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UK Nuclear Ventilation Review 2018-2022

Bernard Swinnerton
Sellafield Ltd, Warrington WA3 6GR, UK

ABSTRACT

These notes summarise some of the work carried out within the UK, in the nuclear ventilation discipline, since the 2018 ISNATT Air Cleaning Conference. They cover the development of high-strength filters, the ongoing work of the National Nuclear Ventilation Forum in the continuous development of the UK nuclear industry ventilation Engineering Standards and Design Guides, a brief update of work on the Sellafield site, and recognition of the 2019 and 2021 IMechE Nuclear Ventilation Conferences.

DEVELOPMENT OF HIGH-STRENGTH HEPA FILTERS FOR THE UK

The new Code Section FM, due to be published in the 2022 Edition of the ASME AG1 Code on Nuclear Air and Gas Treatment, will offer more robust options to conventional glass-fibre media HEPA filters which are known to have limitations under certain operating conditions [1,2].

In the UK, the Sellafield site alone has over 3500 final discharge HEPA filters and the cost of replacing these filters due to age management or exposure to moist air streams, when considering filter disposal costs, can be significant. As high-strength filter media has been shown to be significantly stronger than conventional media [1], if evidence can show that this increased strength is maintained in-service, then this would give a basis for extended filter life on those filters that are changed for the purposes of age management or those filters exposed periodically to moisture. This would offer significant benefits in reducing filter waste and waste disposal costs and result in less exposure of operators to the hazards of filter changing. It would also provide significant environmental benefits of less waste filters in the ground and the reduced carbon emissions for replacement filters which would support the UK Nuclear Decommissioning Authority's (NDA) Carbon Net Zero Emissions Beacon Project.

Testing of high-strength filters within the UK, at the Atomic Energy Research Establishment Harwell laboratory, was reported at the 34th Nuclear Air Cleaning Conference [3]. The tests using Lydall media 255LW were described as promising, but the work was not pursued due to the priority to develop circular radial flow filters and the inability to fabricate machine pleated panels with the high-strength media [3]. Following the closure of the Harwell laboratory in the 1990s, there does not appear to have been anymore work carried out within the UK to develop high-strength glass-fibre filters for the nuclear HVAC market.

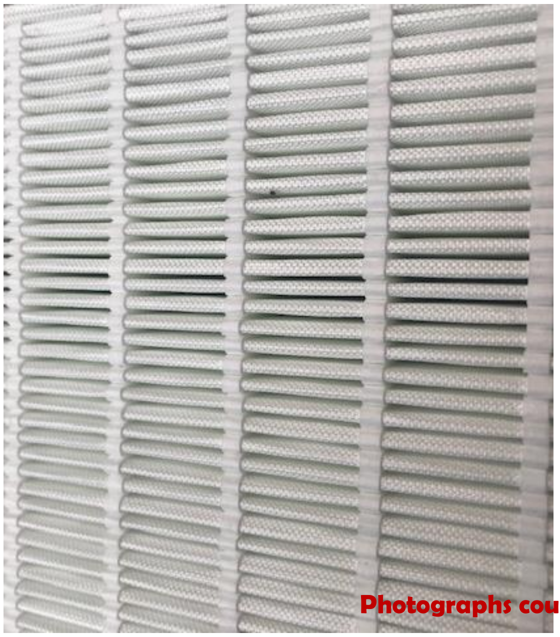
Current day high-strength glass fibre filter media available from Lydall [4] uses conventional 3398 nuclear grade media which is then laminated on either one side or both sides with a woven glass scrim. 3398-L1W high-strength media has a single layer of reinforced glass scrim. 3398-L2W high-strength media has a layer of reinforced glass scrim on either side.

Due to the limited funding readily available to develop high-strength glass fibre filters in the UK, the recent work commissioned by Sellafield Ltd has focused solely on the double scrim 3398-L2W media. The following sections detail a timeline of this development work carried out, on behalf of Sellafield Ltd, by Emcel Filters Ltd with observations on results obtained up until March 2022.

Initial pleating trials and preliminary testing of high-strength media

In early 2020, pleating trials were carried out on 3398-L2W high-strength media [5]. Using 50mm deep pleats, 3 off 309 x 309 x 95mm casing dimension filters were manufactured, each comprised of approximately 70 pleats.

Using a similar pleat density, 3 off filters of the same size using conventional AX3398 media were also manufactured to allow some comparison testing between the two types of media. The 3 off AX3398 filters comprised approximately 75 pleats.



Photographs courtesy of Emcel Filters Ltd

Figure 1 - 3398-L2W pleated filter pack [5]

Figure 2 – 309 x 309 x 95 mm 3398-L2W filter

The UK industry, going back into the 1980s has adopted a 500°C 10 minute oven test for its high temperature filters with no apparent scientific basis, other than demonstrating that the filter materials of construction will not support combustion when subjected to a temperature similar to that used for testing standard building components [3]. To meet this 500°C test, the filters use a ceramic encapsulent making it more fragile with cracking of the encapsulent observed on new filters which may have been mishandled. This in turn can increase the likelihood of a ‘failed’ filter on its pre-service efficiency test.

These high-strength filter test samples were manufactured to withstand an oven test upper limit set at 325°C, which is 17°C below the lower tolerance level allowed on the ASME AG1 370°C +/- 28°C heated air test. This lower test temperature (compared to the historic 500°C figure) allowed the trial use of an elastomer encapsulent which is more forgiving than the ceramic encapsulent, with the intention of making the filters more robust and potentially leading to less damaged filters.

All filters were initially tested for pressure drop and efficiency over a range of flowrates before one of each filter type was subjected to progressive 2 hour oven trials at 150°C, 250°C and 325°C after which they were observed and then re-tested for pressure drop and efficiency.

One of the non-oven tested high-strength filters was fully immersed in a water trough for 5 minutes and after drying out was re-tested for efficiency and pressure drop. All of the filter efficiency tests were carried out using a thermally generated DOP challenge.

Airflow	**23.6l/s (50cfm)**	**47.2l/s (100cfm)**	**70.8l/s (150cfm)**	**94.4l/s (200cfm)**	**118l/s (250cfm)**
Pressure drop					
AX3398	87Pa	160Pa	279Pa	388Pa	505Pa
3398-L2W	89Pa	186Pa	289Pa	400Pa	521Pa
Penetration					
AX3398	0.0013%	0.0040%	0.0060%	0.0098%	0.0128%
3398-L2W	0.0020%	0.0067%	0.0111%	0.0160%	0.0213%
Efficiency					
AX3398	99.9987%	99.9960%	99.9940%	99.9902%	99.9872%
3398-L2W	99.9980%	99.9933%	99.9889%	99.9840%	99.9787%
70.8l/s equates to approx. 3.15cm/s (6.2ft/min) for AX3398 and 3.37cm/s (6.6ft/min) for L2W media					

Table 1 – Average pressure drop and filter efficiency results prior to oven testing [6]

Table 1 shows the average values of pressure drop and efficiency for the test filters in a clean dry state. Each of the 6 filters was tested at 5 different flow rates ranging from 50cfm to 250cfm. The results column highlighted in yellow for a flow rate of 150cfm or 70.8l/s corresponds to the approximate rated flow for filters containing this amount of filter media.

AX3398 designates the conventional filter media, and 3398-L2W designates the high-strength media with the double reinforced scrim. The results show the average pressure drop for the 3 high-strength filters at 150cfm was 289Pa , compared with 279Pa for the conventional filters so less than 4% higher.

For the same flow rates, the average efficiency of the high-strength filters is lower than the efficiency of the conventional filters. As the medias are made to meet different flat sheet efficiencies - 99.994% for the European sourced conventional filter media [7] versus 99.985% for the US sourced high-strength media [8]– this may have accounted for some of the recorded efficiency difference along with the higher velocity through the high-strength media.

For the oven trials, one of the conventional media filters and one of the high-strength filters was placed in the oven for a period of 2 hours at an oven operating temperature of 150°C. After removal of the filters from the oven there were no signs of degradation on either filter.

The same filters were placed in the oven for a further period of 2 hours at an oven operating temperature of 250°C. Figure 3 shows both filters after removal from the oven. The media on both filters had browned, with the pleats showing signs of distortion. The encapsulant was still visually in-tact, but it appeared as though softening of the encapsulent may have aided pleat distortion.

Photographs courtesy of Emcel Filters Ltd

High-Strength media Conventional media

Figure 3 – Oven testing – 250°C for 2 hours [5]

The same filters were placed in the oven for a further period of 2 hours at an oven operating temperature of 325°C. Figure 4 shows both filters after removal from the oven. The encapsulent had bubbled on both filters with pleat distortion prominent.

Photographs courtesy of Emcel Filters Ltd

High-Strength media Conventional media

Figure 4 – Oven testing – 325°C for 2 hours [5]

Table 2 shows the results when these 2 filters were then both re-tested for pressure drop and efficiency for the same 5 flow rates ranging from 50cfm to 250cfm as for the pre-oven testing.

Airflow	**23.6l/s (50cfm)**	**47.2l/s (100cfm)**	**70.8l/s (150cfm)**	**94.4l/s (200cfm)**	**118l/s (250cfm)**
Pressure drop					
AX3398	86Pa	179Pa	275Pa	380Pa	496Pa
3398-L2W	90Pa	188Pa	294Pa	409Pa	531Pa
Penetration					
AX3398	0.0011%	0.0022%	0.0050%	0.0077%	0.0122%
3398-L2W	0.0030%	0.0069%	0.0117%	0.0138%	0.0204%
Efficiency					
AX3398	99.9989%	99.9978%	99.9950%	99.9923%	99.9878%
3398-L2W	99.9970%	99.9931%	99.9883%	99.9862%	99.9796%
70.8l/s equates to approx. 3.15cm/s (6.2ft/min) for AX3398 and 3.37cm/s (6.6ft/min) for L2W media					

Table 2 – Average pressure drop and filter efficiency results post oven testing [6]

The pressure drop for the high-strength filter @150cfm had increased by 5Pa post oven. The pressure drop for the conventional filter @150cfm showed a drop of 4Pa post oven. The measured efficiencies of the 2 filters @150cfm were virtually identical compared with the pre-oven testing.

The oven trials had therefore not significantly affected either the pressure drop or efficiency of the tested filters – although it should be noted that these oven trials were carried out on only a single filter of each type.

Table 3 shows the results for pressure drop and efficiency of the single high-strength filter pre and post water bath test. The filter was fully immersed in a trough of water for 5 minutes. It was then removed from the trough and after drying overnight was placed in an oven at 100°C for one hour. The filter was allowed to cool before being tested for efficiency and pressure drop.

Airflow	**23.6l/s (50cfm)**	**47.2l/s (100cfm)**	**70.8l/s (150cfm)**	**94.4l/s (200cfm)**	**118l/s (250cfm)**
Pressure drop					
Pre immersion	88Pa	185Pa	285Pa	403Pa	517Pa
Post immersion	122Pa	242Pa	340Pa	442Pa	580Pa
Penetration					
Pre immersion	0.0008%	0.0054%	0.0076%	0.0132%	0.0189%
Post immersion	0.0032%	0.0097%	0.0177%	0.0193%	0.0247%
Efficiency					
Pre immersion	99.9992%	99.9946%	99.9924%	99.9868%	99.9811%
Post immersion	99.9968%	99.9903%	99.9823%	99.9807%	99.9753%
70.8l/s equates to approx. 3.15cm/s (6.2ft/min) for AX3398 and 3.37cm/s (6.6ft/min) for L2W media					

Table 3 – Results for 3398-L2W filter pre and post water immersion [6]

The immersion in water and subsequent drying of the filter had a negative effect on its performance, with both the recorded pressure drop and penetration rising compared to the pre immersion values. The increased pressure drop (from 285Pa to 340Pa) suggests that there may have been some residual moisture held up in the filter media. However, the filter continued to function at an efficiency only marginally less than the 99.99% required to meet the UK standard for a thermally generated DOP challenge [9].

Comparative efficiency testing of 5 no. 160l/s radial flow high-strength filters

In 2021, 5 no. cylindrical (radial flow) filters were manufactured by Emcel Filters using 3398-L2W media to the same geometry as that used for a 160l/s rated filter manufactured using conventional nuclear grade AX3398 filter media. 220 pleats at 50mm were used giving an open media area of 6.05m^2 and an approximate media velocity of 2.6cm/s. The filters were each efficiency tested at the rated flow of 160l/s. For comparison purposes, each filter was tested using 3 different test methods.

Filter No.	BS 3928 Sodium flame	EN 14644-3 DOP Laskin nozzle	EN 14644-3 DOP Thermally generated	Pressure drop @ 160l/s
1	99.9947%	99.9955%	99.9820%	440Pa
2	99.9990%	99.9989%	99.9843%	455Pa
3	99.9989%	99.9994%	99.9869%	450Pa
4	99.9988%	99.9990%	99.9844%	615Pa
5	99.9986%	99.9990%	99.9859%	327Pa

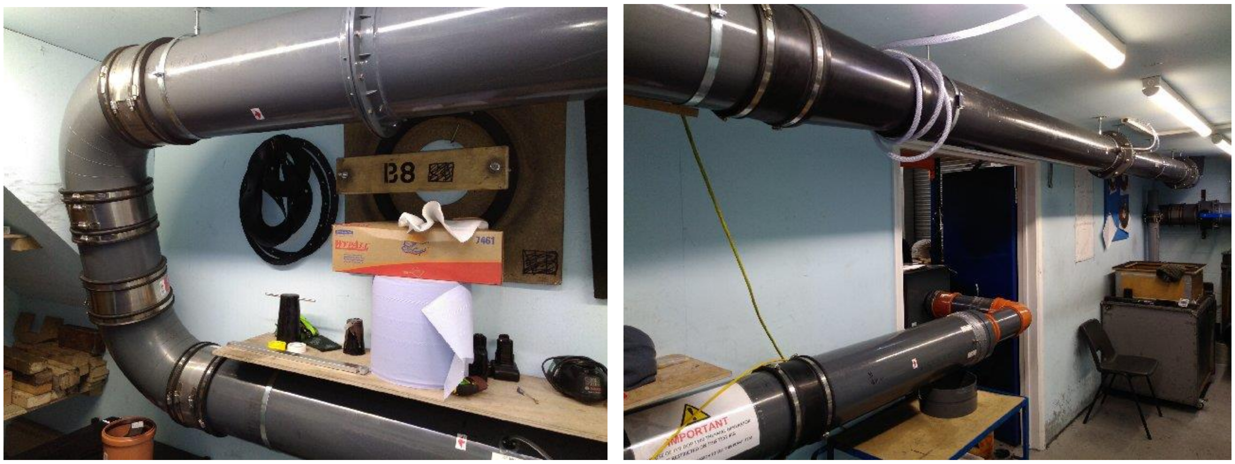
Table 4 – Results of efficiency testing for 3398-L2W 160l/s radial flow filters [10]

The results in Table 4 show that the BS3928 sodium flame test gives very similar results to a laskin nozzle cold DOP test. This testing also indicates that the thermally generated hot DOP test is a more searching test for HEPA filters as it shows significantly lower efficiencies and therefore lower decontamination factors. It was unclear why the pressure drop across filters 4 and 5 were significantly different than the other 3 filters.

Cyclic moisture testing of 160l/s high-strength radial flow filters

In the event of any moisture carryover onto final discharge HEPA filters, the current practice on the Sellafield site is to instigate a filter change. This is based on the established knowledge that both the tensile strength and stiffness of the glass fibre media, in conventional nuclear grade HEPA filters, decrease significantly when the media becomes wet [2]. It is not uncommon for free moisture generation to occur within vessel ventilation systems leading to wetting of the downstream HEPA filters. As early work carried out on high-strength filters [1] showed that their tensile strength can be typically 90 times greater when wet than that of conventional glass-fibre media, a series of moisture trials, using a steam challenge, was carried out on the 160l/s rated radial flow high-strength filters to measure the effect of repeated wetting/drying cycles. The results would contribute to the substantiation of a case for challenging the precautionary approach of initiating filter change-out if filter wetting is suspected.

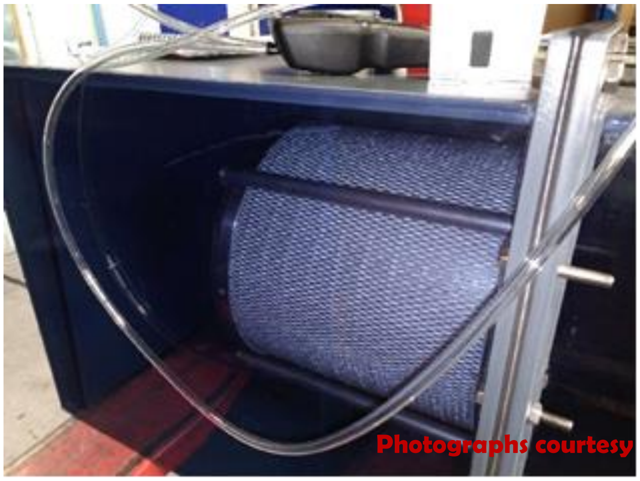
All 5 filters were placed in an oven for 2 hours at 120°C before commencing the cyclic moisture testing. Filter 1 was used to trial the performance of the test rig assembled for the moisture testing, to establish the required capacity for steam injection equipment and establish a reasonable time interval between wetting cycles to allow the filter pressure drop to fully recover. During these trials, Filter 1 was subject to a moisture challenge for a total period of 59 minutes.



Photographs courtesy of Emcel Filters Ltd

Figure 5 - 160l/s cyclic moisture filter testing rig [11]

As the tests were being carried within a working factory with little control over room air temperatures or humidity, and the steam injection would be done with no feedback control; it was apparent that an element of trial and error (using filter 1) was required to establish how much steam capacity would be required to maintain 100% relative humidity (RH) within the airstream. Similarly, the required steam capacity would vary dependent upon room humidity levels, which in turn would vary with external ambient conditions. Without feedback control, to ensure a 100% RH airstream was maintained through the test filters, it was required to super saturate the air. This led to the presence of 'free moisture' within the air upstream of the filter and resulted in an increase in differential pressure across the filter.



Photographs courtesy of Emcel Filters Ltd

Figure 6 – 160l/s filter in test box under test [11]

Figure 7 – 160l/s high-strength filter [12]

Prior to commencing the cyclic moisture trials, Filter 2 was re-tested for efficiency using a thermal DOP challenge, before being subjected to 6 x 3 minute steam challenges with a 15 minute recovery interval between each wetting cycle. On completion of the 6 off wetting cycles Filter 2 was again tested for efficiency.

Following the 6 wetting cycles and efficiency testing, Filter 2 was disassembled, and samples were cut from the filter pack for tensile strength testing. 12 samples were cut each approximately 500mm long. The 2 ends of each sample were of 25mm width with the middle section tapered from each end to give a 12mm width neck in the centre section of the sample. These tensile strength tests were carried out 4 days after the moisture testing, so the filter pack was in a dry state.

Filter 3 was re-tested for efficiency using a thermal DOP challenge, before being subjected to 16 x 3-minute steam challenges with a 15-minute recovery interval between each wetting cycle. On completion of the 16 off wetting cycles Filter 3 was again tested for efficiency. Tensile strength tests were then carried out on filter 3. These tests were completed 14 days after the moisture testing with the filter pack in a dry state.

For one of the samples tested from the Filter 3 pack, an estimate was made of media elongation prior to rupture. The distance between the 2 clamping devices, with a 20kg (16.3kN/m) load added and no obvious visible elongation of the sample, was measured at 308mm. Just prior to sample rupture this distance had increased to 321mm showing that elongation of this sample prior to rupture was approximately 4% of its original length.

Filter 4 was re-tested for efficiency using a thermal DOP challenge, before being subjected to 48 x 3 minute steam challenges (over a 3 day period) with a 15 minute recovery interval between each wetting cycle. On completion of the 48 off wetting cycles Filter 4 was again tested for efficiency. Tensile strength tests were then carried out on filter 4. These tests were completed 16 days after the moisture testing with the filter pack in a dry state.

	Recorded efficiency using a thermal DOP challenge @ 160l/s			
	Filter 1	**Filter 2**	**Filter 3**	**Filter 4**
Pre -oven	99.9820%	99.9843%	99.9869%	99.9844%
Post-oven	99.9816%	99.9791%	99.9740%	99.9780%
Post 59 mins of moisture challenge	99.9700%			
Post 6 x 3minutes of moisture challenge		99.9810%		
Post 16 x 3minutes of moisture challenge			99.9720%	
Post 48 x 3minutes of moisture challenge				99.9687%
Post 48 x 3minutes of moisture challenge plus 4 days to ‘dry out’				99.9824%

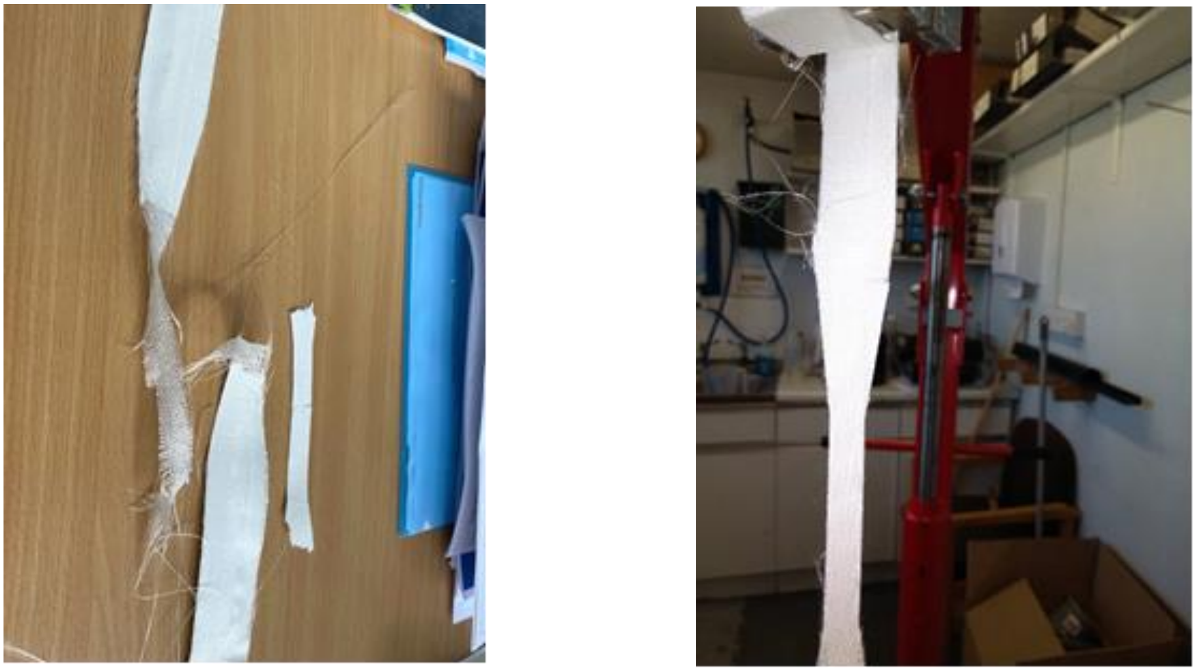
Table 5 – Recorded filter efficiencies pre and post cyclic moisture testing [10, 11]

Table 5 shows how the measured efficiency of the test filters exhibited a tendency to reduce marginally with increasing numbers of moisture challenges, when the efficiency of the filter was measured in the still ‘wet’ state immediately after completion of the requisite number of the moisture challenge cycles. However, when filter 4, which was subjected to 48 moisture cycles, was re-tested 4 days later, it appeared to show a recovery in its measured efficiency to a level very close to the pre-testing value. Similarly, as filter 4 moisture cycles were carried out over 3 days, with efficiencies measured at the start and end of each day, the filter exhibited some recovery in efficiency overnight [10, 11].

	Average Tensile strength of samples (kN/m)
Raw filter media (unpleated)	27
Pleated filter media	26
Pleated filter media post 2hrs in oven @ 120°C	28
Filter 2 post oven and 6 moisture cycles	24.5
Filter 3 post oven and 16 moisture cycles	23.6
Filter 4 post oven and 48 moisture cycles	26.9

Table 6 – Media tensile strength test results pre and post cyclic moisture testing [10, 11]

Whilst the cyclic moisture testing was carried out on only 3 filters, and therefore it could be argued that the results are not fully conclusive or be relied upon to give absolute values, the consistency of the results in Table 6 give a level of confidence that, when the high-strength media is subjected to moisture challenges, it retains a significant percentage of its original tensile strength. Similarly, placing the pleated high-strength media in an oven at 120°C for 2 hours does not appear to reduce the tensile strength.



Photographs courtesy of Emcel Filters Ltd

Figure 8 –High-strength filter media tensile strength testing [11]

As the tensile strength for conventional nuclear media is typically around 0.7kN/m, for these test samples, the high-strength filter media is showing tensile strengths after wetting more than 30 times greater than that of conventional media in its dry state.

Only a single media sample (from filter 3 post moisture challenge) was measured for elongation prior to rupture with an elongation value of 4%. Whilst this is not conclusive, on all samples it was easy to see the media sample 'stretching' prior to rupture. This is not the case during tensile testing of conventional AX3398 media. More elongation testing is required to estimate an approximate elongation to rupture value for the 3398-L2W media, but the visual indications give sufficient confidence to suggest that high-strength HEPA filters under challenge would be far less brittle than conventional AX3398 media HEPA filters.

	Pressure drop at start of cycle 1 of moisture testing @ 160l/s	**Pressure drop following completion of 6, 16 or 48 cycles of moisture testing plus the 15 minutes drying period @ 160 l/s**
Filter 2	497Pa	470Pa
Filter 3	457Pa	440Pa
Filter 4	646Pa	648Pa

Table 7 –Pressure drop pre and post moisture testing [10]

The tests results from Table 7 showed that exposure of the high-strength media to a cyclic moisture challenge did not result in a measurable increase in pressure drop once the filter had been given a short time (15 minutes) to dry out. It is unclear why the pressure drop across filter 4 was significantly higher than the other 2 filters.

Wet pressure tests to 5kPa and 12kPa of 160l/s high-strength radial flow filter

Filter 5 was re-measured for efficiency and differential pressure and then inserted into the filter test box, within the existing test rig. A pressure washer was directed into the box which established a maximum recorded pressure drop across the filter of 5.3kPa [10].

The filter was re-tested for efficiency and differential pressure the following morning. The fan was left to run for some time to dry out the filter, which was then tested again for efficiency and differential pressure. The filter was then left over the Christmas break after which it was re-weighed and re-tested for efficiency.

	Efficiency using a thermal DOP challenge @ 160l/s	**Differential pressure @ 160l/s**	**Mass of filter**
Filter 5 - 14/12/21 dry (pre-test)	99.9719%	327Pa	8066g
Filter 5 - 15/12/21 post 5kPa wet pressure test	99.8790%	1110Pa	
Filter 5 - 15/12/21 12:45 after some drying time	99.9141%	738Pa	9152g
Filter 5 - 16/12/21 morning			8830g
Filter 5 – 04/01/2022	99.9542%		8099g

Table 8 –5kPa wet pressure test results [10]

Filter 5 was re-tested for efficiency and differential pressure with the main fan. A side channel blower was then set up to conduct a higher differential pressure test on Filter 5. Water was then added using the pressure washer up to a differential pressure of 12kPa which was the limit of the side channel blower. The filter was removed from the test rig with the recorded weight above 9kg and left to dry out before carrying out an efficiency test using the main test fan to examine the impact of the 12kPa wet pressure test.

	Efficiency using a thermal DOP challenge @ 160l/s	**Differential pressure @ 160l/s**	**Mass of filter**
Filter 5 – 17/01/22 dry (pre-test)	99.9560%	352Pa	8106g
Filter 5 – 21/01/22 7.30am post 12kPa wet pressure test	99.9002%		8600g
Filter 5 – 21/01/22 8.30am after running the test rig for 1 hour	99.9192%		8159g

Table 9 –12kPa wet pressure test results [10]

Subjecting Filter 5 to a water spray resulted in a marked decrease in efficiency, but after a drying out period to allow evaporation of residual moisture, the recorded efficiency improved again, although not to its pre-wetted level. Subjecting the filter to a dry air stream was shown to be the quickest way to remove the moisture. It was suggested that exposure to the water and the high differential pressure may have ‘flattened’ the ‘loft’ in the media and caused some of the smaller fibres in the media to combine. This may have contributed to reducing the efficiency of the filter.

Manufacture of ‘full size’ high-strength radial flow filters

In early 2022, 4 no. cylindrical radial flow filters were manufactured using 3398-L2W media to the same geometry as that used for a 950l/s rated filter manufactured using conventional nuclear grade AX3398 filter media to ES_0_1737_2 [13]. Approximately 330 pleats at 67mm were used giving an approximate effective media area of 330 x 0.067 x 2 x 0.575 = 25.4m^2. The filters were efficiency tested at 950l/s and 850l/s to establish the rated flow using the acceptance criteria for filter efficiency of 99.99% minimum using a thermally generated DOP challenge.

Photographs courtesy of Emcel Filters Ltd

Figure 9 – ‘Full size’ high-strength radial flow filter and filter under test in bag change housing [11]

Filter	efficiency @ 950 l/s	pressure drop @ 950 l/s	efficiency @ 850 l/s	pressure drop @ 850 l/s	mass
1	99.9916%	375Pa	99.9908%	335Pa	24.428kg
2	99.9905%	385Pa	99.9919%	340Pa	24.215kg
3	99.9904%	390Pa	99.9928%	340Pa	24.183kg
4	99.9924%	385Pa	99.9922%	340Pa	24.585kg

Table 10 – Recorded filter efficiencies for ‘full size’ high-strength radial flow filters [11]

All 4 no. filters gave a measured efficiency which just exceeded the 99.99% minimum requirement at 950l/s. UK manufactured 950l/s radial flow filters using conventional nuclear grade AX3398 filter media have been observed to routinely deliver efficiencies in excess of 99.995% using a thermally generated DOP challenge.

Reducing the flowrate to 850l/s gave only a marginal increase in measured efficiency and so the rated flow was therefore established as 950l/s on the basis that the 3398-L2W unpleated media probably has a lower efficiency than conventional nuclear grade AX3398 unpleated filter media. As the 2 medias are made to meet different flat sheet efficiencies - 99.994% for the European sourced conventional filter media versus 99.985% for the US sourced high-strength media - this may account for some of the recorded efficiency difference along with the higher velocity through the high-strength media.

Should future testing of high-strength filters (using different batches of 3398-L2W media) show similar efficiency results, then the minimum efficiency requirement for double scrim high-strength filters, for use in the UK, could well be set below the 99.99% figure for a thermally generated DOP challenge currently used for filters manufactured using conventional nuclear grade media manufactured to comply with ES_0_1730_2 [14].

Forward work plan for high-strength filter development

Despite an argument that could be put forward for adopting high-strength filters on most nuclear ventilation systems, purely for reasons of improving resilience and reliability, it is not unforeseeable - given an industry which has been using essentially the same type of comparatively weaker (but cheaper) conventional media filter for the past 40-50 years – to predict that a viable economic case will need to be made before end users in the UK nuclear industry choose to widely adopt high-strength filters.

Consequently, the planned Sellafield Ltd funded development work going forward will aim to provide substantiated cases for extended filter life of high-strength filters both in benign air streams and in air streams exposed to a moisture challenge. Any significant increase in filter life will lead to a reduction in waste disposal costs (typically per filter an order of magnitude greater than filter purchase cost) that will, over time, far outweigh the increase in purchase cost of a high-strength filter compared to a conventional nuclear grade media filter.

It is envisaged that this ongoing development work will include the following tasks:

- wet pressure testing up to 12kPa of a 950l/s rated radial flow high-strength filter
- dust loading up to 10kPa of a 950l/s rated radial flow high-strength filter
- comparative cyclic moisture testing on 3 no. 160l/s rated radial flow AX3398 media filters
- investigate artificial ageing testing of high-strength pleated media and associated filters
- manufacture rectangular axial flow 850l/s rated mini pleat high-strength filters to commence long term in-service ageing tests on air inlet systems
- agree through the UK National Nuclear Ventilation Forum (NNVF) on the type (qualification) testing programme for high-strength filters
- complete type testing of 500l/s axial flow deep pleat, 850l/s axial flow mini-pleat and 950l/s radial flow high-strength filters

ONGOING WORK OF THE NATIONAL NUCLEAR VENTILATION FORUM (NNVF)

The NNVF is a sub-group of the UK Nuclear Engineering Directors Forum. The NNVF is attended by members of UK nuclear site licence companies, representatives of the Office for Nuclear Regulation and Environment Agency, nuclear ventilation practitioners within the supply chain and representatives from ventilation plant item manufacturers. The NNVF meets 3 times per year to discuss and document good practices relating to nuclear ventilation.

In 2018 the NNVF set up its Group page on the NDA HUB, which is the UK Nuclear Decommissioning Authority’s approved platform for business units to collaborate with one another in a secure environment. The HUB has become the main communication platform and knowledge management tool for the NNVF, allowing external parties (suppliers, regulators, partners etc.) to access and share information.

On-line training

In 2020 a Training sub-group of the NNVF was set up to focus on providing free-to-attend training for anyone working in, or with an interest in, the nuclear ventilation discipline. The sub-group arranges monthly, 1 hour long, on-line continued professional development (CPD) presentations given by a variety of speakers on a wide range of subject matter relating to the discipline. Originally aimed at apprentices, graduates and younger engineers, the presentations have been very successful in attracting audiences at all levels of experience both within and outside of the nuclear ventilation discipline with attendances for the on-line presentations exceeding 200. Presentations are uploaded onto the HUB for free access.

New Standards for glove box filters

As part of its remit, the NNVF has input into the production and periodic update of the NDA Engineering Standards and Guides. Since 2018 new Engineering Standards have been produced for two types of filters designed for use within glove boxes on air or gas inlet flows. The dimensions of the filters are such that they can be posted through a 190mm diameter posting port.

Figure 10 shows the 6l/s bayonet mounting filter manufactured to ES_0_1739_2 [15]. Figure 11 shows the 1.5l/s bayonet mounting canister filter manufactured to ES_0_1713_2 [16].

Photographs courtesy of Camfil Ltd

Figure 10 – 6l/s bayonet filter [15]

Figure 11 – 1.5l/s bayonet canister filter [16]

New Guide and Standard for Vortex Amplifiers

Vortex Amplifiers (VXAs) have been used across several UK nuclear licensed sites since the 1970s. The VXA is a no-moving-parts variable fluid resistance device originally developed in the early 1960s for the manipulation of pneumatic and hydraulic signals, but subsequently much larger devices were developed with a view to direct control of process flows of various types. The pressure-flow characteristics of the VXA were found to satisfy certain requirements for the control of active ventilation systems in the nuclear industry - and more specifically for depression control on glove boxes - and the no-moving-parts nature of the device offered very high reliability and maintenance free operation.

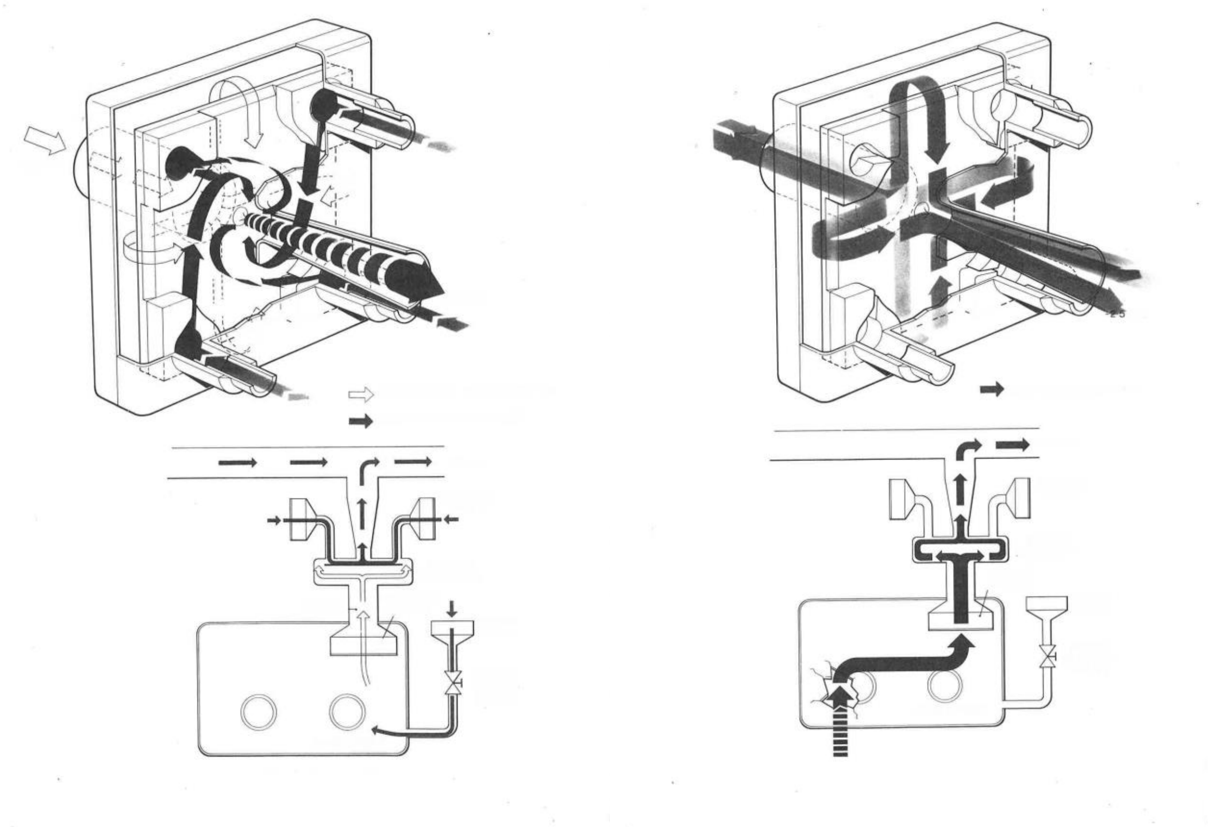


Figure 12 – 1974 UKAEA VXA design showing ‘normal’ flow (L) & ‘breach’ flow (R) [17]

The following graph, Figure 13, shows a typical VXA performance characteristic when fitted onto a glove box.

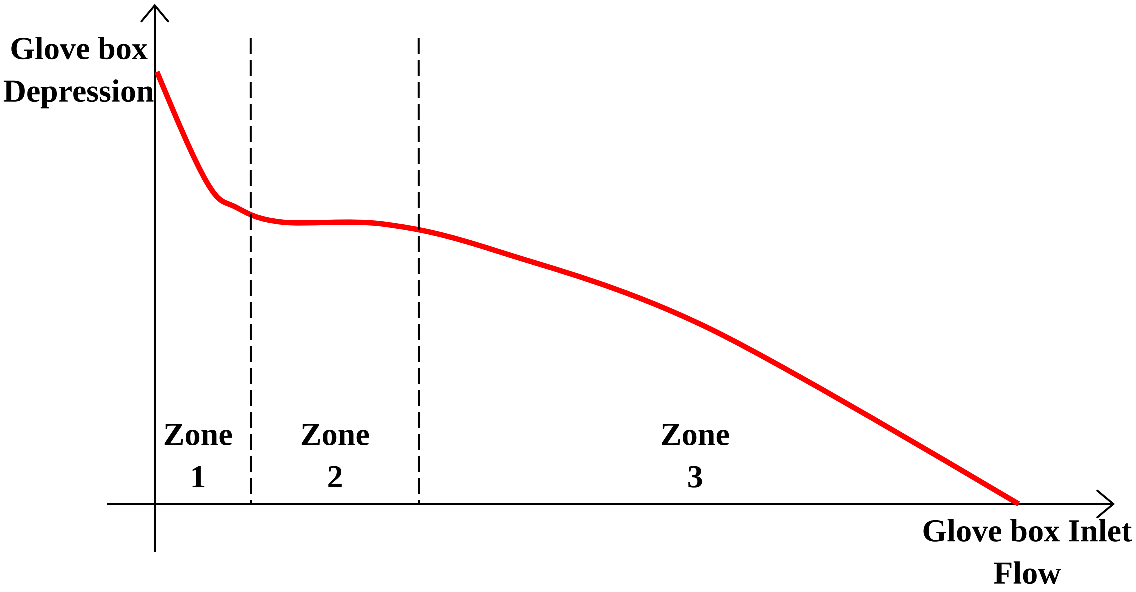


Figure 13 - Typical Vortex Amplifier Performance Profile [17]

Zone 1 – At the start of the test with the inlet to the glove box closed off, all of the air flow into the VXA is through the control ports with zero flow from the glove box. As the inlet valve to the glove box is opened gradually, air begins to enter the glove box and there is a sharp initial drop in glove box depression. The air flow through the control ports drops initially when the inlet valve is first opened and then remains fairly constant.

Zone 2 – As the inlet valve to the glove box is progressively opened more, the glove box depression remains fairly constant for a range of inlet flows. The air flow through the control ports is also fairly constant over this range. This is considered as the normal working zone for vortex amplifiers, such that they can maintain a steady glove box depression for a relatively large range of inlet flows.

Zone 3 - As the inlet valve to the glove box is opened still further and the air flow into the glove box increases to match and start to exceed the air flow through the control ports, the glove box depression starts to drop. This drop in glove box depression increases with increasing air flow into the glove box, such that most of the air flow into the vortex amplifier is coming from the glove box. This is the region in which the vortex amplifier operates during a ‘breach’ of the glove box, e.g., loss of a glove when the increase in flow ensures a minimum velocity through the breach opening of at least 1m/s. At the breach flow condition, and consequent loss of glove box depression, the header depression will also decrease although this will depend on the fan characteristic and the installed system configuration.

There are a number of VXAs currently being manufactured and tested for projects on the Sellafield site, and whilst most historical VXA installations on UK Nuclear Licensed sites have been bespoke, the current VXA work is being used to allow designers to move away from these bespoke designs and adopt a standard design which is known to be suitable for a range of conditions.

A new design guide EG_0_1706_1 [17] is in the process of being written to provide both background information on the use of VXAs as a depression control method for glove boxes, and to assist the designer in the specification of VXAs to the new generic specification ES_0_1706_2 [18].

The standard design of VXA, for which the Engineering Standard ES_0_1706_2 is written, incorporates a 'push through' filter on the downstream side of the VXA, the design of which has been used for a number of years on the Sellafield site, and is depicted in Figure 14.

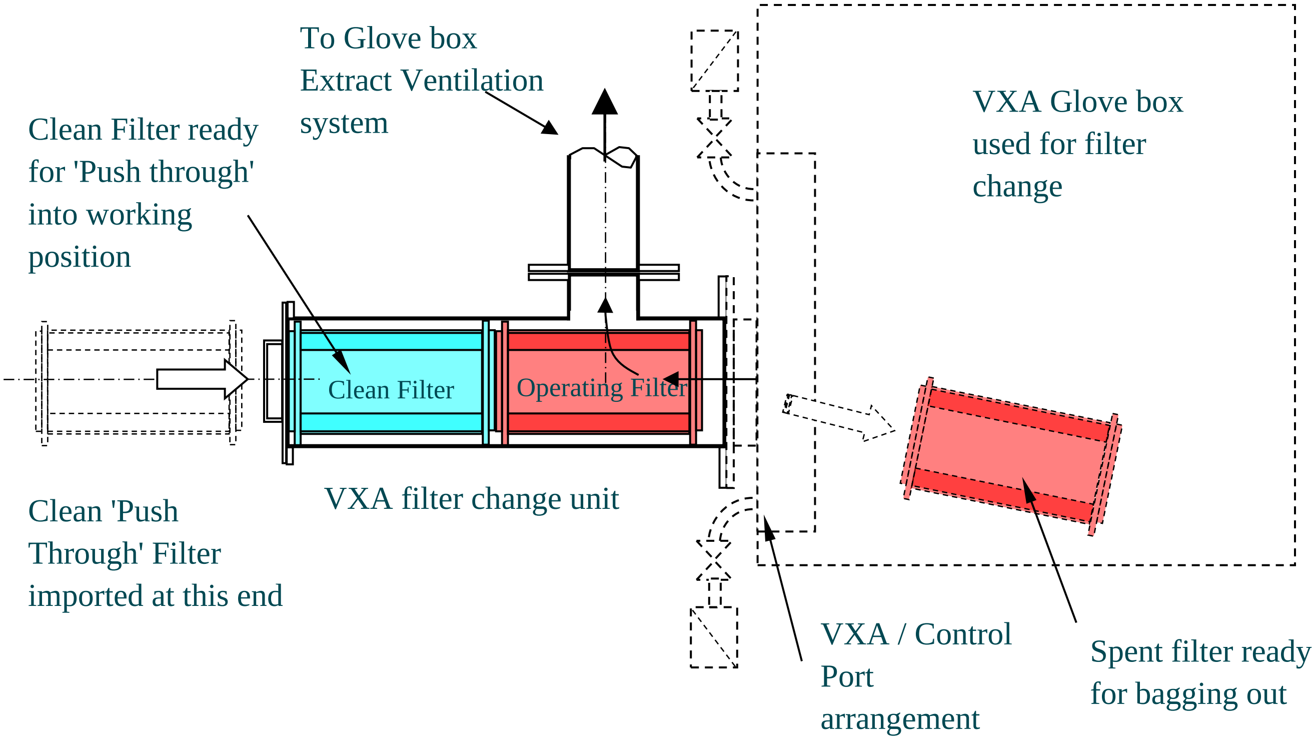


Figure 14 - General Arrangement Showing VXA with 'Push Through' Filter [19]

There are alternative configurations for the standard VXA. Duty and standby VXAs (to allow on-line filter change) can be installed into the end of a dedicated VXA glove box, i.e., a glove box not required as a 'working' or 'process' glove box but provided purely for housing the VXA. This allows a pair of VXAs to serve a suite of glove boxes.

For single glove box installations, the standard VXA design can be installed, space permitting, on the end face of the glove box. Alternatively, a separate dedicated VXA glove box would avoid having to fit the VXA within the 'process' glove box and would give the flexibility for further glove boxes to be added on that system at a later date.

Figure 15 - Standard VXA with 6l/s control port filters [17]

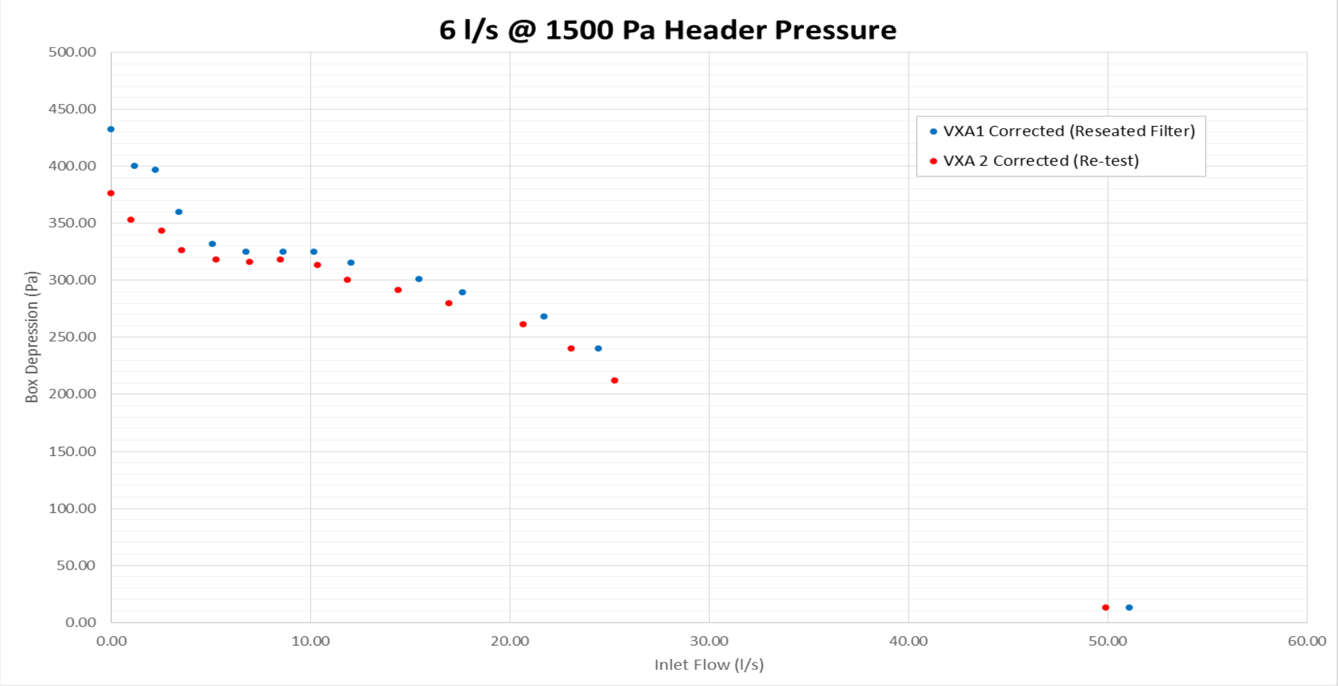


Figure 16 – Test results graph of box depression vs flow for standard VXA [17]

Figure 15 shows a photograph of a standard VXA, under test, with 6l/s control port filters installed on the end of the glove box and a flexible hose connecting the outlet port to the test fan. This standard VXA design will cover a normal glove box inlet flow operating range of approximately 5 to 12l/s during which the glove box is held at a fairly constant depression. This can be seen from the ‘flat’ part of the curves on the graph in Figure 16, which depicts test data from 2 VXAs fitted to the same glove box. From this approximate range, the designer can decide how many glove boxes a single VXA can support once the requirements for the individual glove box flow rates are known.

UPDATE FROM THE SELLAFIELD SITE

The Sellafield site has continued its transformation with the end of reprocessing on the site and the focus moving onto accelerated progress in decommissioning and hazard reduction. Sellafield has the largest radioactive inventory and the most complex facilities to decommission amongst the 17 Nuclear Decommissioning Authority sites across the UK, with current plans indicating it will take more than 100 years to complete nuclear clean-up and waste management across the sites [20].

The site continues to focus on safe, efficient management of wastes, including: the conversion of Highly Active Liquor into passively safe vitrified waste; the return of vitrified material overseas; and the management of on-site intermediate and low level wastes. The areas of principal focus are the redundant Legacy Ponds and Silos facilities, which supported the development of the nuclear programme in the UK from the early 1950s. The programmes include the removal of nuclear fuel, sludge and solid material prior to treatment and storage in a passive condition [20].

Historically, Sellafield Ltd has managed and delivered complex major projects by self-performing the early design works and engaging the supply chain in various engineer, procure, construct type arrangements on a project-by-project basis. The Programme and Project Partners model has now been put in place to establish long-term relationships to deliver Sellafield Ltd’s major projects and decommissioning programme. The Programme and Project Partners is the delivery vehicle for all new build major projects on the site over the next 20 years, with a total forecast spend of £7 billion over its 20-year duration [21].

This approach partners Sellafield Ltd with 4 lot partners each of which has a designated scope covering Integration, Design and Engineering, Civils Construction Management, and Process Construction Management. Each lot partner integrates their areas of expertise together with Sellafield Ltd resources, to form Aligned Delivery Teams [21].

2019 IMECHE NUCLEAR VENTILATION CONFERENCE

The 9th Institute of Mechanical Engineers (IMechE) Ventilation Conference was held as a 2-day event in Manchester in November 2019 comprising 23 presentations covering ventilation themes from Nuclear New-Build, Waste Stores, Decommissioning, Ageing Management, as well as the latest work being carried out in the field of HEPA filtration and Vortex Amplifiers [22]. There was significant international representation at the Conference with presenters from France, Germany, China, and the United States. A summary of two of the presentations from the Conference is given below.

‘Protecting the Investment’: The Interim Storage of Radioactive Waste Packages in the UK – C. Nash, R Hardy [23]

Radioactive waste stores are in operation at 25 sites across the UK. Further stores are planned up to approximately 40 with half of these required on the Sellafield site. More than 80,000 waste packages are presently in interim waste stores with an estimated 220,000 in total destined for the Geological Disposal Facility which is planned to provide long term storage.

Photographs from Radioactive Waste Management presentation reference 23

Figure 17 – 500l waste container [23]

Figure 18 – 500l drum stillages in waste store [23]

The Nuclear Decommissioning Authority publish industry guidance on interim storage of packaged higher activity waste, which covers common principles and specific approaches for the lifecycle of interim storage and variation in higher activity waste packages [24]. The guidance is intended to assist in the design and planning of new stores and improve existing arrangements.

The presentation high-lighted store ventilation as a key consideration for store operators in preserving the assets. Dependent on the nature of the waste packages relevant principles to be considered include [23]:

- avoidance of extremes of temperature, contrasting air and waste package surface temperatures, leading to condensation, deliquescence, and efflorescence (drying out of salt)
- avoidance of major fluctuations in relative humidity, as transient conditions increase the risk of condensation and deliquescence with concentrated salt solutions
- prevent ingress of corrosive contaminants into the store, including salt particles and aerosols from the external environment

Laser Cutting of Stainless Steel and Associated Coatings in Support of Sellafield Ltd Alpha Glovebox Decommissioning - J. Dodds, J. Konovalovaite [25]

The presentation discussed the operation of a non-active test rig located at the National Nuclear Laboratory in Workington, which demonstrated that laser cutting is potentially a viable option for alpha contaminated glove box decommissioning tasks.

A series of stainless steel plates (4 off un-painted and 3 off painted) and 'mock' gloveboxes (2 off) were successfully cut, or size reduced into smaller pieces. Measurements of fume, dross and dust generated by the cutting were recorded and were found to be of similar values reported within the internal and external literature. The Krantz local extract ventilation system performed well throughout various trials for both unpainted and painted surfaces and showed evidence of successful re-cleaning of the primary filter during its standard blow-back cleaning cycle prior to switch-off.

The trends of dust concentration within the cutting enclosure generally showed a rapid increase during cutting (e.g., 104mg/m^3 for plate P1.1) followed by a rapid decrease (e.g., 4mg/m^3 for plate P1.1) once the Krantz extract was initiated. The dust concentrations measured at the outlet of the Krantz (post-filtration) remain constant throughout the laser cutting around a level of 0.3 mg/m^3, indicating that no measurable fume passes the unit.

The filter was not challenged sufficiently by fume (particulate) during any of the cutting operations to necessitate an on-line clean; although it was difficult to determine how close filter loading came to this threshold.

2021 IMECHE NUCLEAR VENTILATION CONFERENCE

The 10th Institute of Mechanical Engineers (IMechE) Ventilation Conference was held on-line as a single day event in November 2021 comprising 10 presentations on the themes of HEPA Filters Design and Performance; and Operational Case Studies [26]. The Event again had a strong international presence including speakers from China and Sweden. From the United States, ISNATT President Dr Ron Bellamy delivered the Keynote Address on "The ASME AG-1 Code on Nuclear Air and Gas Treatment" [27]; and Interim Director of MSU's ICET Jaime Rickert presented a "Status Report of ICET Air Filtration Research" [28]. A summary of two of the presentations from the Conference is given below.

Update on the Development of the Classified HVAC Systems for the Hinkley Point C Project – I Johnston [29]

The EDF Hinkley Point C (HPC) project is sited on the north Somerset coast on the Bristol Channel and will be the first new build nuclear power station to be commissioned in the UK since 1995. At a rated capacity of 3.2 GW, it will produce 7% of the UK's electrical power demand. HPC will employ the European Pressurised Reactor (EPR) - a third-generation pressurized water reactor as developed by EDF.

The Project has 24 classified HVAC systems and will involve the manufacture and delivery to site of 14,400 individual items of equipment. The equipment qualification programme covers 244 individual tests encompassing 34 equipment types covering conditions such as thermal/irradiation ageing, fire, temperature, seismic plus aeroplane crash, explosive pressure wave and prolonged operation. 10% of the items will be manufactured in the UK (fans, dampers, and heating coils) with the remainder being manufactured mainly in France. The £22bn plant has a scheduled date of June 2026 for starting electricity generation.

Photographs from Axima Nuclear presentation reference 29

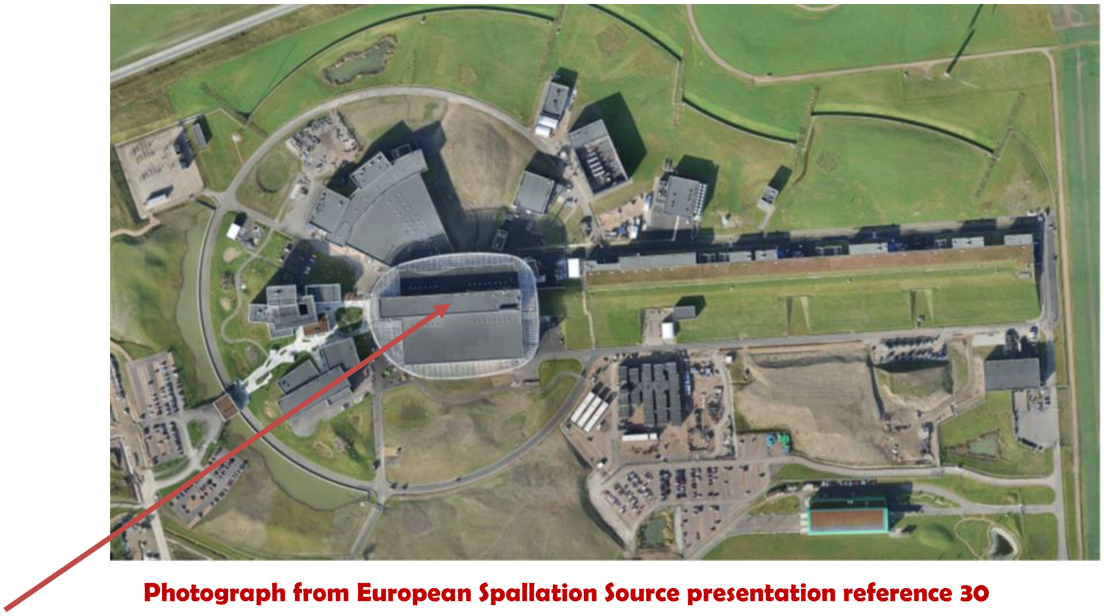
Figure 19 – artist impression of HPC [29]

Figure 20 – Site progress at HPC [29]

ESS Target Station ventilation: Moving from design towards commissioning – D Jodlowiec [30]

European Spallation Source (ESS) is a European Research Infrastructure Consortium. Currently under construction is a multi-disciplinary research facility based on the world's most powerful neutron source, located on the outskirts of Lund, a city in southern Sweden. It has 13 contributing European member countries with over 500 employees of more than 50 nationalities with a construction budget of €1843million.

The presentation described the Target Station Building HVAC and off-gas system. The Target Station Building HVAC consists of 6 ventilation subsystems (2 supply assemblies, 3 filtration and exhaust assemblies, 1 vehicle exhaust point), and 25 fan coils to supplement heating and cooling needs across different areas of the building. The systems treat approximately 65,000 m^3/h of external air, conditioning and providing pressure cascade in over 50 rooms. The Target Station off-gas system collects effluents from process systems located inside of the utility block.



Photograph from European Spallation Source presentation reference 30

Target Station Building

Figure 21 – ESS site overview [30]

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