Containment Isolation system analysis and its contribution to level 2 PSA results in Doel 3 unit

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Abstract: Containment structures and their isolation systems are designed to reduce the radiological consequences and risk to the public from various postulated normal operating and accident conditions. The design should be such as to ensure that these isolation systems can be reliably and independently closed when this is necessary to isolate the containment. The containment isolation system(s) availability is one of the 14 attributes which characterizes the Plant Damage State (PDS) at the onset of a severe accident in the Belgian internal events level 2 PSA model. The PDS scenario and its frequency are computed based on the transition tree of the interface PSA level 1 – level 2 study and some of the attributes outcomes are assigned by the analyst.

The current paper aims to share practices and experiences related to the methodology to derive the containment isolation (CI) systems availability, the CI attribute outcomes, and finally its contribution in the level 2 PSA risk metrics for Doel 3 unit (PWR, 3 loops, 2 safety levels systems) internal events level 2 PSA study.

Keywords: PSA, Containment Isolation, Unavailability, Plant Damage State, Release Frequencies

1. INTRODUCTION

The containment isolation failure results in the breach of the containment and the loss of the final barrier against the radioactive releases. Containment structures and their isolation systems are designed to prevent or limit the escape of fission products that may result from postulated normal operating and accident conditions, thus to reduce the radiological consequences and risk to the public. The design should be such as to ensure that these isolation systems (i.e. piping, valves and actuators) can be reliably and independently closed when this is necessary to isolate the containment.

The failure of containment isolation systems can be either due to a hardware failure (e.g. isolation valve fails to close, failed logic actuation) or due to latent conditions (e.g. valve left open following test activities). In case of a non-isolable containment penetration, makes the containment leakage rate exceed the allowable limit during the normal operating and accident conditions, and consequently harms the environment and public.

The present work does neither differentiate the sizes of the break, nor applies any screening criterion of the containment penetration lines, but it aims at identifying the unavailability (Q) of the containment isolation, and its consideration and contribution into the level 2 PSA study results of Doel 3 unit (PWR, 3 loops). Thus, there is no assessment performed to identify the impairment probability versus the leak area, as it was done in [1].

The Containment Isolation (#CI) is one of the 14 attributes that characterizes the plant damage state (PDS), which is given as input to the level 2 PSA study. The Containment Isolation attribute has 4 different outcomes, and each one of them is characterized by a value that represents its unavailability.

The outcomes are the following:

- containment isolated (CI);
- containment not isolated due to mechanical failure of the isolation valves (FIV);

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- containment not isolated due to isolation signals failure (FSIG);
- containment not isolated due to left open personnel air lock (CO).

As it can be observed, there is one outcome related to success and three related to failure, thus their probability of success (availability) and probability of failure (unavailability) equals to 1.

$$CI + FIV + FSIG + CO = 1 \quad (1)$$

The assessment of the unavailability is considered for all plant operating states (POS), from POS A (at power conditions) until POS F (low power shutdown state, plant before refueling conditions). Therefore, 6 distinct plant operating states are to be considered. However, the air lock state is different between the different POSs, and in this regard, two plant operating configurations (with/without closed air lock) are considered in the study.

During POSs A, B and C, the personnel air lock is closed, therefore not considered as being a cause for containment isolation function failure. For the other POSs (i.e. D, E and F), it is considered a fail to close probability equal to 5.00E-06/demand, from contributions such as, malfunction of the powered systems, mechanical failure of the door, and human failure to close the door. The value is one order of magnitude lower than the one estimated in [1].

The Plant Damage State (PDS) frequencies are obtained by making use of an event tree, also called interface or bridge event tree, which then are introduced in the level 2 PSA Accident Progression Event Tree (APET), as initiators. The containment isolation unavailability (Q) is computed by employing fault trees and with the aid of PSA software, RiskSpectrum®.

Containment Isolation is chosen because it is a PDS attribute with direct impact on the level 2 PSA results. The containment isolation systems impairment is one of the Containment Failure (CF) modes, along with the containment bypass, direct containment heating, ex-vessel steam explosion, pressure rise at vessel failure, long term static overpressure and basemat melt-through.

2. CONTAINMENT ISOLATION SYSTEM ANALYSIS (Q)

The containment isolation system analysis is meant to quantify the unavailability (Q) of all containment penetration lines that perform the isolation function during normal operating and accident conditions. In Doel 3 unit there are 43 containment penetration lines, which belong to 13 different systems, such as, safety injection (SI), main feedwater (MFW) or main steam system (MS).

The containment penetration lines contain 4 different types of isolation valves, namely: pneumatic (air operated) valves, motor operated valves, check valves and manual valves, each one of those having specific failure modes function of their initial state. Their initial state is either open, and then they are potentially assumed to fail to close; or closed and then it's assumed that they may have spurious opening. For the manual isolation valves where their initial state is closed, no failure mode is considered. For the motor operated valves when the power supply is lost, and their fail-safe mode is closed. Besides the failure mode related to the isolation valves initial position, were considered also the other unavailability causes, such as support systems (power supply, air supply), common cause failures (CCFs), instrumentation and control (I&C) logic actuations, pre-accidental and post-accidental human errors. Regarding the support systems, in most cases their unavailability leaves the isolation valves in closed fail-safe position, which does not endanger the containment isolation function. But in case of recovery of the failed isolation signal then the support systems are needed for the remote actuation. The support systems are considered also in case of a spurious opening (i.e. fail to remain closed), when the closure back action is performed with their help.

The CCFs were considered in case the penetration line had at least 2 similar type of valves (i.e. both motor valves), and they had the same initial position. For the power supply, except for 2 isolation valves, all the rest of the motor operated valves had position closed as failsafe position. Reliability data of the CCF parameters comes from [2].

Regarding the I&C logic actuations for each isolation valve concerned, it was considered the sensors configuration (i.e. series, parallel), their actuation logic (i.e. 2 out of 3) that induces the closure of the valve, signal redundancy, sensor failure and their power supply (115 V). Most of the isolation valves closure is induced by a main signal, and then it is backed up by a redundant signal, which is called SUB – related also to second level safety systems. The latter signal is conservatively not considered for the redundancy.

For the pre-accidental human errors, for each system that has a penetration line and belongs to the containment isolation system, the associated testing and maintenance procedures were verified to be exempt of dormant failures, such as left open isolation valve, wrong calibration or alignment. Indeed, such potential situations from the Belgian nuclear power plants were revealed by the OECD study [3]. In case that there was the same type of isolation valves, which underwent testing/maintenance activities performed by the same crew, with the same procedures, then it was assumed also a CCF for these situations. In case the isolation valve had an alarm, or any cue associated to, or their position indicated in the main control room, then recovery factors were considered for decreasing the base pre-accidental human error probability. There were also few cases, where no testing/maintenance activities procedures were associated, and in these cases, it was conservatively assumed a residual human error, with a probability equal to 1.00E-05/demand. The pre-accidental human reliability assessment methodology is based on [4].

For all these containment isolation valves, whether their position recovery was possible either by local operator action or from the main control room, it was assumed a post-accidental human error. Conservatively, all local operator recovery actions were assumed as not feasible, thus their state as basic events in the fault trees was set to TRUE. For those recovery actions possible from the main control room, the human error probability is quantified based on SPAR-H methodology, [5]. The performance shaping factors levels are assumed all nominal, and thus the human error probability is equal to 1.10E-02 / demand. Based on all these assumptions is computed the unavailability for each containment penetration line that are then summed up to obtain the total Q (/demand) for all 43 penetrations. Following the fault trees employed and the associated assumptions, the containment isolation unavailability (Q) is computed, which is equal to 3,90E-03/demand with the following contributions:

- containment not isolated due to mechanical failure of the isolation valves (FIV), Q = 1.24E-03 /demand
- containment not isolated due to isolation signals failure (FSIG), Q = 2.66E-03/demand

As it can be observed, the bigger contribution to the containment unavailability (Q) is due to the isolation signal failure, related to the failure of pressure transmitters (55%) and the CCF of pressure sensors (10%) and CCF of isolation valves (15%). Most of the isolation valves from the top contributors were those where the back-up signal was not considered, and their signal failure recovery was possible only by local operator action, which was conservatively assumed not feasible. Indeed, for the containment isolation valves which are normally open and should close following the signal actuation, their signal failure and not feasible recovery action leads to containment isolation function impairment. Thus, there is a master fault tree, which models the 13 systems and associated penetration lines for reflecting the two outcomes – FIV and FSIG. The contribution of the FIV – containment not isolated due to mechanical failure of the isolation valves was obtained by setting to FALSE all basic events related to signal failure (FSIG).

From equation 1, the probability of success (availability) of the CI outcome for the different plant operating states yields

$$CI_{POS\ A,\ B,\ C} = 1 - FIV - FSIG = 9.96E\text{-}01 \ / \ demand \qquad (2)$$

$$CI_{POS\ D,\ E,\ F} = 1 - FIV - FSIG - CO = 9.96E\text{-}01 \text{ / demand} \quad (3)$$

Given the low probability of fail to close for the personnel air lock (5.00E-06/demand), the availability values for the containment isolated outcome for all the POSs the 2 plant configurations are almost the same. The contribution of the personnel air lock in the total containment isolation unavailability is comparable with the one from [1].

The total containment isolation unavailability found for the two outcomes, FIV and FSIG, i.e. 3,90E-03/ demand corresponds to the estimate made in [1] for a large leakage event (e.g. open containment isolation valves), which is comprised in the range of 1.00E-03 to 1.00E-02. The latter study is considered by [3], to have very conservative assumptions. Also, the estimated value from Doel 3-unit study corresponds to the range which was considered by WASH 1400 study [6], where it was assigned a containment failure probability of 2.00E-03 due to inadequate isolation of the containment openings and penetrations.

3. CONTAINMENT ISOLATION ATTRIBUTE - INTEGRATION IN THE TRANSITION TREE OF THE INTERFACE PSA

The state of the plant at core damage is the key input for level 2 PSA. Each minimal cut set (MCS) of the level 1 accident scenarios leading to core damage contains specific information regarding the status of the power plant at the onset of core damage. However, the results coming from level 1 PSA are not directly usable by level 2 PSA, and additional information is necessary for modelling the progression of a severe accident. For that purpose, Plant Damage States (PDS), representing sequences with expected severe accident progression are the direct input to be used for the Accident Progression Event Tree (APET) of the level 2 PSA and represent the output of the interface PSA level 1/level 2 study. The objective of the interface PSA is to calculate the occurrence frequency of each PDS based on the level 1 PSA scenarios, and some additional information, such as, the state of the containment isolation function.

3.1. Plant Damage State (PDS) Attributes Outcome

The attributes outcomes concern the initiator, state of the safety systems and plant configuration at the onset of core damage. There are in total 59 different outcomes for 14 PDS attributes. The criteria for the definition of the plant damage states (PDS) are the similarities of the failure states regarding the progress of the accident in the reactor coolant system, functionality of the active containment systems and response of the containment structure to the potential loads.

Each PDS is characterized by a set of 14 attributes, each one of them with different possible outcomes, so that each level 1 PSA accident sequence can fit into one single outcome for each PDS attribute. The scenarios of a same family are grouped based on their a priori similar behavior during the progression of severe accidents and their similar containment response. The interface process provides means of reducing the detailed information of the level 1 PSA minimal cut sets into boundary conditions for the severe Accident Progression Event Tree (APET) analyses, which leads further to the quantification of the containment performance. The interface PSA is performed based on a transition/bridge tree which will be linked to the individual level 1 core damage sequences and which is only used for the level 1 / level 2 interface. In this way, each level 1 sequence is extended to provide all information necessary for level 2 PSA. Some of the attributes cannot be assessed with the transition tree (only 9 out of 14 attributes) and a specific analysis had to be made. The 14 attributes are also the first 14 questions of the CP-APET. The attributes and their definitions are shown in Table 1.

Table 1: Plant Damage State Attributes

PDS Attribute	Definition	Nb. of PDS Outcomes
#POS	Plant Operating State	6

#INIT	Initiating Event	12
#AC1	Status of AC Power first level	2
#AC2	Status of AC Power second level	2
#PRCS	Status of Reactor Coolant System (RCS) Pressure at Core Damage	3
#PPORV	Status of Pressurizer Pilot Operated Relief Valves	3
#SG	Status of Pressurizer Pilot Operated Relief Valves	3
#HPSI	Status of High Pressure Safety Injection	5
#LPSI	Status of Low Pressure Safety Injection	5
#2SI	Status of Second Level Safety Injection	3
#SPRAY	Status of Containment Sprays	5
#RWST	Status of Reactor Water Storage Content (RWST) content	3
#CI	Status of Containment Isolation	4
#FAN	Status of Containment Fan Coolers	3

The allowed outcomes of the attributes refer to possible situations foreseen during the postulated accidental conditions for the considered plant configurations and states of the safety systems.

3.2. Interface PSA methodology

The Interface PSA defined 14 attributes for characterizing the PDS. 9 out of 14 are function events/headings of the Transition Event Tree (see Table 2), 4 are assigned by analyst (e.g. POS, RCS pressure, RWST status, level 2 PSA corresponding IE), and one is computed in the dedicated study described in the present paper (i.e. the Containment Isolation). The headings considered by the Transition Tree are adapted accordingly from the top gates of the function events used in level 1 PSA model.

Table 2: Transition Tree Headings

Heading	Definition
AC1	First level protection of Stand-by Diesel Generators
AC2	Second level protection of Stand-by Diesel Generators
FAN	Containment Fan Coolers
HPSI_I	High Pressure Safety Injection - Mode Injection
LPSI_I	Low Pressure Safety Injection – Mode Injection
2SI	Second level Protection Primary Safety Injection
SP_I	Containment Spray System – Mode Injection
HPSI_R	High Pressure Safety Injection - Mode Recirculation
LPSI_R	Low Pressure Safety Injection – Mode Recirculation
SP_R	Containment Spray System – Mode Recirculation
OP_PORV	Open Pressurizer Pilot Operated Relief Valves
CL_PORV	Close Pressurizer Pilot Operated Relief Valves
SG	Secondary Side Water Supply

The Transition Event Tree represents all the logical-possible outcomes of the different attributes defined for the plant state at the onset of core damage.

The CDF scenarios which are passed to the transition event tree represent 99,66% of the total plant CDF, and their CDF is higher or equal to 1.00E-09/r.y. In case there are sequences with the same IE, POS, RCS pressure and RWST content outcomes, then they are grouped together (i.e. their CDF summed up) and further given to the transition tree.

The transition event tree was built based on the assumptions described above, which considers 13 headings (or function events), and it resulted in 1541 logical-possible sequences. These latter are processed by RiskSpectrum, and only those with frequencies higher than 1.00E-12/r.y. are passed to the transition tree matrix.

The Transition Tree Matrix reflects all the possible combinations of the different attributes outcomes given in the Transition Event Tree. Because the attributes outcomes are different for each POS considered, then also the transition tree matrix is different and reflects accordingly the POS concerned, thus there is a matrix for each POS analyzed. For obtaining the final PDS sequence characterized by the 14 attributes, all PDSs that had the same attributes outcomes, but different values are grouped together, and their frequencies are summed up in one final PDS value. For Doel 3 unit, the interface PSA study led to the identification of 1052 PDS scenarios, which, all together summed up, had a frequency value equal to that of the CDF considered as input to the transition event tree.

Table 3 shows all (23) plant damage state scenarios, which have at least 1% contribution to the internal events CDF, and cumulated have almost 85%. The obtained results are in line with the level 1 PSA results, in terms of top contributors to CDF.

Table 3: Top Contributing Plant Damage States Scenarios

POS	INIT	AC1	AC2	PRCS	PPORV	SG	HPSI	LPSI	2SI	SPRAY	RWST	CI	FAN	% CDF
A	TRANS	AC1	AC2	H	APPORV	SG	HPSI	LPSI	2SI	SPRAY	RWST	CI	FAN	13,21%
A	SLOCA	AC1	AC2	L	APPORV	SG	HPSI	LPSI	2SI	SPRAY	RWST	CI	FAN	9,85%
A	SLOCA	AC1	AC2	M	FPPORV	SG	HPSI	LPSI	F2SI	SPRAY	CNT	CI	FAN	7,92%
A	VSEQ	AC1	AC2	H	APPORV	SG	HPSI	LPSI	2SI	SPRAY	RWST	CI	FAN	5,60%
A	TRANS	AC1	AC2	H	APPORV	SG	FHPSI	FLPSI	2SI	FSPRAY	RWST	CI	FFAN	5,47%
E	LOOP	AC1	AC2	L	OPPORV	FSG	HPSI	FLPSI	F2SI	FSPRAY	RWST	CI	FAN	4,82%
E	LOOP	AC1	AC2	L	OPPORV	FSG	HPSI	FLPSI	2SI	FSPRAY	RWST	CI	FAN	4,12%
A	ATWS	AC1	AC2	H	APPORV	SG	HPSI	LPSI	2SI	SPRAY	RWST	CI	FAN	3,58%
A	SLOCA	AC1	AC2	L	APPORV	SG	FHPSI	FLPSI	2SI	SPRAY	RWST	CI	FAN	3,58%
A	SLOCA	AC1	AC2	L	APPORV	SG	HPSI_I	LPSI_I	2SI	SPRAY_I	CNT	CI	FAN	3,34%
E	LOOP	AC1	AC2	L	OPPORV	FSG	HPSI	FLPSI	F2SI	FSPRAY	RWST	CI	FAN	2,55%
A	SLOCA	AC1	AC2	L	APPORV	SG	FHPSI	FLPSI	2SI	FSPRAY	RWST	CI	FFAN	2,41%
E	SLOCA	AC1	AC2	L	OPPORV	FSG	HPSI	LPSI	2SI	FSPRAY	RWST	CI	FAN	2,31%
D	TRANS	AC1	AC2	M	APPORV	SG	HPSI	LPSI	2SI	FSPRAY	RWST	CI	FAN	2,31%
D	LOOPST	AC1	AC2	M	FPPORV	SG	HPSI	LPSI	F2SI	FSPRAY	RWST	CI	FAN	2,02%
E	TRANS	AC1	AC2	L	OPPORV	FSG	HPSI	LPSI	2SI	FSPRAY	RWST	CI	FAN	1,98%
A	LOOPLT	AC1	AC2	H	FPPORV	SG	HPSI	LPSI	F2SI	SPRAY	RWST	CI	FAN	1,81%
A	SLOCA	AC1	AC2	L	APPORV	SG	HPSI_R	LPSI_R	2SI	SPRAY_R	RWST	CI	FAN	1,72%
A	SLBIN	AC1	AC2	H	APPORV	SG	FHPSI	FLPSI	2SI	FSPRAY	RWST	CI	FFAN	1,43%
A	SLBOUT	AC1	AC2	H	APPORV	SG	HPSI	LPSI	2SI	SPRAY	RWST	CI	FAN	1,37%
A	MLOCA	AC1	AC2	L	APPORV	SG	FHPSI	FLPSI	2SI	SPRAY	RWST	CI	FAN	1,28%
D	LOOPLT	AC1	AC2	M	FPPORV	SG	HPSI	LPSI	F2SI	FSPRAY	RWST	CI	FAN	1,07%
A	MLOCA	AC1	AC2	L	APPORV	SG	HPSI	LPSI	2SI	SPRAY	CNT	CI	FAN	1,03%

4. EVALUATION OF CONTAINMENT FAILURE DUE TO ISOLATION DEFECT IN LEVEL 2 PSA

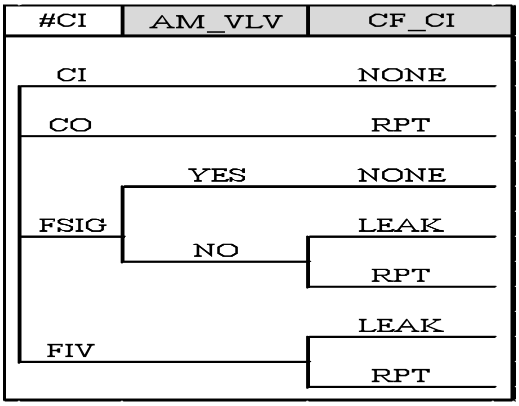
The PDS attribute #CI is taken from the level 1 / level 2 interface study as the input for the event tree evaluating the Containment Failure (CF) due to isolation defect. A simplified representation of the related event tree is given in Figure 1. The quantification of the containment failure due to isolation defect can be summarized as follows:

- In case of isolated containment (i.e. the outcome of #CI being CI), there is no occurrence of CF due to isolation defect.
- In case of opened containment (i.e. the outcome of #CI being CO), the containment confinement is compromised, and the failure is categorized as “rupture” (noted as RPT).

- In case of isolation signals failure (i.e. the outcome of #CI being FSIG), human actions can be taken according to the Severe Accident Management Guidance (SAMG) to isolate the related valve(s). If the human action is successful (i.e. the outcome of AM_VLV being YES), there is no CF due to isolation defect; otherwise, the containment confinement is compromised, and the failure may correspond to a "rupture" or a "leak" (noted as LEAK), depending on the size of the non-isolated penetration line.
- In case of isolation valve mechanical failure (i.e. the outcome of #CI being FIV), the containment confinement is compromised, and the failure may correspond to a "rupture" or a "leak", depending on the size of the non-isolated penetration line.

The threshold between a "rupture" (RPT) and a "leak" of the containment corresponds to the containment opening size above which the containment cannot be pressurized during an accident. For Doel 3, the probabilities of RPT and LEAK in case of CF due to isolation defect are assessed to be approximatively 0.5 and 0.5 respectively.

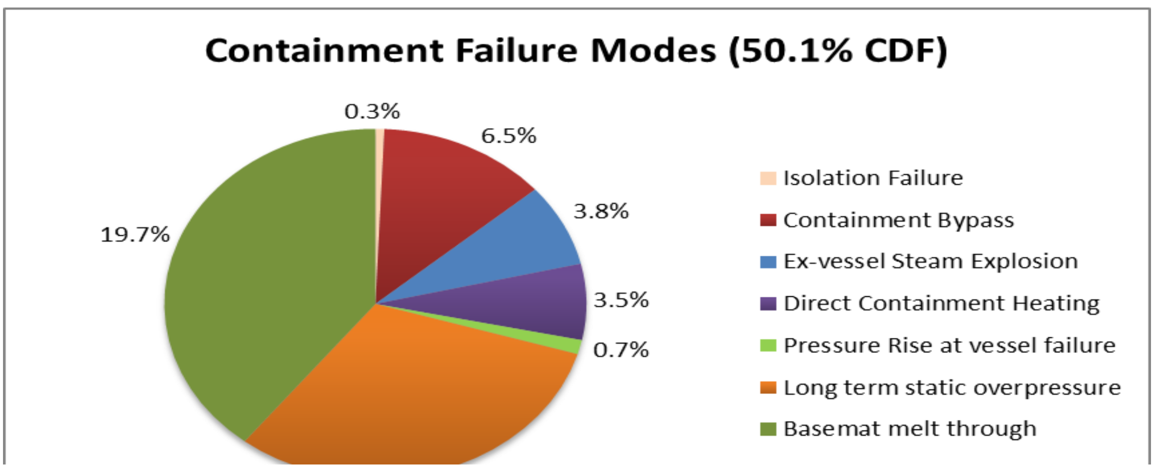
Figure 1: Simplified event tree for containment failure due to isolation defect



5. CONTAINMENT ISOLATION CONTRIBUTION TO LEVEL 2 PSA RESULTS

The main level 2 PSA results are the CF frequency and the Release Category (RC) frequencies. Note that values in percentage provided in Figure 2 and Figure 3 are relative to the internal events CDF. The main CF modes are shown in Figure 2, the CF frequency equals to 50.1% of the internal events CDF. It is observed that the frequency of containment isolation failure (i.e. 0.3% of the CDF) is relatively low comparing to the other containment failure modes, see Figure 2. If in the containment isolation systems (function) unavailability, the contribution of the outcomes with the failed state (i.e. FIV, FSIG, CO), is approximatively 0,4%, then in the level 2 PSA related results its contribution changes to 0,3%, due to operator recovery actions foreseen in the SAMGs. If multiple CF modes occur in one given CDF sequence, the first CF mode (in the chronological order) is assigned as characteristic of the sequence. For instance, in one CDF sequence, the containment could be non-isolated and the basemat is melt-through at the long term, for such situation, the sequence is categorized as "isolation failure".

Figure 2: The major containment failure modes



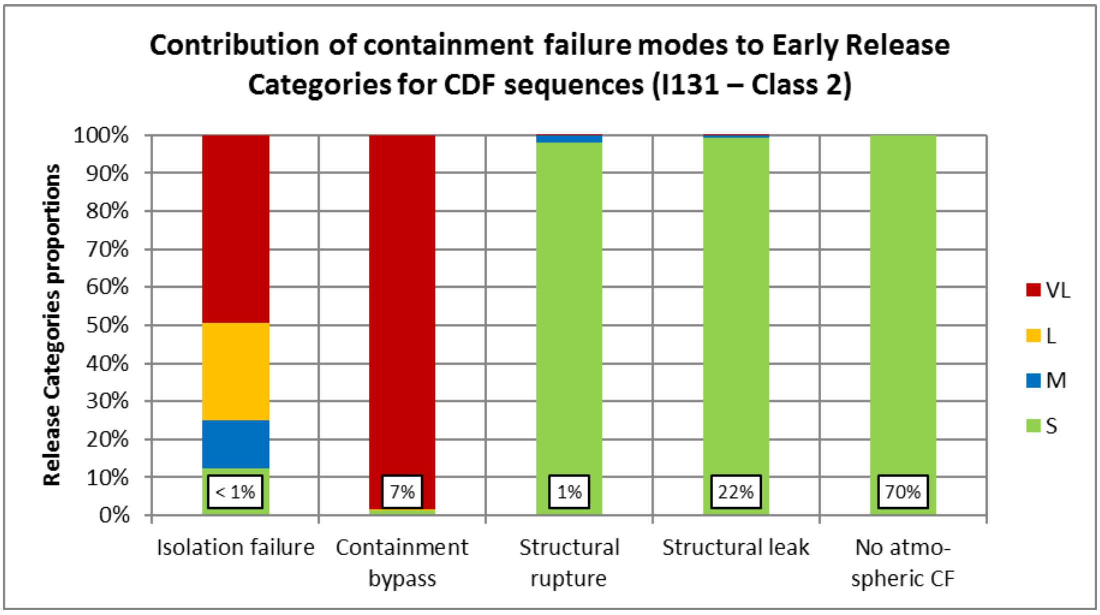
Concerning release categories (RC) frequencies, it needs to be clarified that in the Belgian level 2 PSA there are two distinct time phases and four RCs defined for the releases. Regarding the temporal aspect, the Early phase corresponds to the period between the start of the core damage and the moment of vessel failure; and the Late phase corresponds to the period after the vessel failure. Thus, the time phases are phenomenological related.

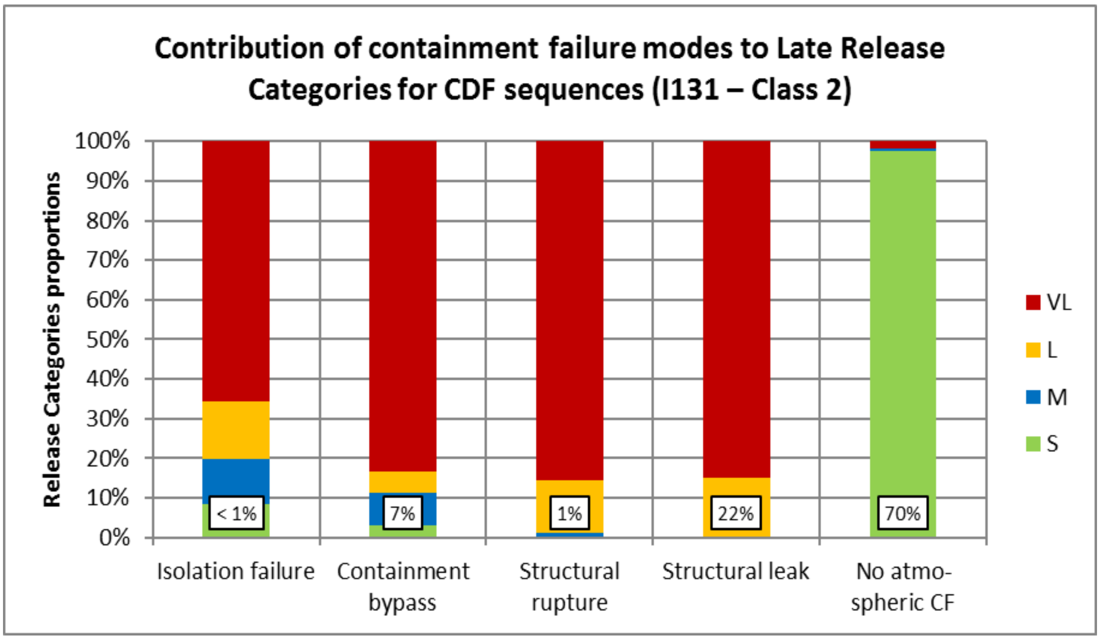
Regarding the Release Categories (RCs), the definitions are the following:

- Small (S): less than 0.01% of the initial core inventory;
- Medium (M): between 0.01% and 0.1% of the initial core inventory;
- Large (L): between 0.1% and 1% of the initial core inventory;
- Very Large (VL): above 1% of the initial core inventory.

I-131 of the NUREG class 2 [7] is taken in this paper as example of the releases for the discussion, given the fact that it is the second most volatile class (thus, the second radioactively consequential) after the noble gases of the NUREG class 1 [7]. The contributions of atmospheric CF modes to the Early and Late RCs are provided in Figure 3. Remark that "ex-vessel steam explosion", "direct containment heating", "pressure rise at vessel failure" and "long term static overpressure" in Figure 2 are grouped into "structural rupture" and "structural leak" in Figure 3 depending on the quantified containment damage extent (i.e. rupture or leak); whereas, "no atmospheric CF" in Figure 3 includes "basemat melt-through" from Figure 2, and the CDF sequences without CF.

Figure 3: Contributions of atmospheric containment failure modes to the Early and Late RCs





Thus, it can be observed from Figure 3 that despite its limited frequency (i.e. 0.3%), containment isolation failure leads to significant proportions of Very Large Early and Late releases. Comparing to the other atmospheric CF modes, the proportion of Very Large Early releases in case of isolation failure is the second most significant (after the one in case of containment bypass). However, for the Late phase the CI failure it's not anymore, a major contributor to the Very large releases.

6. CONCLUSIONS

The results of the study dedicated to Containment Isolation unavailability or impairment probability proved to be within the same range of estimates from similar studies [1] and [3], or assumptions considered in [6], being the equivalent of large leakage events (e.g. open containment isolation valves), which is comprised in the range of 1.00E-03 to 1.00E-02.

The containment isolation systems impairment is one of the Containment Failure (CF) modes, along with the containment bypass, direct containment heating, ex-vessel steam explosion, pressure rise at vessel failure, long term static overpressure and basemat melt-through. This study shows that the frequency of containment isolation failure (i.e. 0.3% of the CDF) is relatively low comparing to the other containment failure modes. If in the containment isolation systems (function) unavailability, the contribution of the outcomes with the failed state (i.e. FIV, FSIG, CO), is approximatively 0,4%, then in the level 2 PSA related results its contribution changes to 0,3%, due to operator recovery actions foreseen in the SAMGs. But, however, despite its limited frequency, this containment failure mode leads to significant proportions of Very Large (VL) Early and Late releases, but it should be kept in mind that this particular failure mode is very unlikely (less than 1%). Specifically, for the early phase, if comparing to the other atmospheric containment failure modes, the proportion of VL Early releases in case of isolation failure is the second most significant, after the one from containment bypass failure mode.

Thus, such insight was possible only after employing the systematic and elaborated studies (i.e. Containment Isolation unavailability, Interface PSA, level 2 PSA) for identification of the plant safety issues during the postulated accidental conditions related to the internal initiating events.

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