}/y$. [30]

The predominant safety significance of the detected defects in Tihange 2 and Doel 3 lies in the fact that this could possibly be the trigger for such a catastrophic vessel failure. The effects of these defects actually are comparable to a reduction of the wall thickness of the vessel. In face of the enormous potential consequences of a catastrophic vessel failure it must be completely excluded that the defects have significant effect on the probability of a catastrophic vessel failure. Therefore, it is imperative to determine the probability of such a catastrophic vessel failure for the vessels of Tihange 2 and Doel 3 with and without defects by conservative analysis, that is, to answer the question: How does the probability of failure of the vessel has changed by the defects? Here strict standards are to be applied, that is,

uncertainties in the worst possible conditions must be taken into account. Reliable analysis are not yet known, there is only a general statement of the FANC available that the failure of the pressure vessel must be excluded.

Question 41: Which effect have the observed RPV defects on the CDF, at the Doel 3 and Tihange 2 plants. Specify the calculated CDFs before and after the discovery of the defects.

Question 42: Discuss how the calculated change in CDF (delta CDF) leads to the conclusion that plant operation with a degraded RPV does not compromise public safety.

Question 43: Discuss the models that were used to calculate the delta CDF. The discussion does not have to be very detailed and exhaustive but it should provide sufficient information so that the reader can assess the validity of the conclusion regarding plant safety. For example, model description should include at the minimum:

1. The number of operational transients (both past and anticipated) that have been considered.
2. Type of the transients during design basis accidents.
3. Uncertainties in material properties.
4. Uncertainties in crack geometries due to ultrasonic measurement limitations.
5. Magnitudes of stress intensity factors introduced by surface defects.
6. Uncertainties in the location of the maximum stresses.

Question 44: Present a sensitivity study showing the sensitivity of delta CDF to the above listed uncertainties.

Question 45: Show how the mitigating actions taken by the licensee (e.g reduction in the severity of start up and shutdown transients) reduce the delta CDF.

6.4 Manufacturing Documentation

To assess the quality of individual components of the RPV a complete and consistent documentation is mandatory. Only with it, the quality of the component can be evaluated. In-service inspections are important and necessary, but they can never serve solely to evaluate the quality of a component this can only be done in conjunction with the production documentation.

The assessment of the current quality of components depends not only on the continuous testing during operation but also on the following steps during production:

- Tests and other measures of quality assessment carried out with funds according to the state of science and technology.
- The tests and creation of production documentation are accompanied by independent experts.
- These tests are logged.
- The production documentation is archived and is permanently and completely accessible.

6.4.1 Missing Documentation

There are conflicting evidences of FANC on the completeness of the documentation.

In October 2012 it is stated: „*Notably, detailed documentation about the first thermal treatment performed by RDM (which according to the LOFC has been done), an intermediate UT inspection and some RDM specifications are lacking.*“ [02]

Im Januar 2013, the licensee is cited as follows: „*The manufacturing data and documentation proved to be complete, traceable, and in accordance with international codes and standards*“ [04]

In the same document, FANC ascertained: “*Given that the whole documentation currently available was exploited and no additional finding can be derived from that material, the FANC issues no further requirement on this topic.*”

Im May 2013, the topic is not mentioned in the Final Report [14] any more.

Question 46: Explain your different conclusions to the documentation.

Question 47: Which acceptance reports of the individual shells and the entire RPV are available?

6.4.2 Contradictory Documentation

The FANC suspected a confusion of manufacturing documentation of the upper and lower core shell of the RPV of Doel 3. The conference participants do agree that in further investigation of these possible interchanging is meaningless and renounce to any further questions.

The conference participants review this interchange but as further evidence of the inadequate quality of the production documentation.

6.5 Necessary conditions for restarting

In 2013 FANC has linked the restart of the reactors to conditions. These are described in the subchapters. The conference participants conclude that not all the necessary investigations were carried out before restart. It is not understandable that these proves took place prior restart. Again, it must be noted that this is not a conservative approach.

6.5.1 Preparatory Work of the Operator

The operator Electrabel has pre-defined limiting conditions for the continued operation of the reactors [14]:

- *For Doel 3 and Tihange 2, the licensee has reduced the authorized heat-up and cool-down gradients during start-up and shut-down operations. According to the licensee, this will further reduce the thermal and pressure loadings on the reactor pressure vessels during normal operation.*
- *For Doel 3, the licensee implemented a permanent preheating of the safety injection water reservoirs to 30°C.*
- *All operators of the Doel 3 and Tihange 2 reactor units had a refresher training session on the full scope simulator. An extended briefing will be given to all shift personnel about the start-up and changes in the operational parameters and specifications.*

These reductions of loads are conditions for the calculations for the proof of the structural integrity of the RPV.

Question 48: Would an ongoing operation of the reactors have been possible during the entire calculated lifespan even without the above mentioned reductions of loads?

6.5.2 Requirements of FANC

6.5.2.1 A complete reactor-inspection after any significant deviation from the normal operation

Apart from the requirements for the restart of the plant (Requirements 1 - 16) and the operator's preconditions, FANC additionally required that a complete check of the reactor must be made on any sign of a significant deviation from normal operation [14]:

- *As an additional precautionary measure, whenever a severe transient occurs during the future operation of the Tihange 2 and Doel 3 reactor units (such as an effective safety injection in the reactor coolant system during power operation), an additional in-service inspection of the reactor pressure vessel is required to detect a potential evolution of the flaw indications before the reactor unit will be allowed to resume its operation after this transient.*

Based on this requirement it must be assumed that even FANC fears that the reactor pressure vessels cannot adequately withstand pressures, that are to be expected.

Question 49: Explain what you understand as “severe transient“?

6.5.2.2 FANC Requirements 1 – 16

The FANC requirements apply to three different periods of time:

- Measures prior to the restart (to May 2013)
- Measures during on-going reactor operation
- Measures during the next revision and exchange of fuel assemblies

In the “Provisional Report“ of January 2013 [04], FANC made the restart of the reactors dependent on certain requirements. These requirements were listed again in the “Final Report“ of May 2013 [14] and numbered as described below (page 37). Herein ignored were the demands made by the international expert review board (IERB) :

- „continuing a neutron fluence reduction program to minimize further material embrittlement until clarification is achieved on the other issues.“ [04]
- „In view of the potentially large increase in RT_{NDT} that may be revealed by the tests just described, the Board recommends that before restart, a sensitivity study be performed using a RT_{NDT} shift up to 100 °C (instead of 50 °C used in the current calculations) to take into account the uncertain effect of the segregation of chemical impurities and other uncertain effects. It is the Board’s view the successful outcome of such a sensitivity analysis provides assurance of the continued operating safety of these reactors while the necessary experiments are being conducted.“ [04] (For details see page 24)

Further the participants of the conference note,

- that the evidence of the existence of a complete manufacturing documentation has to be a mandatory condition for the approval of the restart. Such a requirement has not been demanded by FANC.

Question 50: Why has a „neutron fluence reduction program“ not been demanded?

Question 51: Why has a „RT_{NDT} shift up to 100 °C“ not been demanded?

Question 52: Why has a complete manufacturing documentation not been demanded?

Requirements prior to the restart

This section covers the Requirements 1, 2, 3, 4, 5, 6, 9, 10, 14, 15, and 16, see appendix „Requirement of FANC for restarting“, page 40. The Final Report [14] only mentions their “successful implementation”. But it does not describe, how the operator’s successful evidence was conducted.

Question 53: Provide details of this “successful implementation”, including your reasons for acceptance.

Requirements during on-going reactor operation

This section covers the requirements 7, 11, 12, and 13, see appendix „Requirement of FANC for restarting“, page 40.

FANC noticed a substantial amount of open questions. From the conference participants’ point of view all these “requirements” should have been clarified before starting operation in Mai 2013. It was therefore untenable to re-connect the plant to the net. The procedure was not in accordance with a conservative approach. Again it must be mentioned, that all information about experimental tests with non-representable probes must be rejected. Because this missing representative they can not achieve reliable results. Therefore they are not able to prove the structural integrity of the RPV.

Question 54: On which date have these requirements been completely fulfilled?

Question 55: Provide details for the fulfilling of the individual requirements. Including your reasons for acceptance.

Requirements during the next revision and exchange of fuel assemblies

This section covers the Requirement 8, see appendix „Requirement of FANC for restarting“, page 40

According to a current research (16.02.2014), the next revisions are planned as follows:

- Doel 3 - 26.04. - 30.05.2014
- Tihange 2 - 31.05. - 11.07.2014

Question 56: Is the successful implementation and publication of the requirement 8 one of the preconditions for a renewed re-start of the two reactors?

7 Appendix

7.1 Questions to FANC

- Question 1: Which assumptions in the reports of Electrabel are based on "best estimate" assumptions? Please list these in detail. _____ 14
- Question 2: How high is the inaccuracy in the determination of the radial component of the defects? _____ 17
- Question 3: How high is the probability that hidden defects are not detected? _____ 17
- Question 4: Why do you consider a calibration of UT on basis of the block VB395/1 as sufficient? _____ 17
- Question 5: How can the claim of production-related origin of the defects be maintained even if during production control no defects have been found, although the technique for detection was available at that time and was used? _____ 18
- Question 6: How can the hydrogen flaking be explained by the H + S concentration of the ingots? _____ 18
- Question 7: What is the background for the note on page 16 (FANC, Final Report) [14] that in the samples with hydrogen flakes the carbon concentration is higher? _____ 18
- Question 8: How can it be explained that only shells of the RPVs of Doel 3 and Tihange 2 are affected? _____ 18
- Question 9: How can it be explained that the defects occur only at a certain depth from the inner surface? _____ 18
- Question 10: How can it be explained that the defects are not equally distributed throughout the volume? _____ 19
- Question 11: According FANC the pressure vessel would have been rejected during acceptance if affected with a defect density found in 2012. How can it be that the discovery of the defects in 2012 does not immediately lead to the same argument and an immediate and permanent closure of the reactors? _____ 19
- Question 12: How can it be that for the demonstration of the structural integrity of the RPV non-representative samples are used, neither comparable with respect to manufacturing nor with respect to specifications (AREVA block)? _____ 20
- Question 13: Why are the nozzle cuts considered as representative samples? Do they contain a comparable defect density? If not, then it is just sample material that

would be assigned to a defect-free region of the RPV, in which case the operational loads and the irradiation history is still missing.	20
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Question 24: It was asked for earthquake loads in chapter 6.2.1.2. Were these loads also considered for plant shutdown?	23
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- Question 32: Provide comparisons of crack propagation predictions from the "Grouping Model" with the appropriate experimental data. _____ 23
- Question 33: How does the Grouping Model accounts for interaction between fatigue and embrittlement? _____ 24
- Question 34: Which uncertainties in the input data used to calculating crack propagation are assumed? _____ 24
- Question 35: How does uncertainties in crack depth measurements affect crack growth predictions? _____ 24
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- Question 39: If according to Electrabel 25 °C of the 50 °C shift should cover the toughness decrease by existing hydrogen flakes (these are data from non-representative samples) and additional 17 °C covers embrittlement and macro-segregation, where is a safety margin for covering the uncertainty of irradiation effect on hydrogen flakes? _____ 25
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- Question 43: Discuss the models that were used to calculate the delta CDF. The discussion does not have to be very detailed and exhaustive but it should provide sufficient information so that the reader can assess the validity of the conclusion regarding plant safety. For example, model description should include at the minimum: _____ 27
- Question 44: Present a sensitivity study showing the sensitivity of delta CDF to the above listed uncertainties. _____ 27

- Question 45: Show how the mitigating actions taken by the licensee (e.g. reduction in the severity of start up and shutdown transients) reduce the delta CDF. _____ 27
- Question 46: Explain your different conclusions to the documentation. _____ 28
- Question 47: Which acceptance reports of the individual shells and the entire RPV are available? _____ 28
- Question 48: Would an ongoing operation of the reactors have been possible during the entire calculated lifespan even without the above mentioned reductions of loads? _____ 30
- Question 49: Explain what you understand as "severe transient"? _____ 31
- Question 50: Why has a „neutron fluence reduction program“ not been demanded? _____ 32
- Question 51: Why has a „RTNDT shift up to 100 °C“ not been demanded? _____ 32
- Question 52: Why has a complete manufacturing documentation not been demanded? _____ 32
- Question 53: Provide details of this "successful implementation", including your reasons for acceptance. _____ 32
- Question 54: On which date have these requirements been completely fulfilled? _____ 32
- Question 55: Provide details for the fulfilling of the individual requirements. Including your reasons for acceptance. _____ 32
- Question 56: Is the successful implementation and publication of the requirement 8 one of the preconditions for a renewed re-start of the two reactors? _____ 32

7.2 Requirement of FANC for restarting

Subsequently, all the requirements and the timing of their provision are listed, that FANC has placed at the further operation of the two reactors [14].

No.	Description	Until
1	CLAD INTERFACE IMPERFECTIONS: The licensee shall re-analyze the EAR acquisition data for Tihange 2 in the depth range from 0 to 15 mm in the zones with hydrogen flakes to confirm whether or not some of these technological cladding defects have to be considered as hydrogen flakes.	before restart
2	NON-INSPECTABLE AREAS: The licensee shall demonstrate that no critical hydrogen flake type defects are expected in the non-inspectable areas.	before restart
3	IDENTIFICATION OF POTENTIALLY UNREPORTED HIGHER TILTED FLAWS: The licensee shall demonstrate that the applied ultrasonic testing procedure allows the detection of the higher tilt defects in the Doel 3/Tihange 2 data (2012 inspections) with a high level of confidence.	before restart
4	INDICATIONS WITH 45°T SHEAR WAVE RESPONSE: The licensee shall present the detailed report of all macrographical examinations including the sample with the 45°T reflections and shall also analyze and report additional samples with 45°T reflectivity.	before restart
5	PARTIALLY HIDDEN INDICATIONS: The licensee shall include a set of defects partially hidden by other defects for macrographic examination, to confirm whether the sizing method continues to function well.	before restart
6	INCLINATION OF FLAWS DETECTED BY ULTRASONIC TESTING: The licensee shall re-analyze the tilts of the defects in the VB-395/1 block with the same method as applied on-site.	before restart
7	FULL QUALIFICATION: As soon as possible after the restart of both reactor units: The licensee shall achieve a full qualification program to demonstrate the suitability of the in-service inspection technique for the present case. The qualification shall give sufficient confidence in the accuracy of the results with respect to the number and features (location, size, orientation...) of the flaw indications. Where appropriate, the process shall be substantiated by appropriate experimental data using representative specimens. The full qualification program shall be	ASAP after Restart

No.	Description	Until
	achieved before the next planned outage for refuelling.	
8	FOLLOW-UP IN-SERVICE INSPECTIONS: After the restart of both reactor units, the licensee shall perform follow-up in-service inspections during the next planned outage for refuelling to ensure that no evolution of the flaw indications has occurred during operation.	During the next planned outage for refuelling
9	<p>ADDITIONAL CHARACTERIZATION OF THE MATERIAL MECHANICAL PROPERTIES: The licensee shall complete the material testing program using samples with macro-segregations containing hydrogen flakes. This experimental program shall include:</p> <ul style="list-style-type: none"> • small-scale specimen tests: <ul style="list-style-type: none"> • local toughness tests at hydrogen flake crack tip, • local tensile tests on ligament material near the flakes; • large-scale (tensile) specimen tests 	before restart
10	RESIDUAL HYDROGEN: The licensee shall perform additional measurements of the current residual hydrogen content in specimens with hydrogen flakes, in order to confirm the results of the limited number of tests achieved so far. For example, the licensee has estimated an upper bound on the amount of residual hydrogen that might still be present in the flaws. The licensee shall demonstrate that the chosen material properties are still valid, even if the upper bound quantity of hydrogen would still be present in critical flaws.	before restart
11	IRRADIATION PROPERTIES: A further experimental program to study the material properties of irradiated specimens containing hydrogen flakes shall be elaborated by the licensee.	ASAP after Restart
12	LOCAL MICROSCALE PROPERTIES: The licensee shall further investigate experimentally the local (micro-scale) material properties of specimens with macro-segregations, ghost lines and hydrogen flakes (for example local chemical composition). Depending on these results, the effect of the composition on the local mechanical properties (i.e. fracture toughness) shall be quantified.	ASAP after Restart
13	THERMAL AGEING: The licensee shall further evaluate the effect of thermal ageing of the zone with macro-segregation.	ASAP after Restart

No.	Description	Until
14	<p>SENSITIVITY STUDY OF HIGHER TILTED FLAWS: The licensee shall evaluate the impact of the possible non-reporting of flaws with higher tilts on the results of the structural integrity assessment (taking into account the results of the actions related to the previous requirement on the detection of the higher tilt defects during in-service-inspections).</p>	before restart
15	<p>LARGE SCALE VALIDATION TESTS : The licensee shall complete the on-going material testing program by testing larger specimens containing hydrogen flakes, with the following 2 objectives:</p> <ul style="list-style-type: none"> • Objective 1: Tensile tests on samples with (inclined) multiple hydrogen flake defects, which shall in particular demonstrate that the material has sufficient ductility and load bearing capacity, and that there is no premature brittle fracture. • Objective 2: An experimental confirmation of the suitability and conservatism of the 3D finite elements analysis. 	before restart
16	<p>LOAD TESTS: In addition to the actions proposed by the licensee and the additional requirements specified by the FANC in the previous sections, the licensee shall, as a prerequisite to the restart of both reactor units, perform a load test of both reactor pressure vessels. The objective of the load test is not to validate the analytical demonstration on the reactor pressure vessel itself but to demonstrate that no unexpected condition is present in the reactor pressure vessels. The methodology and associated tests (acoustic emission and ultrasonic testing...) will be defined by the licensee and submitted to the nuclear safety authority for approval. The acceptance criterion will be that no crack initiation and no crack propagation are recorded under the pressure loading.</p>	before restart

Table 1 - Requirements of FANC for restarting of Doel 3 and Tihange 2

7.3 Source Directory

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- [02] Flaw indications in the reactor pressure vessels of Doel 3 & Tihange 2, FANC, October 2012
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- [04] Report on independent analysis and advice regarding the safety case - Doel 3 Reactor Pressure Vessel Assessment, International Expert Review Board, May 2013
- [05] Doel 3 - Tihange 2 RPV issue - Final Report, International Expert Review Board, January 2013
- [06] Report of the National Scientific Expert Group on the RPVD3T2, National Scientific Expert Group, January 2013
- [07] Doel 3 / Tihange 2 – Justification of the Reactor Pressure Vessel (RPV) shell, AIB-Vinçotte, January 2013
- [08] Safety Evaluation Report – Flaw indication in the RPV of Doel 3 and Tihang 2, Bel V, January 2013
- [09] Safety Case Report: Doel 3 - Reactor Pressure Vessel Assessment, Electrabel, December 2012
- [10] Report on independent analysis and advice regarding the safety case - Doel 3 Reactor Pressure Vessel Assessment, Electrabel, December 2012
- [11] Safety Case Report: Tihange 2 - Reactor Pressure Vessel Assessment, Electrabel, December 2012
- [12] Report on independent analysis and advice regarding the safety case - Tihange 2 Reactor Pressure Vessel Assessment, Electrabel, December 2012
- [14] Doel 3 and Tihange 2 reactor pressure vessels: Final evaluation report, FANC, May 2013
- [15] Report of the National Scientific Expert Group on the RPV Doel 3, National Scientific Expert Group, May 2013
- [16] Report of the National Scientific Expert Group on the RPV Tihange 2, National Scientific Expert Group, April 2013
- [17] Doel 3 – ISI 2012 – Justification of the Reactor Pressure Vessel (RPV) shell, AIB-Vinçotte, May 2013

- [18] Tihange 2 – ISI 2012 – Justification of the Reactor Pressure Vessel (RPV) shell, AIB-Vinçotte, May 2013
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- [21] Safety case report - Addendum: Tihange 2 - Reactor Pressure Vessel Assessment, Electrabel, April 2013
- [22] Report on independent analysis and advice regarding the safety case addendum - Doel 3 Reactor Pressure Vessel Assessment, Electrabel, April 2013
- [23] Report on independent analysis and advice regarding the safety case addendum - Tihange 2 Reactor Pressure Vessel Assessment, Electrabel, April 2013
- [28] FANC experts give positive opinion on restart Doel 3 & Tihange 2 reactor units , FANC, May 2013
- [29] In 1979 al scheurtjes in Doel 3, De Morgen, August 2012
- [30] Vorgespannte Guß-Druckbehälter (VGD) als berstsichere Druckbehälter für innovative Anwendungen in der Kerntechnik, W. Fröhling et al., Schriften des Forschungszentrums Jülich, Reihe Energietechnik Bd. 14, 2000
- [30] Untersuchungen zum Nichtleistungsbetrieb von 900 MW und 1300 MW StandardDWR, Electricité de France, 1990

7.4 Index

ASME 11	paleoseismology 22
Best Estimate 13	radiation surveillance program 13
BPVC 11	RDV 4
design basis accidents 21	surveillance program 25
earthquake 22	transients 21
FANC 4	underclad cracking 16
IERB 5, 7, 11, 24	