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Analysis of the effect of water ponds on HTR confinement behavior under accident conditions

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ABSTRACT

The HTR/VHTR is one of the six system concept chosen within the Generation IV Forum (GIF). A great deal of research is presently being done worldwide on innovative features of this system among which safety is of major importance. One specific aspect which is deserving attention is the potential use of a confinement instead of a containment. To do so, it should be demonstrated that the confinement approach would be capable of reducing early and late offsite doses.

This paper presents an analysis of the performance of postulated HTR/VHTR confinements. Two main configurations have been modeled, which major difference is the presence of pools in the vent pathway to the environment (wet confinement). These pools would provide a passive closure of the confinement once the depressurization is completed. However, it could change strongly the thermal-hydraulics and decontamination capability of the confinement. To illustrate the effect of water pools on accident scenarios and of the pool design on the confinement response, a Very Large Break accident has been simulated with the ASTEC v1.3 code. Results, given in terms of the fraction of radioactive material that would reach the environment, show that water pools strongly change the thermal-hydraulic evolution within the building. Moreover, water pools are efficient aerosol traps which scrubbing efficiency depends on their configuration (i.e., vent cross section and pool submergence). A correlation has been obtained for the decontamination factor (DF) in terms the pool geometrical features. Finally, by assuming moderate filter efficiency, the addition of filters downstream the water ponds would result in total source term attenuation ten times higher than in the case of a dry confinement.

1. Introduction

High Temperature Reactors (HTRs) date back to the 50's last century (Daniels, 1956), when helium was used as a coolant of a 5 MW experimental reactor. Nowadays, evolution of those designs has resulted in one of the six system concepts chosen within the Generation IV International Forum (GIF), the so called Very High Temperature Reactors (VHTRs) (Bouchard, 2009). The HTR/VHTR main feature is the high temperature of the coolant at the reactor exit, which would enable these designs to cope with a broader energy demand than just power production, i.e., sea water desalination, co-generation, hydrogen production, etc. This potential for energy products diversity is the main reason supporting this nuclear technology as one of the three pillars of the European Sustainable Nuclear Energy Technology Platform (SNETP) (EC-DGR, 2007).

Much of innovative nature of VHTRs is related to the high temperature to be achieved at the reactor outlet (around 1000 °C). This high temperature entails technological challenges in many different fields, Brayton power cycle layout, fuel behavior, etc. (Methani, 2006). Even though many of these have been and are being addressed by international projects (i.e., RAPHAEL – Hittner et al., 2006 – and ARCHER – Groot et al., 2010) and R&D networks (i.e., HTR-TN – Hittner et al., 2007) all over the world, they did not begin from scratch. There is a sound background of previous research that supported the historical HTR development. Much of it has been compiled by international bodies, like IAEA, in extensive reports including a substantial number of references (IAEA, 2001).

Fig. 1 provides a sort of historical snapshot of HTR technology in terms of thermal power and size. As highlighted by the two different colors used, the two main development trends can be grouped according to their fuel configuration: prismatic fuel (blue) and pebbles (red). The prismatic technology was developed in USA and its prototype (Peach Bottom, 40 MWe) led to a larger

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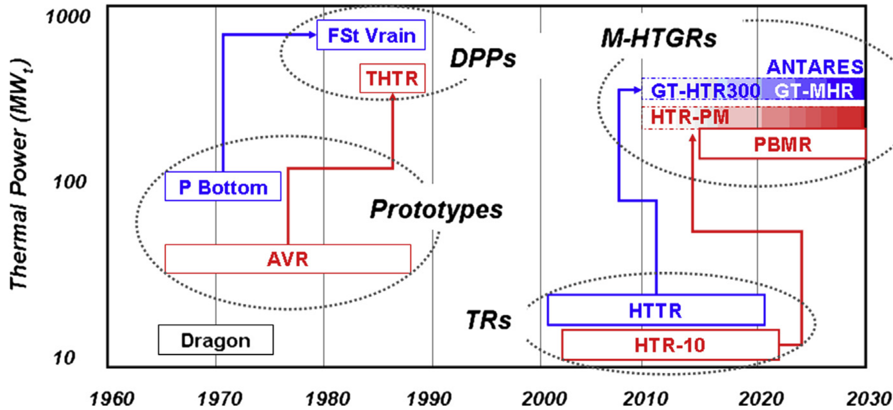

Fig. 1. Historical development of the HTR technology.

demonstration plant (Fort St. Vrain, 330 MWe). The pebble one was developed by Germany and, unlike the prismatic one, its prototype (AVR, 15 MWe) worked for more than 2 decades and drove to the construction of the THTR (300 MWe), which hardly operated for 5 years. After no activity in any of these two development lines during a whole decade, both emerged in the early 2000 in Asian countries, like Japan (HTTR) and China (HTR-10), again as low-power prototypes from which to build up Modular High Temperature Gas-cooled Reactors (M-HTGRs): GT-HTR300 (Japan) and HTR-PM (China). In addition, some other countries have their own developments, like ANTARES (France) or PBMR (South Africa); the latter was abandoned in the latest year of the first decade of this century due to the economic crisis.

The significant innovation embodied in any of these two HTR/VHTR technologies affects also their safety. Heavily relying on passive systems and scenarios exclusion by design, HTR/VHTR safety has to be demonstrated in a convincing manner (Ball et al., 2008). In particular, this is the case of the reactor confinement concept versus the reactor containment. On one side, confinement designs include effective filtration systems so that early offsite doses would remain well under the authorized limit; on the other, delayed release from the core would occur at a time in which no primary-to-confinement discharge is already taking place (i.e., long after the primary system depressurization). These postulated benefits, however, should be tested before accepting a so drastic change in the defense-in-depth strategy.

This paper presents a set of design analysis of a generic confinement building. Two main configurations of a postulated confinement have been modeled, which major difference is the presence of pools in the source term pathway to the environment (wet confinement). The main emphasis is given to the effect of water ponds on the accident scenarios and the sensitivity of the confinement response to pool design. The accident scenario explored has been the Very Large Break and their results are compared and discussed in terms of the amount of material that would reach the environment, under the hypotheses and approximations of the studies conducted. Other supplementary results for the case of dry confinements are also summarized for the purpose of comparison. The analyses have been conducted with the ASTEC code, which applicability was confirmed elsewhere (Fontanet et al., 2009).

2. Scenario description

The reactor operation generates graphite dust particles in the core that are carried by the helium in the primary circuit. Furthermore, fission products are mostly released from the core as vapor species, either condensable or non-condensable (i.e., noble gases). Condensable ones can interact directly with primary circuit surfaces (i.e., direct plate-out) or indirectly, by attaching to particulate matter (e.g., graphite dust) as it is carried by helium or even once it is already deposited onto primary circuit surfaces.

In the event of a Helium Pressure Boundary (HPB) break, the primary system depressurization would sweep fission products and graphite particles circulating within the primary circuit into the reactor building. More importantly, helium discharge from the primary system would make a fraction of previously deposited particles lift-off from surfaces and add-up to the source term into the confinement.

HTR confinements house two types of compartments: on one side, those containing fundamental equipment, like reactor pressure vessel and major components of the Power Conversion Unit (PCU); on the other, all those compartments belonging to the automatic Depressurization Vent Shaft (DVS). In this study a generic $\sim$50000 m^3 confinement has been postulated; the key compartments and dimensions are gathered in Table 1. A simplified diagram of the postulated confinement layout is shown in Fig. 2.

The helium exiting the primary circuit would lead to the pressurization of the specific compartment of the Power Conversion Unit (PCU) where the break is located. The flow path connection between the different compartments of the PCU would distribute the excess of helium to other rooms. Finally, the helium would be directed toward the DVS (PCU and DVS are postulated to be connected through rupture panels that break down if pressure difference across reaches 5 kPa), through which the gas, the aerosols and the fission products would be released to the environment. Filter

Table 1
Geometric characteristics of main confinement compartments.

Compartment	Volume (m^3)	Hor. surfaces (m^2)	Vert. surfaces (m^2)
Pre-cooler	1350	205	1050
Intercooler	1350	210	1050
Precooler MS	4100	515	1650
Intercooler MS	4600	535	1800
COP1	1600	300	790
Recuperator	3900	405	2350
Turbine outlet pipe compart.	1250	300	800
Turbine generator system hall	16900	2315	3250
DVS (west and east)	2550	90	1450
PRS filter inlet	1300	765	380
Filters houses	5600	4500	2000
Stack inlet	2200	2100	575
Others	3400	520	1650

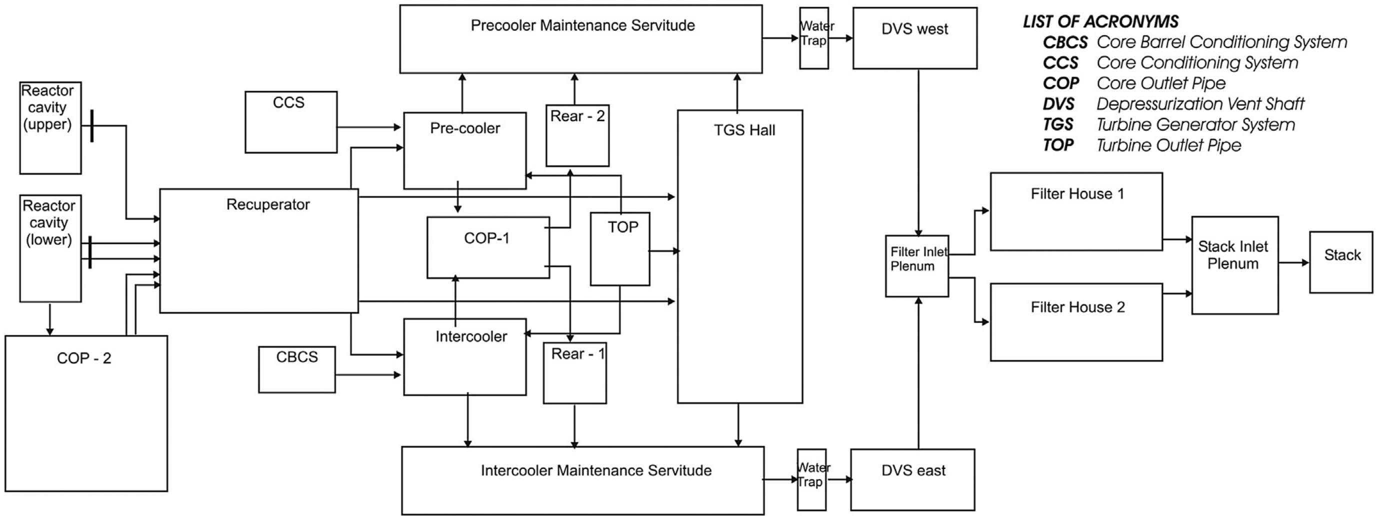

Fig. 2. Simplified diagram of the layout of a postulated PBMR confinement.

chambers at the top of the building and before the vent stack would retain a good fraction of the materials dragged by the gas.

Therefore, the behavior of the fission products and the aerosols into the building under hypothetical accident conditions caused by a break in the HPB has a relevant importance in the safety performance of the confinement. Most of the fission products are expected to eventually become attached to airborne dust particles, so that the aerosol concentration suspended into the building and their transport are key magnitudes strongly affecting the amount of radioactivity potentially leaking to the environment. In addition, aerosol interaction and removal mechanisms like gravitational settling, diffusive depletion and filtration, will reduce to some extent the source term to the environment.

The inclusion of a permanently filled pool in the pressure relief path inside the confinement (i.e., "wet confinement") would provide a passive closure of the confinement once the depressurization was completed. But, furthermore, it could strongly affect the gas thermal-hydraulics and the decontamination capability of the confinement.

3. Major modeling aspects

3.1. Tool and nodalisation

The performance of an HTR confinement has been simulated with the ASTEC v1.3 code (Van Dorsselaere and Schwinges, 2006). ASTEC is an integral code developed in the field of LWR but its containment module, CPA (Klein-Hessling and Schwinges, 1998) has analytical models to properly simulate thermal-hydraulics and aerosols behavior in HTGR confinement scenarios under hypothetical accidents (Fontanet et al., 2009).

The confinement volume has been split in more than 40 compartments. The resulting nodalization as well as interconnecting flow-paths are shown in Fig. 2. In case of a wet confinement, two pool compartments are introduced in the building layout before the Depressurization Vent Shaft (DVS): one in the east side of the building and the other in the west side.

3.2. Reference scenario

A good number of scenarios, from small to large breaks, had been previously explored by the authors (Fontanet et al., 2009; Fontanet et al., 2010). In order to set a comparison between dry and wet confinements performance, a Very Large Break (VLB) sequence has been chosen. The accident, defined as a 1000 mm sudden to DEGB end state in the piping directly coupled to the recuperator outlet (Bredin, 2006), was considered as a Licensing Basis Event (LBE) for the PBMR reactor.

The helium injection into the confinement was calculated with the FLOWNEX code (Van Ravenswaay et al., 2004) and the primary circuit depressurization lasted 55 s (Mazana, 2008). Fig. 3 shows the normalized flow rate. The dust mass entering the confinement is estimated as a fraction of the total aerosol mass accumulated within the HPB during operation. An approximation of the lift-off fraction from the circuit surfaces was calculated with the Shear Ratio Model (Sawa et al., 1992), using the prevailing flow conditions. Dust and fission products injections to the discharge compartment in the confinement, have been assumed to occur at the same rate as the helium one. This hypothesis means an immediate contribution of the mass previously depleted to the "in-confinement" source term.

Additionally, a number of hypotheses have been adopted for the "in-confinement" source term analysis:

- Fission products are attached to dust (i.e., no fission product is deposited on circuit surfaces). Therefore, fission products evolution is determined by the graphite dust behavior.

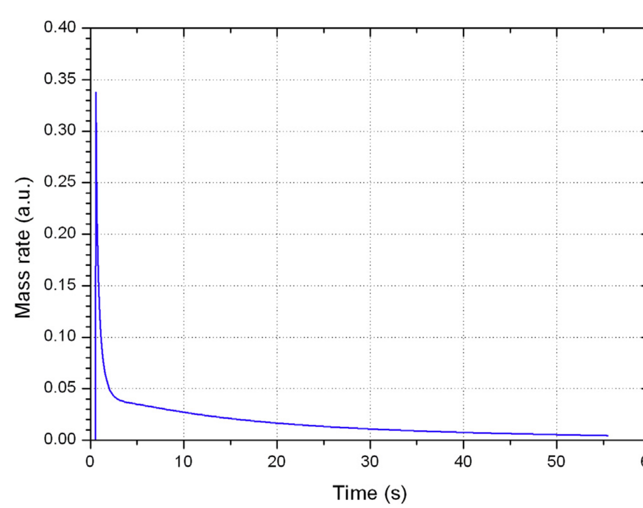

Fig. 3. Helium flow rate and temperature escaping from the primary circuit in a very large break.

– Graphite agglomerates are non-hygroscopic, fully dense spheres (i.e., dynamic and agglomeration shape factors are set to 1.0 in the ASTEC input deck).
– The aerosol size distribution is described by a mass median diameter (MMD) of 4.4 μm and a geometric standard deviation (GSD) of 1.7 (Wawrzik et al., 1987).

3.3. Pool design

The effect of a water pond in the confinement performance in case of an accident might heavily depend on its configuration. In order to explore the effect of the pool design on the confinement response a set of scoping studies have been carried out. Two different depths have been studied: deep (4.25 m) and shallow (2.25 m); the corresponding water volumes are 95.625 m^3 and 50.625 m^3, respectively. For each pool depth, two more variables have been considered: the number of discharge tubes submerged into the water and their diameter. The whole set of scenarios analyzed are gathered in Table 2. As noticed, these pool characteristics make venting cross section range in a broad interval. These scoping studies would allow highlighting the most favorable configuration to minimize source term to the environment.

3.4. Aerosol scrubbing

Aerosol scrubbing in water pools is modeled in ASTEC through an adaptation of the original SPARC90 code (Owczarski and Burk, 1991). This modeling is based on two decontamination stages: the injection region, in which depletion mechanisms such as inertial impaction and diffusiophoresis are the dominant ones, depending on boundary conditions; and the bubble rise zone, in which centrifugal mechanisms, sedimentation and diffusion (small particles) drive most of the aerosol removal. In addition to the lack of a sound, systematic and thorough validation (Allelain et al., 2009), this approach would be working out of its natural domain under the conditions prevailing in the scenario explored, since some correlations were derived from a different set of conditions. Such is the case, for example, of the initial globule diameter, which was derived for the "globule injection" regime ($We < 10^5$), whereas during VLBs gas enters the pool under the so called "jet injection" regime ($We \geq 10^5$). Anyway, the drawbacks attributed to the ASTEC model of scrubbing would be applicable to other integral codes, like MELCOR, which share the same approach to pool scrubbing.

4. Results

4.1. Reference scenario

Dry confinement has been adopted as the reference scenario, particularly the one corresponding to a VLB. Nonetheless, a scoping study focused on a broader set of scenarios encompassing from small to very large breaks, allowed getting insights into a "generic" dry scenario. Fig. 4 compiles all those studies. Two major observations can be made: on one side, the fraction of mass released to the environment is in all the cases a very minor fraction (less than 8%); on the other, the longer the residence time of gas flowing inside the building, the smaller the release fraction. Even further, this trend has been correlated through:

$$Y_{leak} = 1.3 \cdot t_{residence}^{-1/2} \quad (1)$$

This correlation, which regression coefficient (R^2) is higher than 0.9, has been obtained for residence time greater than 500 s and states that, according to the model built, the influence of the different boundary conditions can be encapsulated in the time that the aerosols take to get to the confinement exit.

In the particular case of a VLB, the mass fraction released resulted to be 2.7%. Given the uncertainty in some of the modeling assumptions (i.e., duration of aerosol mass injection, location of primary system breach and particle size distribution), a set of sensitivity calculations was conducted. A total of 8 cases were run, as shown in Table 3. As noted the only major change was obtained when the injection rate was increased in about a factor 100 (a too extreme hypothesis) and, even in that case, the effect was about a factor of 2.0. The reason is that in case of VLBs most of aerosol removal takes place in the filter units, so that variables affecting to natural depletion processes (like particle size, for instance) hardly affect the mass leaked to the environment. Anyway, the results got in the base case (BC) are independent of the explored variables.

Table 2
Parametric cases of suppression pool.

Volume pool (m^3) (pool height – m)	Diameter (mm)	Number of tubes	Total tubes cross section (m^2)
95.625 (4.25)	25	200	0.098
		400	0.196
	50	100	0.196
		200	0.393
	100	100	0.785
50.625 (2.25)	25	50	0.025
		200	0.098
		600	0.295
	50	50	0.098
		100	0.196

4.2. Wet confinement

The inclusion of water ponds in an HTR confinement entails changes in the thermal-hydraulic response of the building and in the source term to the environment. Both aspects are analyzed and discussed next in comparison to what observed in the reference case.

The thermal-hydraulic evolution in the building (i.e., pressure) will affect the gas discharge from the primary circuit. However, the large pressure difference during most of the He injection resulted in small flow rate variations; noticeable discrepancies in flow rate occurred only once about 90% of particulate matter has already been injected in the building. As a consequence, the same He mass flow rate has been assumed in all the cases.

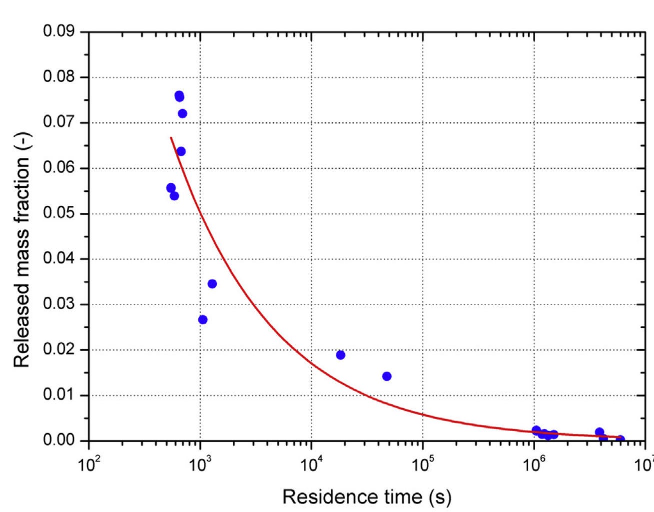

Fig. 4. Dependence of the released mass fraction with the residence time.

Table 3
Release mass to the environment for the very large break sequence.

Case	Injec. period (s)	Location compart.	Aerosol distr. (MMD/GSD)	Released mass (%)
BC	55	Recuperator	AVR data	2.7
PC1	0.5	Recuperator	AVR data	5.6
PC2	0.5	TGS Hall	AVR data	5.4
PC2b	0.5	COP1	AVR data	6.4
PC3a	0.5	Recuperator	4.4/1.7	5.5
PC3b	0.5	Recuperator	4.4/2.3	5.5
PC3c	0.5	Recuperator	2.2/1.7	5.6
PC3d	0.5	Recuperator	2.2/2.3	5.6

4.2.1. Thermal-hydraulics

The thermal-hydraulic building evolution may well be described through pressure. Two major factors govern "in-building" pressure: the helium discharge through the break and the pressure build-up upstream the water ponds, which is a strong function of the gas flow cross section into the pool. Fig. 5 shows pressure in the discharge compartment along time for the case of a shallow pool under several configurations (pressure increase has been normalized). As observed, the pressure evolution shows two phases: pressure build-up, which extends during helium discharge until outgoing flow through the pool is greater than the helium gas flow being discharged in the building. As expected, the smaller the cross section, the higher the pressure and the longer the time to reach it. This behavior is due to the fact that pressure upstream the water pond keeps increasing until the gas flow through the pool exceeds the discharge flow rate, and then the slower slope is the one that allows the smaller gas flow through the pool (i.e., the smaller cross section of gas injection in the pool). The only difference between shallow and deep pools is the steady state value reached after depressurization, which depends on the water column over the injection point.

As shown in Fig. 5, the wet confinement behavior is very different from that of the dry one, in which rupture panels between the DVS and the PCU open when the pressure difference across the junction reaches 5 kPa (their cross section, 8 m^2, being significantly higher than the pool vent cross section in all the cases). At the beginning of the accident the pressure increases rapidly because the inlet mass flow rate is much higher than the outgoing flow (limited only by the flow path cross section between the discharge compartment and those around) and the peak pressure is reached only 1 s after the break. This peak is about a quarter of the maximum peak obtained in the case of the pool with the lowest vent path cross section.

The results obtained highlight that in-confinement pressure is strongly dependent on the flow cross section of the gas entering the pool. Fig. 6 plots, as a function of the flow path cross section (S), the peak pressure reached for each configuration (both deep and shallow pools) normalized to the maximum value. The estimated values are well fitted by a quadratic curve:

$$P_{\mathrm{peak}} = 1.01 - 0.71 \cdot S + 0.45 \cdot S^2 \quad (2)$$

As noted in the plot, the correlation coefficient is pretty high, $R^2 = 0.998$. This good correlation indicates that pressure losses and mass losses (due to steam condensation, for instance) along the flow path are negligible in the scenarios analyzed. In addition to the peak pressure value, the time at which the pressure peak is reached (Fig. 7) is also correlated with the flow cross section of the gas entering the pool, in this case through a linear decreasing trend:

$$t_{\mathrm{peak}} = 56.0 - 43.3 \cdot S \quad (3)$$

with $R^2 = 0.95$.

In other words, the gas flow cross section determines to a good approximation the maximum pressure to be reached within the confinement and how long it would take to reach it.

As for the water heat-up, pool temperature might be a key variable in scenarios where pool temperature reaches or comes near saturation and the potential for diffusiophoresis gets lost. According to the scenarios explored, water pool would hardly experience a few degrees increase, so that it would be far from saturation at all times; this preserves the pool scrubbing capability due to steam phase change in all the cases along the time analyzed.

4.2.2. Aerosol retention

Aerosol scrubbing is usually characterized by the Decontamination Factor (DF), defined as the ratio between the mass entering and exiting the suppression pool. Similarly, a global decontamination factor can be defined as the ratio of the mass injected into the

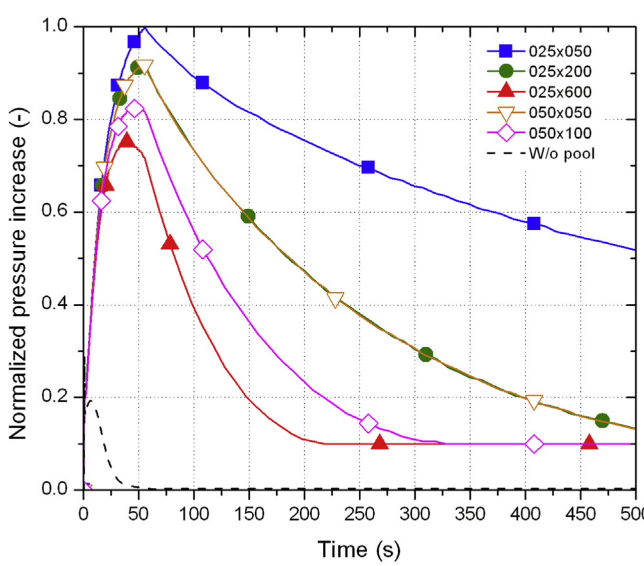

Fig. 5. Pressure evolution in the discharge compartment for different shallow pool configurations.

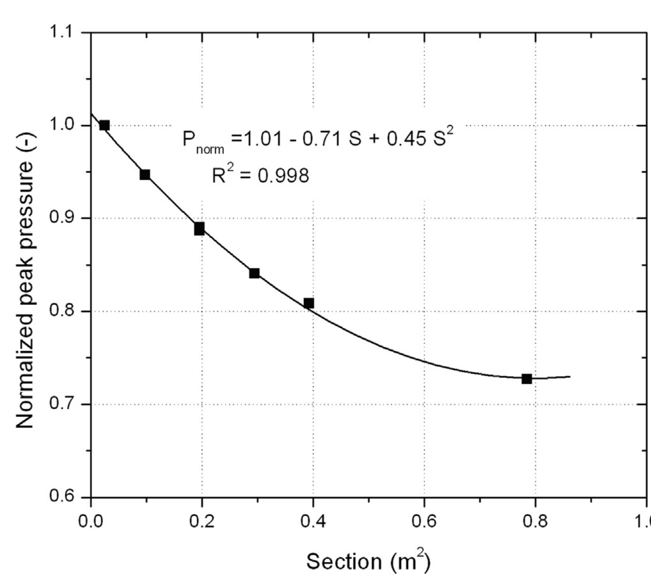

Fig. 6. Normalized peak pressure as a function of the flow path cross section.

building through the HPB break and the mass released to the environment. As the decontamination process can be represented by a series coupling of transport resistances, the global DF could be written as:

$$DF_{global} = DF_{conf}^{upstream} \cdot DF_{pool} \cdot DF_{conf}^{downstream} \quad (4)$$

where the gas decontamination resulting from the aerosol transport through the confinement has been split into two contributions, one upstream and other downstream the pool ($DF_{conf}^{upstream}$ and $DF_{conf}^{downstream}$).Table 4 collates the DF values together with the mass fraction released to the environment; additionally, the resulting DF when using filters instead of a suppression pool is included. A set of observations can be made:

- The pool configuration affects substantially the aerosol release (i.e., aerosol retention). The released mass ranges approximately from 4 to 12.5%, depending on pool configuration.
- The retention in the deep pool is higher than in the shallow one when comparing the same configurations.
- The DF in the suppression pool is lower when increasing the number of pipes or their diameter. The effect of the venting cross section is enhanced with water depth.
- Filters DF are higher than any of the pool DFs (90% filter efficiency assumed for all particle sizes as a conservative value with respect to the usual HEPA filter efficiency – Allelain et al., 2009).

The dependence of DF on pool submergence (i.e., water height above the vent, H) and venting cross section (S) has been correlated as:

$$DF_{global} = 3.54 \cdot H \cdot S^{-0.25} \quad (5)$$

This correlation, although derived from a limited number of points, allows approximating the total aerosol retention in the confinement by just knowing design parameters, like the cross section of gas injection in the pool and the submergence of injectors. Fig. 8 compares the simulation value of the DF_{global} with the estimates using the above correlation. It shows a good agreement for most of the configurations, with an error lower than 20%. In the case with the lowest cross section (50 pipes of 25 mm and $DF_{global} = 25.9$) the error is about 40%. If this value was removed from the database, one would get a reasonable correlation coefficient (R^2) of 0.93.

Table 4
Decontamination factor and mass release calculated for each pool configuration. Data is compared with simulation using filters.

Volume pool (m^3) (pool height – m)	Diameter (mm)	Number of tubes	DF_{global}	DF (SP)	DF conf.	Released fract. (%)
95.625	25	200	25.9	4.3	6.0	3.9
(4.25)		400	20.1	3.0	6.7	4.9
	50	100	18.8	3.2	5.8	5.3
		200	15.1	2.8	5.4	6.6
	100	100	14.5	2.2	6.6	6.9
50.625	25	50	25.9	4.0	6.5	3.9
(2.25)		200	10.7	2.3	4.7	10.3
		600	8.1	1.7	4.8	12.3
	50	50	10.7	2.3	4.7	9.3
		100	8.9	1.8	4.9	11.2
Filters			36.9			2.7

The above expression shows the transmission of the decontamination in the pool to the global DF value. It is worth highlighting that given the series coupling of upstream compartments and the pool DFs, even though both DF values could be similar, the impact of upstream confinement compartments on the aerosol retention would be substantially higher.

In order to assess the effectiveness of the suppression pool concept in the aerosol retention, the mass release from the building using filters instead of a suppression pool is compared with two other cases (Fig. 9) both using filters and suppression pool. Data show that the shallow pool with 50 pipes of 25 mm is an effective way to retain particles as it reduces the mass release to the environment by a factor about 10. However the same pool but with 600 pipes leads to a release about half the release without pool. These two examples have been chosen because they give the highest and the lowest DFs values, respectively.

The size distribution is a major variable for aerosol retention. Pool scrubbing tends to shift the particle size distribution toward particle diameter around 0.1 μm, at which removal efficiency of diffusion and inertial mechanisms draws a minimum. Thus, in wet confinements particles reaching the filter chambers would be smaller than in dry confinements. As injected aerosols have an

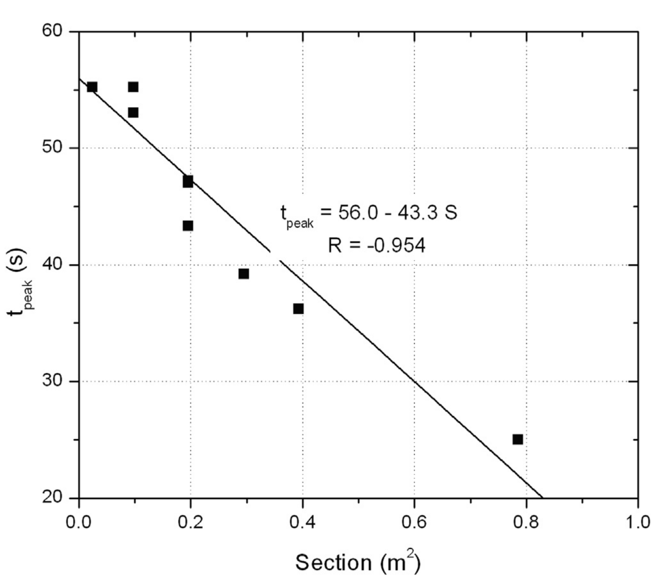

Fig. 7. Time at the pressure peak as a function of the flow path cross section.

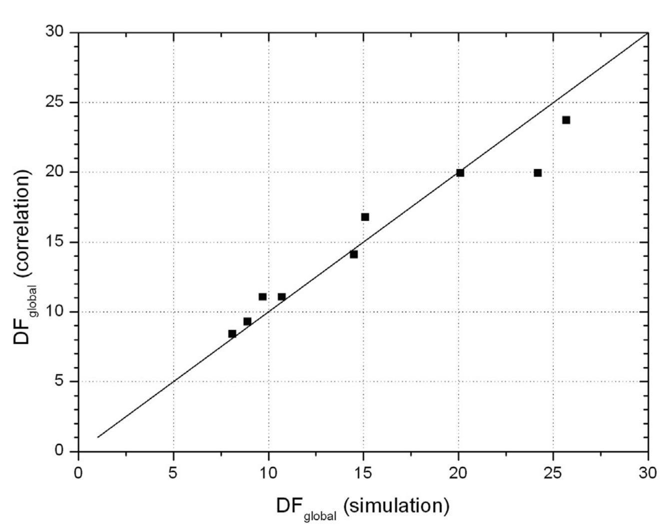

Fig. 8. Correlation-to-simulation comparison for the global DF.

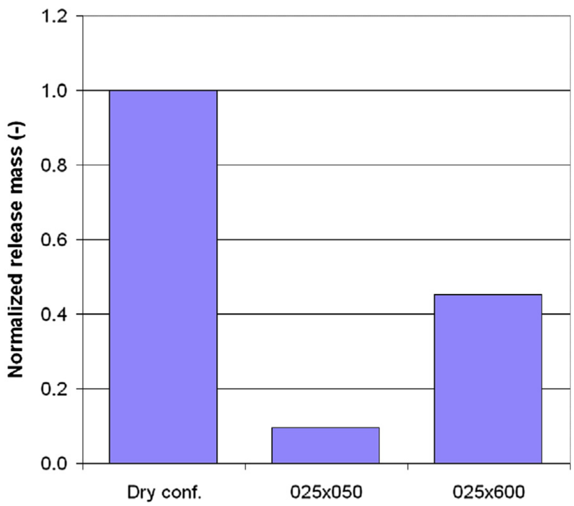

Fig. 9. Comparison of mass release for filtered confinement with different pool configuration.

MMD (Mass Median Diameter) around 4.5 μm, their average size after passing through the suppression pool is notably reduced. Despite that filter retention depends on particle size (smaller efficiency reported for particles smaller than 0.3 μm, – Allelain et al., 2009), no major effect should be expected in the aerosol retention within the building, since the initial fraction of small particles contributes in a small share to the total mass of aerosols injected.

5. Conclusions

In the sections above the main results of an investigation on the potential effect of including water ponds in a postulated HTR/VHTR confinement have been presented. By modeling a postulated very large break in a dry and a wet confinement with the ASTEC v1.3 code, some insights have been gained not just on the potential impact of water ponds on the thermal-hydraulics and the source term attenuation within the building, but also on the optimization of pool design for a more effective fission product scrubbing. Next, a few points are highlighted as the most relevant contributions of this research:

- Under dry conditions, the source term attenuation capability can be approximated as inversely proportional to the square root of the time spent by the particle laden gas flowing from the primary pipe breach to the confinement exit. This engineering approximation allows obtaining rough figures of particle retention without requiring detailed aerosol studies. Even in the most unfavorable scenario, aerosol retention was over 90%.
- Water ponds might be a passive way of confinement isolation, but they would change the thermal-hydraulic evolution within the building. Maximum pressure and time at which it is reached, are governed by cross section area of gas injection in the pool; in other words, in-building thermal-hydraulics would be pool design dependent.
- Water pools are efficient aerosol traps which scrubbing efficiency depends on their configuration, particularly vent cross section and pool submergence. Namely, as in the case of dry scenarios, the source term attenuation (assuming most fission products attached to aerosol particles) can be approximated by an engineering equation depending just on pool-related geometrical features.
- By assuming moderate but size independent efficiency of gas filtration, adding filters downstream water ponds would result in a total source term attenuation ten times higher than in the case of dry confinements.

It is worth noting that theses results are dependent on the current state of the art of aerosol code development and the assumptions taken in the study. In addition, the results were obtained for VLBs and they should be extended to other scenarios to confirm their applicability or to adapt them to a broader domain.

Acknowledgments

The authors are indebted to Alastair Ramlakan for his valuable technical contributions along the investigation of HTR confinement response to Licencing Basis Events. Likewise, the authors acknowledge PBMR for their financial support.

Nomenclature

DF	Decontamination factor
H	Water height above the vent
P	Pressure
R^2	Correlation coefficient
S	Flow path cross section
t	Time
$t_{\text{residence}}$	Aerosol residence time. Time that takes the aerosol to exit the confinement
We	Weber number
Y	Mass fraction leaked to the environment

Subscripts/Superscripts

conf	Confinement
downstream	Downstream the water pool compartment
peak	Maximum value reached
upstream	Upstream the water pool compartment

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