NPP Containment Vent Protection. Why There Is No One-size-fits-all solution – 14424

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ABSTRACT

In the post-Fukushima world, when entire NPPs could possibly be added to the global Nuclear Waste inventory, and where Regulators around the world are examining the need to prevent excessive pressurisation of NPP Containment, and safely evacuate the gaseous consequences of LOCA. There is a need to return to fundamental principles and examine each putative set of data derived from the various models describing the consequence of LOCA and other events.

This paper will describe in depth and detail the individual consequences of each particular aspect of the modeled data. Looking at flowing conditions; pressure, temperature, gas constituents (including water vapor and Caesium and Iodine compounds), vent pressure philosophy, deposition of solids (size, type and quantity), decay heat accommodation/removal, maximum temperature limitations (in terms of metallurgy and the melting point of deposited materials for instance, the melting of CsOH at 273 Celsius) as well the consequences of water condensation on pressure loss, solids removal efficiency, the blinding of the medium, and the structural design of the equipment to make it capable of withstanding the worst case pressure loss (a fully blocked system with full containment pressure across it).

Extensive work performed by the author's company and others shows clearly that no two event models coincide, to the extent that the company is concerned that there is an assumption in the NPP industry that a 'product' exists which will simply meet any need, taking account of solids load, temperature limits, pressure profiles, decay heat deposition and the gross condensation of water vapour.

It is clear, and will be demonstrated, that no single catch-all solution will meet the myriad of needs examined by the company, and the company finds itself in a position where it feels it is compelled to present the argument to the industry, so that the industry can then at least have its deliberations informed by supported and fundamental fact.

Whilst this paper concerns itself with a postulated incident, it considers that a proper assessment

of the possible consequences of a LOCA and other occurrences before the event, can ameliorate the; consequences, costs and timescales after any such event, before the NPP joins the global Nuclear Waste inventory.

INTRODUCTION

If the Fukushima event taught the world anything, that something can be encapsulated in the famous saying by your very own Samuel Clemence, who suggested, "It ain't those things you don't know that gets you into trouble; it's those things you know for sure, which just ain't so".

The error of assumption, the' "It's always been done like this, so it must be OK", the, "A cleverer man than me is in charge, and I can't possibly do it without his permission", is a dangerous attitude to take in this most dangerous of industries.

Fukushima has been described to me as not a technical failure, but a cultural one. As the BBC said just after the event in a written article on its website (paraphrase), "The facility at Fukushima survived the worst earthquake in recorded history and a 100 foot wave, only to be felled by a diesel generator".

A diesel generator, plus an inability to break out a culture of rigidity of thinking and face saving, and a complete unpreparedness to act on initiative without having permission to do so, they could have added.

Whatever the causes of the catastrophe (a catastrophe for society at large, not just our industry), the fact is that the Fukushima facility has joined the Nuclear Waste Inventory, and thus has become a subject of interest and discussion at this conference.

This paper, and indeed the associated presentation, does not concern itself with Fukushima (there is quite enough attention, effort and money being expended on that already). This paper, rather, would like to try to draw attention to a single aspect of the sort of disaster Fukushima represents, and to, at least, perhaps start a dialogue about the preparedness of our industry to mitigate, as far as possible, the consequences both; geographical and financial, should such an event ever happen again.

The purpose of this paper is to put before an interested audience, my company's concerns regarding the "it will be alright on the night" attitude that lead to the facility becoming a subject for the Waste Management Symposia, rather than a celebration of the role of Nuclear Power in a vibrant economy.

Our primary concern, which will be expanded upon later in the paper and the presentation, is that the existing solution providers in the field of Containment Venting, in the event of a LOCA, seem to have established a position that a 'one size fits all' solution is a possibility. We may be wrong, but as an expert engineering company in the field of Nuclear Filtration, and treating every enquiry we have received since the Fukushima incident as an independent application, we have come up with as many separate designs as we have enquiries, not because we view every application as different from the last, but because every application IS different from the last, and is in fact often VASTLY different from the last.

We present this to the public domain so that at least questions get asked. We hope that we are wrong and that everything is fine out there, but we believe we are not. How different the world would be if someone had asked questions about the siting of that diesel generator, or someone felt able to question the cultural issue of not doing anything without superior permission to avoid 'loss of face'.

DISCUSSION

Containment Venting in the event of a LOCA presents a set of parameters so varied and interconnected, that they represent an application unique in the world of specialized filtration.

Porvair Filtration Group is effectively an engineering company dedicated to providing filtration solutions to the Nuclear Industry in its many guises, and as such has an extensive experience of complex, demanding and critical applications. It is, therefore, well positioned to offer the opinions stated in this paper.

What is a LOCA?

- Containment venting applies to all forms water cooled reactors
- The dominant types of water cooled reactors are:
    - PWR (Pressurized Water Reactor)
    - BWR (Boiling Water Reactor)
    - CANDU
    - VVER
    - RMBK

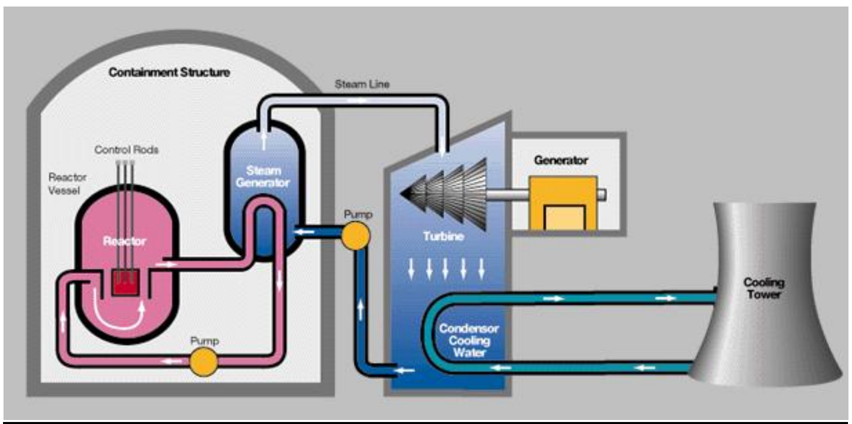


Fig. I - Basic PWR reactor scheme.

- LOCA stands for Loss Of Coolant Accident
- Loss of coolant refers to a failure in the circulation of heat exchange medium (typically water in some isotopic form), allowing fuel cladding failure and production of radiolysed Hydrogen and ultimately the possible melting of the fuel
- Melting fuel if not properly contained could compromise the reactor containment and release irradiated substances into the life environment. Melting fuel will melt and even evaporate the concrete containment surrounding the vessel.

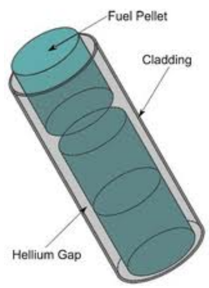


Fig. 2 - Schematic of fuel pellets inside a fuel rod

The containment venting design solution must be capable of performing/dealing with the following:

- Facilitate the controlled release of pressure to atmosphere
- Be capable of operating in the event of a total loss in power
- Remain functional for a specified period of time during and after the event

Whilst achieving a high removal efficiency to prevent the carriage of radioactive particles into the atmosphere, whilst also meeting the customer requirements for coping with:

- Water vapour/possible condensate
- High gas flow rate
- High solids burden (fines nominally 0.2 microns)
- Dissipation of decay heat
- High pressure and temperature
- Effectively remove hydrogen and iodine
- 30 year minimum design life
- A seismic event (demonstrated through seismic qualification)

An Incomplete list of variables associated with the application.

- Gas composition
- Flow
- Pressure
- Temperature

- Solids load
- Solids type
- Particle size
- Moisture content
- Decay heat
- Allowable differential pressure
- Downstream pipework
- Closed vessel, open system
- Caesium hydroxide melting
- Temperature capability of the filter medium/system
- Iodine absorption
- Hydrogen re-combination

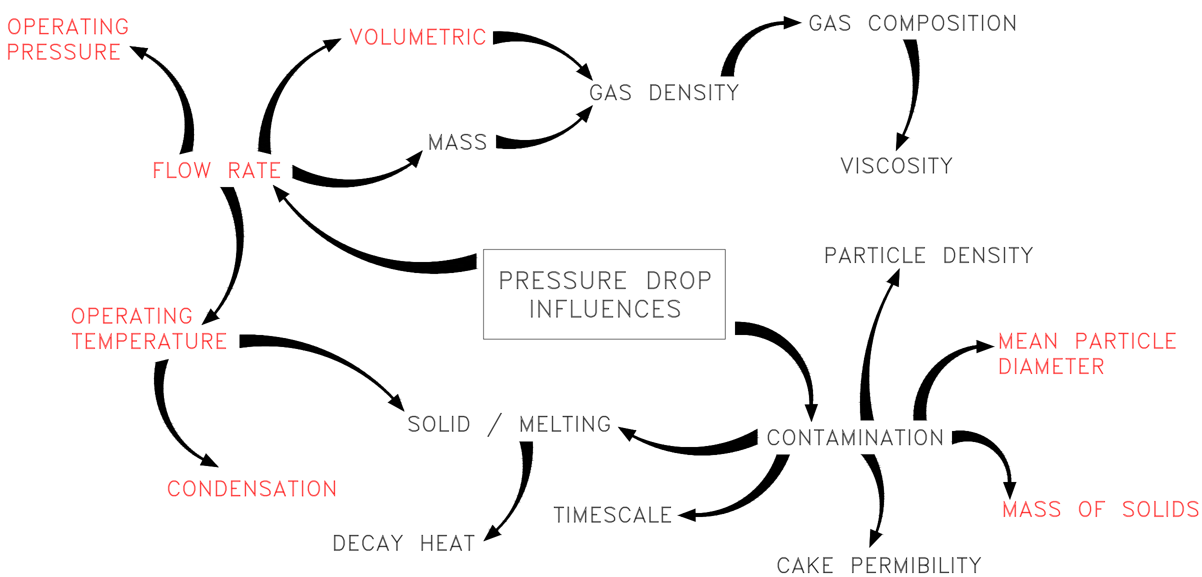


Fig 3 - Visual interpretation of the interaction between various parameters to establish (in this instance) operating DP at various stages of operation of a filter.

Gas composition

Clearly, it is essential to know exactly what it is that the filter is trying to cope with, is the nature of the gases; Basic?, Acidic?, Corrosive?

The filter medium that Porvair would typically employ to meet these duties is metallic, most likely fibrous metallic media, containing metal fibres only microns in diameter. The active surface available in a piece of such a medium can only be imagined, but is certainly in the 100s if not 1000s of square meters per kilo weight.

Without a clear idea of the challenge in terms of its chemical composition and behaviour, the challenge cannot be adequately met or even managed.

Flow

Gas flow through any form of filter defines; separation efficiency, pressure loss and size. Without a clear idea of the expected performance requirements of the filter, a filter's performance cannot therefore be defined. These are industrial pieces of equipment designed for purpose, not self-adjusting 'black boxes' capable of accommodating whatever is thrown at it. A Ford Focus couldn't race a Grand Prix, but equally a Grand Prix vehicle couldn't park in the local mall.

Pressure, Closed Vessel/Open System/ Expansion Upstream or Downstream of the primary solids separation unit/ Down-stream pipework

Gas pressure in the filter defines actual gas volume, which defines gas density, gas velocity through the filter, DP, efficiency and size, among many other things. Typically Containment Venting specs fall into one of two categories. Either the expansion is expected to happen before or after the filter system, the benefit of expanding after the filter is that the actual volume of gas passing through the filter is minimised, so physical size can be minimised. However it has been suggested several times that the filter itself is used as the 'expansion chamber', to allow the venting gas to be brought down to atmospheric pressure (or at least near to) to allow final discharge to atmosphere through a stack.

A typical user scenario is that, once a LOCA has been initiated, the pressure in the reactor containment is allowed to rise to the safe internal design condition for the containment. This is typically 8 bars absolute, once this pressure is reached the system is isolated and the depressurisation valve is opened, allowing a proportion of the pressure in the containment to be relived, typically down to a pressure of 4 bars absolute. This is often performed to keep the short lived nuclides inside the containment and give them a chance to decay to less active species, so even 'at pressure' systems have to be designed to cope with a halving of pressure and dramatic variation in volume flow and even RH.

Fig. 4 - A water containing vessel of a type used in 'Wet Filtration' to solve the LOCA Vent Filtration problem

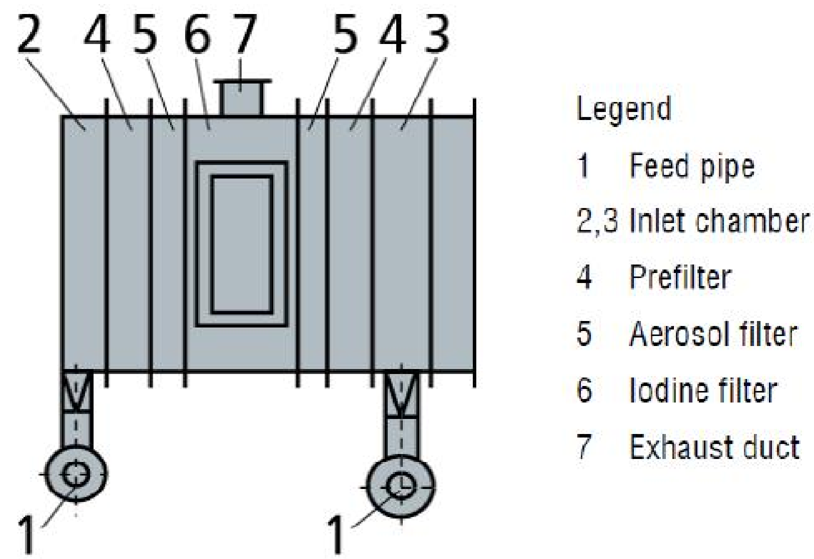


Fig.5 - A generic schematic of a proprietary dry filtration solution to LOCA Vent Filtration, including both condensate aerosol and Iodine removal stages

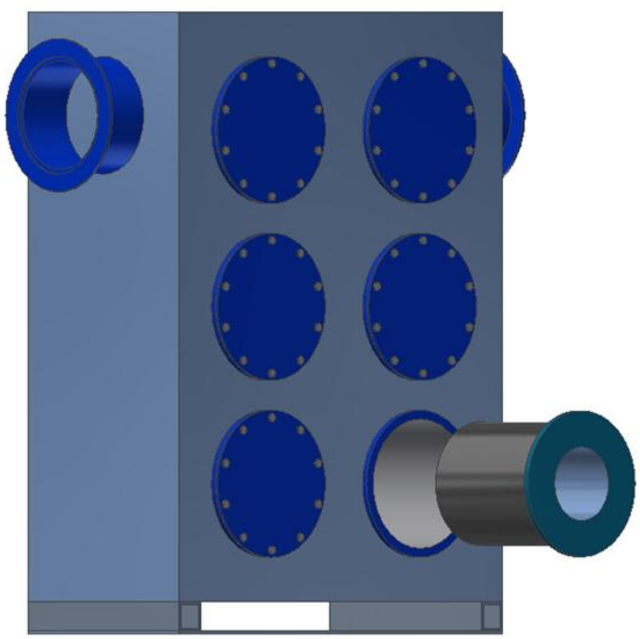


Fig 6 - A generic schematic of a proprietary dry filtration solution to LOCA Vent Filtration, without condensate aerosol and Iodine removal stages

Temperature compatibility, Decay Heat and Caesium Hydroxide Melting

The various models that Porvair has been presented with concerning the actual temperature of the venting gas that the filter must be designed to withstand, has varied from some close-to-ambient conditions to hundreds of degrees Celsius. A consequence of this particular uncertainty is that the suitability of the medium for the duty cannot be assessed. Bearing in mind that once the equipment has been installed, it is intended to sit there lying dormant, hopefully for ever, but certainly for the forty or sixty year life of the plant, without maintenance. Typically stainless steel, the filter plant will happily wait, dormant, to be brought into life, but should the challenge be incompatible with the material used, then the actual in-use life of plant cannot be predicted, and thus far those temperatures seem to be either unreliable or unavailable.

An interesting adjunct to this concern is a recent application in which a modelled vent gas temperature of 250 Celsius was coupled with the presence of Caesium Hydroxide, which melts at 273 Celsius. That being the case, and should the model be 10% inaccurate, the gas stream will contain a liquid CsOH aerosol, which would coalesce out on the filter medium (like any other liquid aerosol), and 'wick' by capillary action, across the medium to block significantly more of the medium, than its, possibly small, quantity would suggest, upsetting any calculations of solids capacity made for the filter.

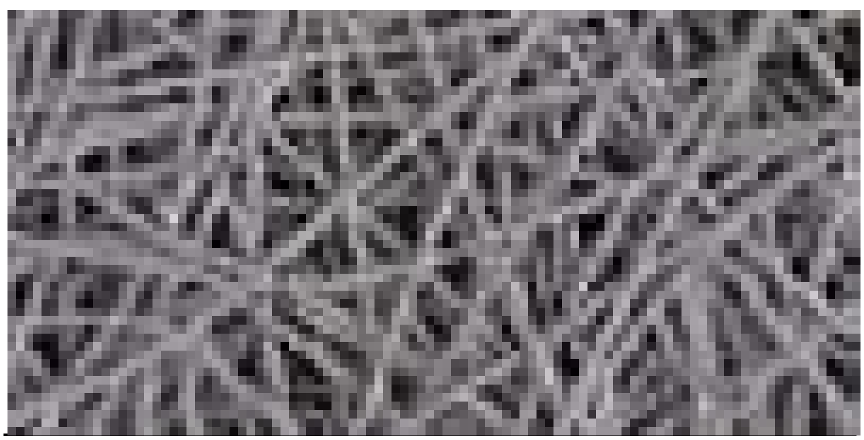
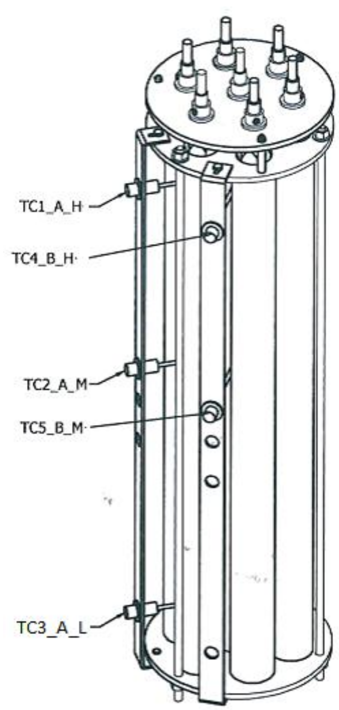


Fig - 7 Close up view if typical Sintered Metal Fibre medium, showing structure (and, therefore, susceptibility to the wicking of liquefied/melted CsOH).

Decay Heat

And then, and then, we have decay heat, the great Bete Noir of the whole subject. Decay heat is the name coined to describe the fact that the purpose of the filter is to catch the flow-borne particle of active matter resulting from the LOCA, fissile material which remains fissile, and decays on the filter creating heat as it does so. Again, the models fail us. The company has seen applications with decay heat levels varying by orders of magnitude for similar events in similar reactors/containments. Possibly the most extreme of these was an application citing 376 kw of collected decay heat, to be managed without flow, without power and without any outside agency for at least 72 hours. As rather jokingly suggested at the time, such a heat input takes away the whole problem, as by the end of 72 hours everything would become dissociated plasma anyway. Clearly, without forced convective flow or an extensive pathway for conduction to take place, the only obvious answer is thermal mass – a lump of metal so heavy that it can keep adsorbing the heat and distributing it within its own mass, without melting until outside help can be brought in or the heating material decays to something a little more benign. The images and test results found in the figures below are taken from a collaborative test program undertaken by Worley Parsons Sofia and Porvair Filtration Group UK.



Figs.8, 9 and 10 - Test set up for an assembly tested with internal heat sources to examine the consequence of decay heat being deposited onto a metallic vent filter (Credit Worley Parsons

Sofia)

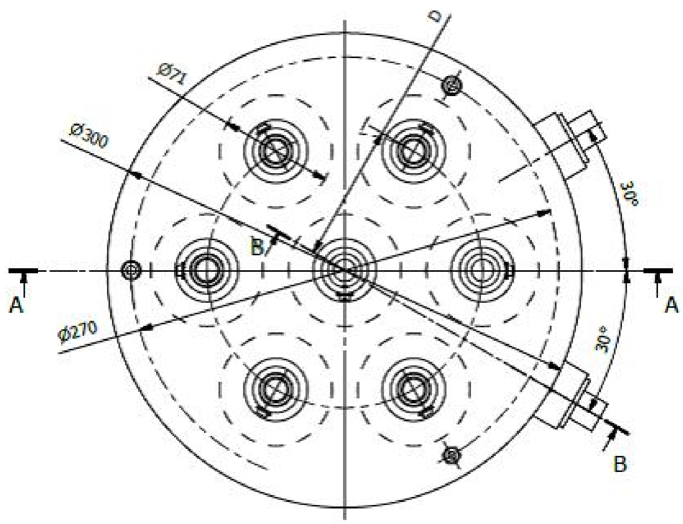


Fig - 9

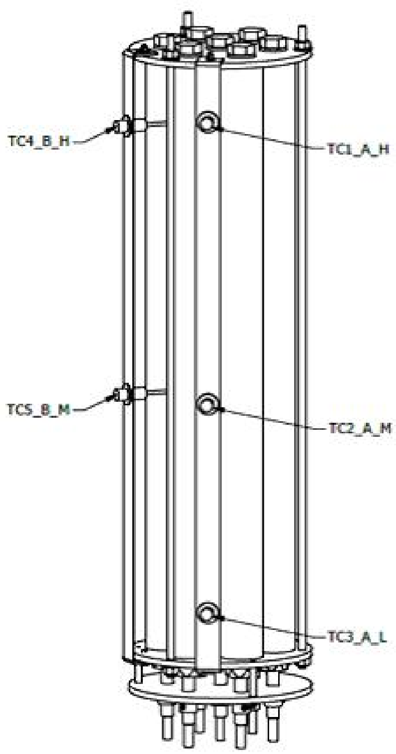


Fig.- 10

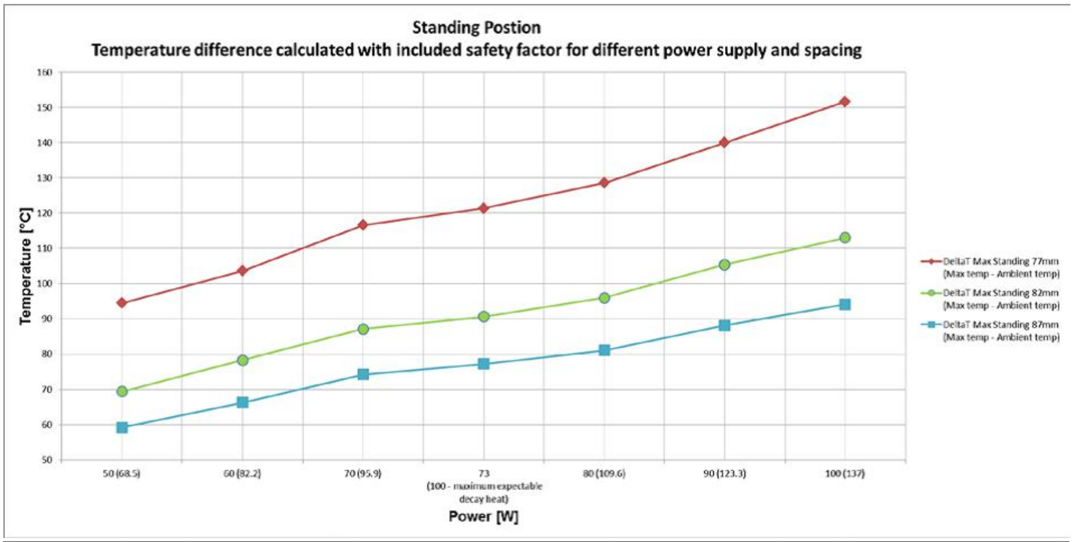


Fig. 11 – A graph showing the effect of element separation on temperature for varying Energy input (for an assembly standing on a floor (Credit Worley Parsons Sofia)

Fig. 12 – A graph showing the effect of element separation on temperature for varying Energy input (for an assembly suspended above a floor) (Credit Worley Parsons Sofia)

Deposited solids particle size

Across the applications the company has been asked to explore, the particle size model seems to suggest a tight distribution around 0.2 microns. The frequency of the appearance and number could suggest that someone 'put their head above the parapet' and suggested the number, and everyone else jumped on that particular bandwagon, rather than do the work necessary to establish exactly what the size range of the deposited material might be in the event of a real LOCA.

The consequences of that number are profound, equipment size is doubled, trebled, quadrupled – take your pick. The permeability of any solids cake collected is miniscule, if indeed a cake can even be formed, as these particles (less than 100th part of the diameter of a human hair) they will more likely be captured in the depth of even a planar medium, blinding it progressively. This would have to catastrophic effect of 'closing down' the filter, totally preventing vent flow. No vent flow, means no depressurisation of the containment.

Moisture content/ Condensate level

This interesting parameter was perhaps, best described at a recent presentation to a major player in the field of NPP services by the drawing of a simple line. 'At this end', I stated, 'all the water vapour (which, in this case, represented virtually the whole of the 'gas' constituency) is liquid, in which case, we are talking about a liquid filter. At this (opposite) end, all the water is vapour, in which case it is a gas filter'.

Of course, the truth is that the client has no idea where, between those two extremes, his problem lies. So the answer is to provide liquid aerosol removal. Not a problem, but the issue needs recognition.

Like so many other parameters in the field, it seems to be brushed aside and filed under, 'Self-adjusting black box'.

Allowable DP

Allowable differential pressure is less of a critical parameter, and somewhat more an interesting illustration of the general ‘laissez-faire’ attitude surrounding this entire subject. A lot of extremely complex modelling and academic work has been expended on trying to understand the various scenarios of a LOCA. However no thought seems to have been given to the simple fact that, if a valve is opened at 8 bars absolute, and of significant quantity of solids with a tiny 0.2 micron particle size is collected on the filter, the system will never get down to (say) 4 bars absolute, to enable that valve to be closed, because the DP across the filter will be higher than that minimum level even at insignificant flows.

Hydrogen Re-combination and Iodine absorption

Strictly, these two headings fall outside the remit of this paper, but are mentioned because of their critical and fundamental importance in the social consequences of a LOCA. Both issues are solvable with investment, Iodine can be removed at lower temperatures by classical absorption onto carbon or zeolites. Hydrogen can be recombined in Passive Autocatalytic Re-combiners with O2, but the Fukushima explosions and the more widespread Iodine population contamination resulting from that event, serves to show that these peripheral considerations do not seem to have been taken into account when plans are formulated to mitigate the possibility of an entire NPP joining the worldwide inventory of nuclear waste.

A suggested solution covering all stated parameters

Porvair has independently arrived at a bespoke solution concept to meet the needs of CV applications, whether the intention is to vent within or without the containment building, at pressure or at atmospheric, with condensate entrained, or without, taking into account allowable DP, total heat creation and in the process, and the presence or otherwise of entrained condensate. In a related project, Porvair has recently proven that the conventional thin wall theory/ligament efficiency models used to design filter element cores is not reliable (see collapsed core pictured below).

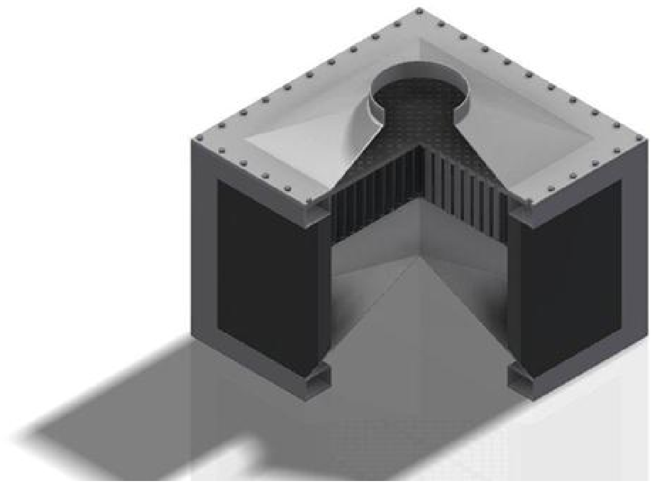


Fig. 13 - A typical example of a Porvair CV filter assembly, accommodating both filtration and condensate removal, shown alongside a recently tested and collapsed filter core, indicating yet another danger, seemingly not envisaged by the current offerings.

A warning

Failure is not an option.

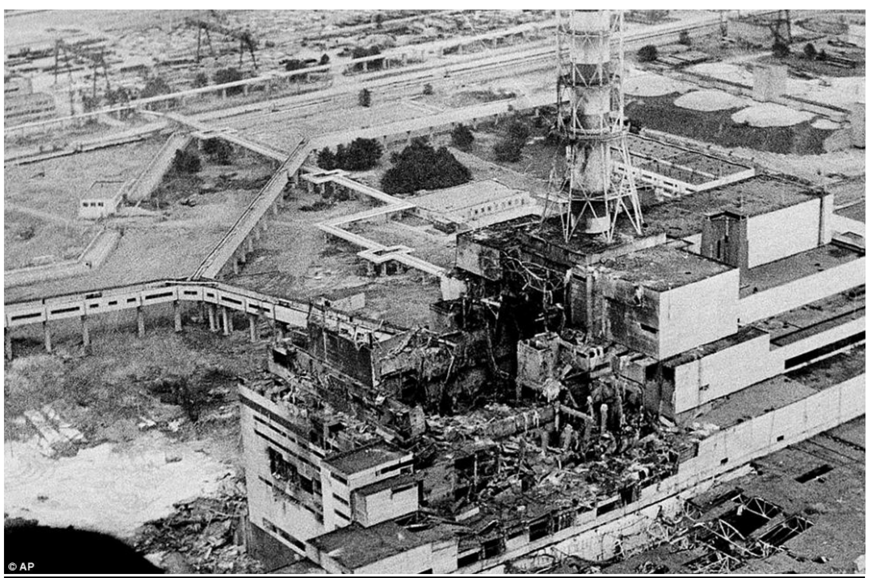


Fig 14 – The consequence of failure

Conclusions

The purpose of this paper is NOT to provide some instant solution, but to highlight what the authors are concerned is an attitude of, ‘It’ll be alright on the night’, about the whole subject of Containment Venting in water cooled reactors.

The idea that a lightweight, one-size-fits all, solution can meet this need is clearly non-sensical, yet that is what is being proposed, and proposed by companies both within and without the nuclear services community.

The Porvair Filtration Group is a specialist in this field and we felt it our duty to the rest of the world to at least be shot down over this issue, and at the very least to raise the debate to a visible level.