Development of High Strength HEPA Filters for Use in Demanding Air and Gas Streams – 17644

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ABSTRACT

High-efficiency particulate air (HEPA) filters are used in a wide variety of applications, including the removal of radioactive particulate from process off-gas streams and the venting of waste storage containers. Porvair Filtration Group, specializing in the design and manufacture of robust filters in numerous industries, has worked to develop HEPA filter designs for use in such high-demand nuclear process-gas and air streams. Using the requirements of section FK of the American Society of Mechanical Engineers AG-1 Code on Nuclear Air and Gas Treatment (ASME AG-1) as a guide, Porvair Filtration Group has designed filters which can withstand upset conditions to include elevated temperatures, high relative humidity, high particle-loading, and an unconventionally high differential pressure across the filter media; while maintaining excellent removal efficiencies.

The process by which Porvair Filtration Group has reached optimized designs was based upon an extended test and development program. Design, manufacture, and testing of flat sheet media samples, geometrically equivalent model filters, and full-scale prototypes was performed at several Porvair Filtration Group facilities located in the United States and the United Kingdom. The methods and results of this development program are outlined in the following paper.

INTRODUCTION

Bechtel National Incorporated (BNI), on behalf of the United States Department of Energy (DOE) is designing, building, and commissioning the world's largest radioactive waste treatment plant in eastern Washington, USA.[1] The plant is designed to process and vitrify 212 million liters (56 million gallons) of radioactive waste generated during US military weapons production activities for World War II and the Cold War. The waste is stored in 177 underground tanks located on the DOE Hanford Reserve. As the prime contractor for operations and maintenance (O&M) activities for the Hanford Waste Treatment Plant (WTP), BNI was tasked with the sourcing of suitable filters for use in all of the WTP facilities.

The need for a new-design high-efficiency particulate air (HEPA) filter for use at the WTP was prompted by the 2011 testing and subsequent failure of existing filter designs to meet the criteria of various gas streams at the WTP.[2] In 2013, Porvair Filtration Group entered into a development contract with BNI to provide a robust radial-flow HEPA filter designed in accordance with the American Society of Mechanical Engineers AG-1 Code on Nuclear Air and Gas Treatment (ASME AG-1) section FK, and the design basis conditions at the WTP. Upon receipt of the initial contract, Porvair Filtration Group, in conjunction with the BNI technical team and nuclear air filtration subject matter experts (SMEs), embarked upon a multi-year development program to meet the unique needs of BNI at the WTP.

PRELIMINARY DEVELOPMENT STRATEGY (2013-2014)

The starting point for the development of a 3400 m^3/hr (2000 cfm) radial flow HEPA filter was the ASME AG-1 code. For reference, Figure 1 depicts the typical construction and cross section of a Type-1 3400 m^3/hr (2000 cfm) radial flow filter as depicted in ASME AG-1 Section FK4100.

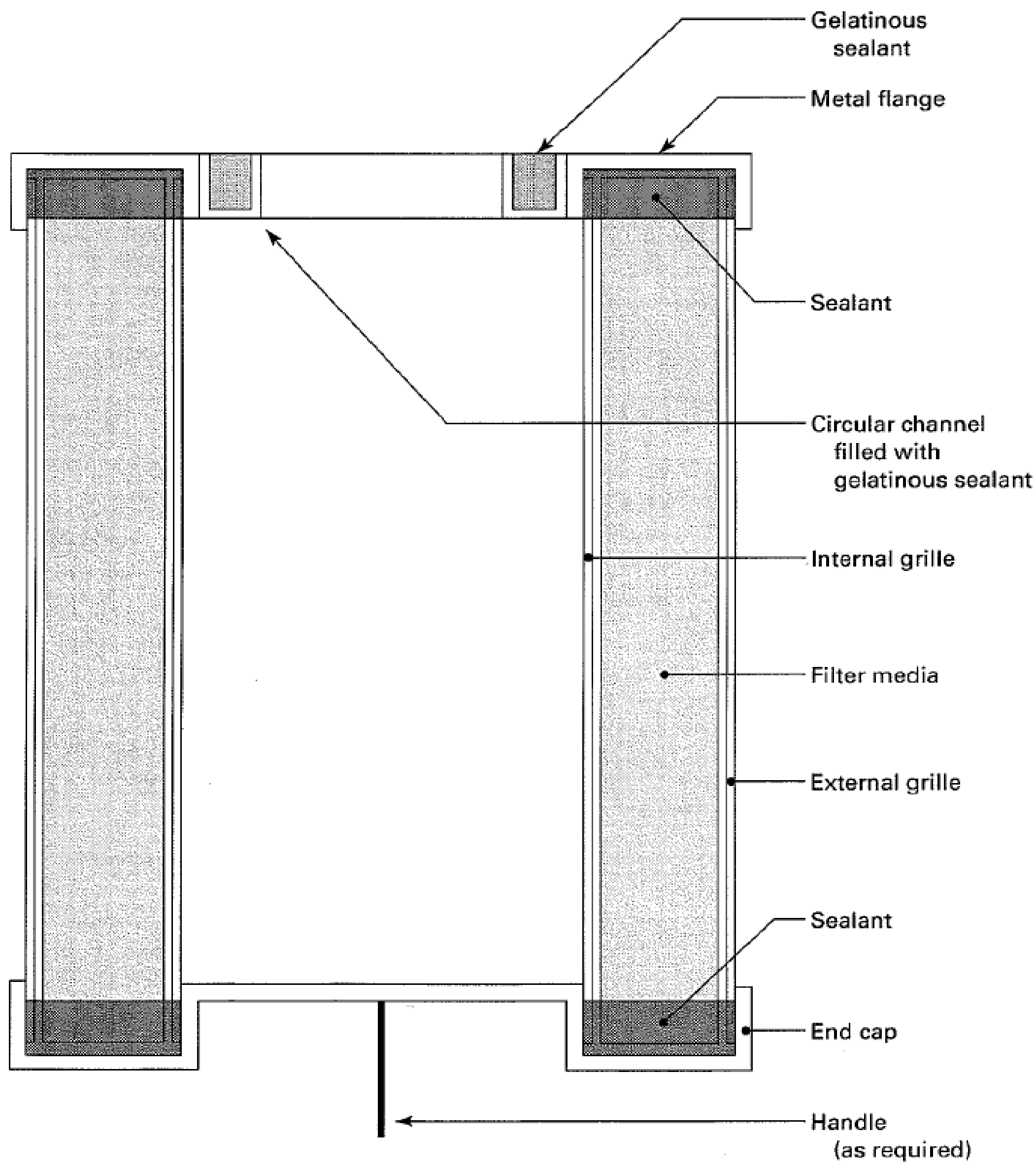

Fig. 1. Type-1 3400 m^3/hr (2000 cfm) Radial Flow Filter [3].

In addition to the ASME code, the methodology pursued by Porvair for the development of 3400 m^3/hr (2000 cfm) radial flow HEPA filters began with several customer-specified design conditions and resulted in multiple preliminary concepts designed to the varying process conditions present at the WTP. Table I is a summary of the anticipated operating conditions in various air and gas streams as defined by the BNI technical team at the start of the project. It includes data for minimum and maximum operating cases as well as abnormal and design basis event (DBE) scenarios.

TABLE I. Preliminary Operating Conditions [4].

Temperature				**Relative Humidity (Based on max. or min. temperature)**				**Static Pressure**	
min. (°C)	**max. (°C)**	**abn. (°C)**	**DBE (°C)**	**min. (%)**	**max. (%)**	**abn. (%)**	**DBE (%)**	**max. (mm WC)**	**max. (in. WC)**
35.6	41.7	N/A	N/A	19.9	9.5	3.6	n/a	-1346.2	-53.0
48.9	71.1	60.6	N/A	33.8	36.5	38.7	n/a	-2159.0	-85.0
46.1	48.9	37.8	37.8	70.0	70.0	100.0	100.0	-2032.0	-80.0
32.2	35.0	58.9	58.9	70.0	70.0	100.0	100.0	-3810.0	-150.0
15.0	45.0	62.6	74.4	77.7	10.7	4.6	100.0	-635.0	-25.0
15.0	45.0	55.0	60.6	77.7	10.7	6.5	TBD	-704.1	-27.7
18.9	26.7	67.2	N/A	77.7	29.4	3.7	N/A	-299.0	-11.8
15.0	35.0	61.7	N/A	77.7	29.4	4.8	N/A	-363.7	-14.3
15.0	35.0	54.4	N/A	77.7	18.3	6.7	N/A	-337.8	-13.3
15.0	45.0	62.6	74.4	77.7	10.7	4.6	TBD	-635.0	-25.0
46.1	48.9	37.8	37.8	70.0	70.0	100.0	100.0	-2032.0	-80.0
32.2	35.0	58.9	58.9	70.0	70.0	100.0	100.0	-3810.0	-150.0
15.0	45.0	55.0	60.6	77.7	10.7	6.5	N/A	-704.1	-27.7
18.9	26.7	43.9	N/A	77.7	29.4	11.3	N/A	-457.2	-18.0
15.0	35.0	43.9	N/A	77.7	29.4	11.3	N/A	-489.0	-19.3
60.0	72.2	60.0	N/A	25.0	29.0	62.0	N/A	-4572.0	-180.0
15.0	35.0	46.7	N/A	78.0	29.0	17.0	N/A	-152.4	-6.0
15.0	35.0	46.7	N/A	78.0	29.0	17.0	N/A	-152.4	-6.0
15.0	53.9	93.3	N/A	78.0	12.0	2.0	N/A	-152.4	-6.0
15.0	45.0	N/A	N/A	78.0	17.0	n/a	N/A	-152.4	-6.0
15.0	50.6	N/A	N/A	78.0	12.0	n/a	N/A	-152.4	-6.0
15.0	35.0	47.8	N/A	78.0	29.0	16.0	N/A	-152.4	-6.0
15.0	35.0	47.8	N/A	78.0	29.0	16.0	N/A	-152.4	-6.0
15.0	51.1	N/A	N/A	78.0	16.0	n/a	N/A	-152.4	-6.0

With such a broad range of operating conditions, three distinct pressure classes were set for the filters based on maximum design differential pressure (DP) rating: 254mm WC (10in. WC) 1143mm WC (45in. WC) and 5715mm WC (225in. WC). The lowest pressure class was directly established using the requirements outlined in ASME AG-1, while the higher pressure classes were derived from postulated

elevated operating conditions at WTP. In addition to the above parameters, filtering efficiency (FE) and media face velocity were driving factors in the initial design strategy, which was centered on a multi-stage prototyping process.
To ensure success in all three pressure classes, Porvair began prototyping with filter designs based around three filter media types. These consisted of Porvair's Sinterflo®[a] F metal fiber media in 316L stainless steel for the highest pressure class, a wire-mesh reinforced fibrous glass HEPA media for the intermediate class, and a reinforced fibrous glass HEPA media for the lowest pressure class.

In order to verify that each potential media type and configuration would meet the necessary HEPA efficiency, a series of testing was performed by Porvair. Summarized below, are the four methods of efficiency testing employed in the development of the candidate filters and media.

Initial Fractional Efficiency per EN1822-3 (2009)

Flat sheet samples of each potential media were tested in accordance with the European test standard EN1822-3, thus providing an indication of the efficiency at 0.3 µm. The aerosol challenge was poly-dispersed but the efficiency at 0.3 µm was determined by using a counter with discreet size bands to measure the challenge and outlet.

While this was not a true mono-dispersed challenge, Porvair interpreted it as an acceptable principle of efficiency testing according to ASME AG-1 2009, section FK-5120: "When using a penetrometer with a particle counter, the penetration at 0.3µm particle size shall be reported."[3] All flat sheet testing was performed to inform the design choices made during initial prototyping, and was thus, not expected to conform to ASME code in all areas.

In-Situ Type Testing: VC-Aero Thermal Generator

This method of testing used a poly-dispersed Ondina smoke challenge provided by a thermal dispersed oil particulate generator and a photometer (SP200 DAS) to measure the concentration of the smoke upstream and downstream. This method of filter efficiency testing, being similar to the way that filters are tested "in-situ" is an acceptable way of confirming a filter's suitability for many Porvair customers.

Porvair has found that the mass mean particle size of hot dispersed oil particulate generators can vary widely and therefore, commissioned a modified VC-Aero thermal generator with precision regulators for both oil and gas lines to facilitate adjustment to an output with a mass mean size of 0.3 µm, and have confirmed this with regular calibration. This generator was used in the efficiency testing of all the full size filter candidates. The intention was that such testing with a true 0.3µm mass mean would be indicative of the results to be expected with mono-dispersed or fractional efficiency testing.

[a] Sinterflo® is a registered trademark of Porvair Filtration Group in the United States and other countries.

In-Situ Type Testing: Cold Dispersed Oil Particulate Generator

This method used a different poly-dispersed challenge provided by cold dispersed oil particulate using a Laskin Type 111-A nozzle, which produced a somewhat wider distribution of particle sizes than the thermal generators. The mass mean size of the Porvair cold dispersed oil particulate generator was found to be significantly higher than 0.3µm. Although not widely used for the project, some small development filters were tested using this challenge early during the project and were then re-tested after being subjected to various physical challenges.

Mono-Dispersed Testing by Subcontractor

In an attempt to gain further confidence in the selected filter designs, a subcontractor was commissioned to create a true mono-dispersed test on some small development filters using the basic Porvair rig and the following instrumentation: 0.3 µm mono-dispersed challenge aerosol of Ondina oil generated from an Aerogene Mini low output smoke generator was size classified using a TSI Inc. differential mobility analyzer. Representative upstream and downstream particle counts were measured using two TSI Inc. condensation particle counters.

Based on the early-stage test results, confirming the effectiveness of metal media to resist damage at high differential pressures, and the fibrous glass media to perform in accordance with the specified removal efficiencies, full-scale radial flow filter prototypes were designed and manufactured in Porvair's Segensworth, UK facility. Testing then commenced in the UK for clean differential pressure and filtering efficiency using an Ondina poly-dispersed aerosol challenge in a custom designed full-scale test rig, seen in Figure 2 (below). A series of filters were made in the "safe change" format for delivery to and eventual testing at a customer sponsored sub-contractor.

Fig. 2. Full-Scale 3400 m^3/hr (2000 cfm) Air Flow Rig, Porvair UK (left) and Porvair Radial Flow HEPA (right).

During the course of in-house and subsequent customer sponsored testing activities, full-scale flow scenarios revealed a higher-than-expected clean differential pressure loss, thus disqualifying the preliminary designs from use without modification of the air-handling equipment at the WTP. The high differential pressure was ultimately found to be caused by pleat deformation and subsequent blinding which resulted from an overly tight-packed arrangement in all three designs. The next phase of Porvair's development efforts worked to mitigate this issue by dramatically increasing pleat depth and thus, filter area. Furthermore, in an effort to accelerate the research and development process and to optimize the next filter designs, Porvair proposed a bench scale design-by-test program, which would rely upon 1/24th scale "quadrant" filters that mimicked full-scale filter geometry but required significantly less time and fewer components to build.

QUADRANT PACK TEST PROGRAM (2014-2016)

Using information from the initial prototyping stage, Porvair worked with BNI to establish a robust bench-scale design process based on a "quadrant" pack filter. Figure 3 (below) shows the quadrant pack filter and test stand.

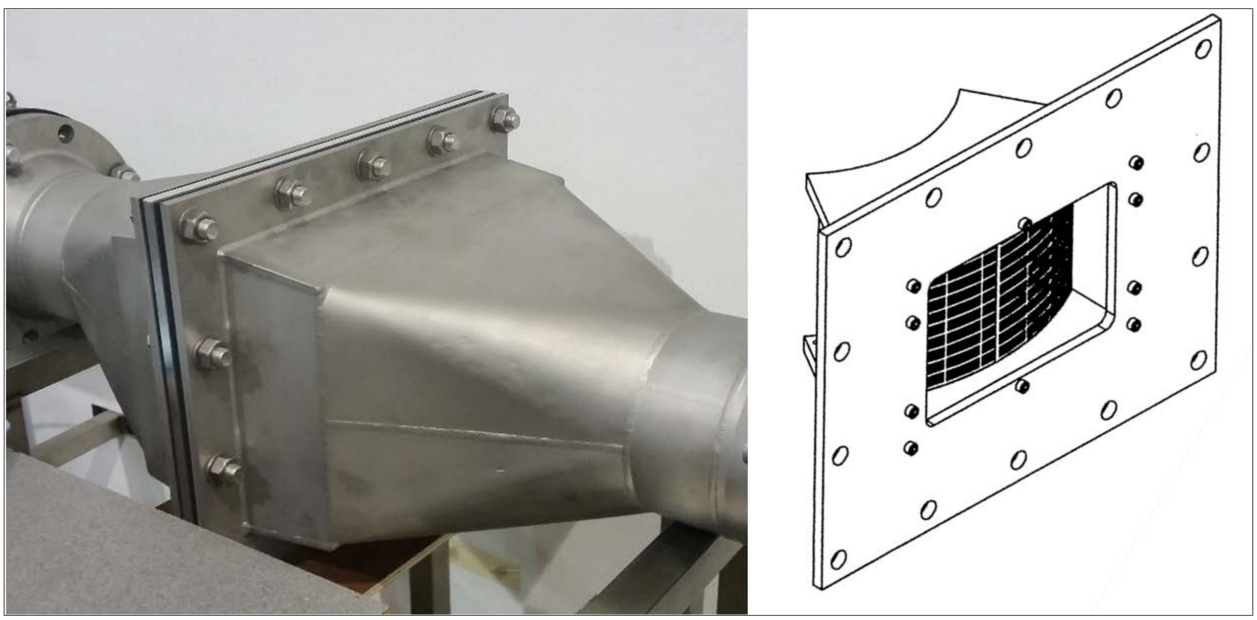

Fig. 3. Quadrant Pack Test Stand (left) and Quadrant Filter (right).

The primary benefit of utilizing a small-scale filter for development was flexibility of design parameters, which allowed for iterative testing to take place over a matter of days as compared to weeks. Ultimately, numerous quadrant packs were manufactured during this phase of the research and development contract. The key parameters which were varied to result in an optimized design are summarized in Table II on the next page

TABLE II. Summary of Design Variables for Quadrant Pack Development Program.

Variable	**Impact of variable on final design**
Media type	Resistance to temperature/humidity
Media rating	Efficiency, total allowable filtration area
Pleat height	Total allowable filtration area, clean DP
Separator type	Resistance to DP, clean DP, dirt holding capacity
Pleat density	Clean DP
Reinforcement type	Clean DP, resistance to humidity, resistance to DP

Prior to the start of quadrant pack testing, a tare value for differential pressure was measured for the housing without filter media. The results are seen in Table III (below) and it should be noted that the tare was actually negligible in this rig as the results show zero measurable DP losses. Figure 4 (below) depicts the quadrant pack hardware used for tare measurements.

TABLE III. Tare DP Measurements for Quadrant Pack Hardware.

Design	**Rated Flow (%)**	**Flow Rate (m^3/s)**	**Pipe Velocity (m/s)**	**DP (in. WC)**	**DP (mm WC)**	**Amb. Temp (°C)**	**Atm. Pressure (mBar)**
Hardware Only	140	0.0602	3.23	0.00	0	21	1001
	120	0.0516	2.77	0.00	0	21	1001
	100	0.0430	2.31	0.00	0	21	1001
	80	0.0344	1.85	0.00	0	21	1001
	60	0.0258	1.39	0.00	0	21	1001
	40	0.0172	0.92	0.00	0	21	1001
	20	0.0086	0.46	0.00	0	21	1001
	0	0.0000	0.00	0.00	0	21	1001

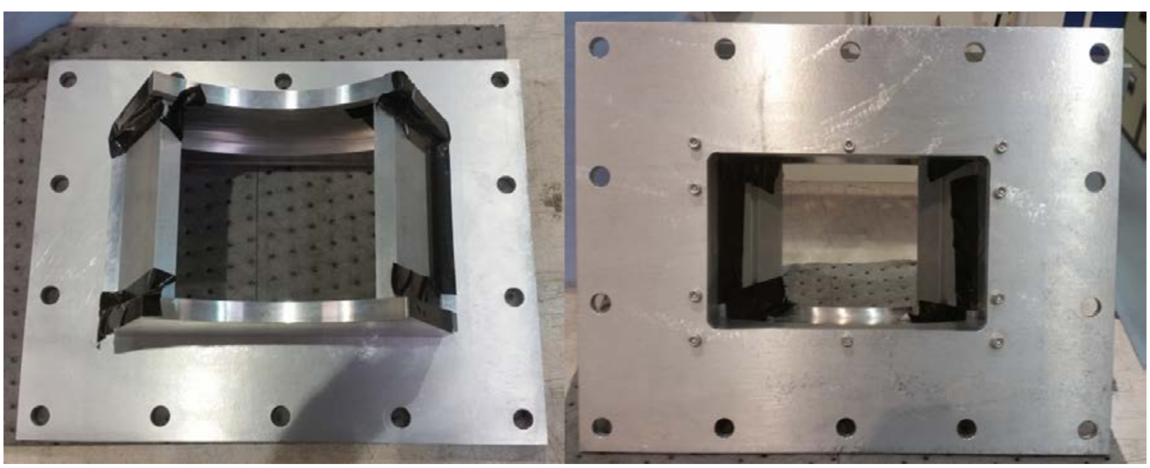

Fig. 4. Quadrant Pack Hardware without Filter Media Rear (left) and Front (right)

Quadrant Pack Test Results

The results of quadrant pack testing allowed Porvair to accelerate the design process, ultimately working towards an optimized solution for use at the WTP. Additionally, throughout the design process, BNI was working to better define the necessary operating conditions and was able to effectively reduce the maximum required differential pressure from 5715mm WC (225in. WC). Porvair then tailored its approach to meet the new, lower requirement and focused its efforts on a singular high strength filter design which could be used throughout the WTP. The quadrant pack testing process produced that design, with a focus on reducing clean DP and maintaining an optimum face velocity at the media.

Tables IV-VIII (below) represent a sample of the DP and FE test results obtained during the quadrant pack development program, listed chronologically from earliest to latest. Over the course of several months, eight designs were tested, with several others being excluded prior to testing due to manufacturing challenges.

TABLE IV. Design 4 Quadrant DP & FE Results (Unit #1).

Rated Flow (%)	Flow Rate (m^3/s)	Pipe Velocity (m/s)	DP (in. WC)	DP (mm WC)	Amb. Temp. (°C)	Atm. Press. (mBar)	Face Velocity (m/s)	FE (%)
140	0.0602	3.23	2.28	58	21	988	0.051	-
120	0.0516	2.77	1.89	48	21	988	0.044	-
100	0.0430	2.31	1.50	38	21	988	0.036	99.9979
80	0.0344	1.85	1.14	29	21	988	0.029	-
60	0.0258	1.39	0.79	20	21	988	0.022	99.9978
40	0.0172	0.92	0.49	12.5	21	988	0.014	-
20	0.0086	0.46	0.24	6	21	988	0.007	99.9975
0	0.0000	0.00	0.00	0	21	988	0	-

TABLE V. Design 4 Quadrant DP & FE Results (Unit #2).

Rated Flow (%)	Flow Rate (m^3/s)	Pipe Velocity (m/s)	DP (in. WC)	DP (mm WC)	Amb. Temp. (°C)	Atm. Press. (mBar)	Face Velocity (m/s)	FE (%)
140	0.0602	3.23	2.17	55	22	1000	0.047	-
120	0.0516	2.77	1.77	45	22	1000	0.040	-
100	0.0430	2.31	1.38	35	22	1000	0.033	99.9992
80	0.0344	1.85	1.06	27	22	1000	0.027	-
60	0.0258	1.39	0.75	19	22	1000	0.020	99.9996
40	0.0172	0.92	0.47	12	22	1000	0.013	-
20	0.0086	0.46	0.20	5	22	1000	0.006	99.9998
0	0.0000	0.00	0.00	0	22	1000	0	-

TABLE VI. Design 1 Quadrant DP & FE Results.

Rated Flow (%)	Flow Rate (m^3/s)	Pipe Velocity (m/s)	DP (in. WC)	DP (mm WC)	Amb. Temp. (°C)	Atm. Press. (mBar)	Face Velocity (m/s)	FE (%)
140	0.0494	2.65	1.26	32	19	1003	0.046	-
120	0.0424	2.27	1.06	27	19	1003	0.039	99.9918
100	0.0353	1.90	0.87	22	19	1003	0.033	99.9921
80	0.0282	1.52	0.67	17	19	1003	0.026	-
60	0.0212	1.14	0.47	12	19	1003	0.019	99.9938
40	0.0141	0.76	0.31	8	19	1003	0.013	-
20	0.0071	0.38	0.16	4	19	1003	0.006	99.9930
0	0.0000	0.00	0.00	0	19	1003	0	-

TABLE VII. Design 5 Quadrant DP & FE Results.

Rated Flow (%)	Flow Rate (m^3/s)	Pipe Velocity (m/s)	DP (in. WC)	DP (mm WC)	Amb. Temp. (°C)	Atm. Press. (mBar)	Face Velocity (m/s)	FE (%)
140	0.0601	3.22	9.61	244	18	984	0.042	-
120	0.0515	2.76	8.46	215	18	984	0.036	-
100	0.0429	2.30	6.85	174	18	984	0.030	99.9512
80	0.0343	1.84	5.67	144	18	984	0.024	-
60	0.0257	1.38	4.09	104	18	984	0.018	99.9381
40	0.0172	0.92	2.52	64	18	984	0.012	-
20	0.0086	0.46	1.30	33	18	984	0.006	99.8286
0	0.0000	0.00	0.00	0	18	984	0	-

TABLE VIII. Design 6 Quadrant DP & FE Results.

Rated Flow (%)	Flow Rate (m^3/s)	Pipe Velocity (m/s)	DP (in. WC)	DP (mm WC)	Amb. Temp. (°C)	Atm. Press. (mBar)	Face Velocity (m/s)	FE (%)
140	0.0601	3.22	22.56	573	21	1017	0.045	-
120	0.0515	2.76	18.43	468	21	1017	0.039	-
100	0.0429	2.30	15.75	400	21	1017	0.032	99.6341
80	0.0343	1.84	12.99	330	21	1017	0.026	-
60	0.0257	1.38	9.84	250	21	1017	0.019	99.4253
40	0.0172	0.92	6.22	158	21	1017	0.013	-
20	0.0086	0.46	3.03	77	21	1017	0.006	98.8261
0	0.0000	0.00	0.00	0	21	1017	0	-

As can be seen in tables VII and VIII, Designs 5 and 6 exhibited greater than 50mm WC (2in. WC) at rated flow and were thus eliminated. Design 1 performed well with regard to DP and FE, but was not robust enough to meet the other demanding conditions at WTP. The test results did, however, indicate that the Design 4 quadrant packs would meet the clean DP and FE requirements for ASME AG-1 and the WTP. This design utilized a heavily reinforced filter media with a pleat separator for pack strength. Following the successful results from the quadrant pack testing, four full-scale prototypes utilizing the Design 4 configuration were manufactured as well as additional quadrant packs for further testing.

Quadrant Pack Spot Flame and Heated Air Testing

In order to provide a level of engineering confidence in the selected filter configuration with regard to its resistance to flammability, per ASME AG-1 section FK-5150 and FK-5160, Porvair built two quadrant packs for testing at Underwriter's Laboratory, in Illinois, USA. Spot flame, 954°C (1750°F) direct flame for 5 minutes, and heated air, 371°C (700°F) heated air at >40% rated flow for 5 minutes, tests were performed in accordance with UL-586 per ASME AG-1 on the sample units, both showing satisfactory results in accordance with the code.

FULL-SCALE PROTOTYPE PROGRAM (2015-2016)

Upon completion of the quadrant pack program, and the selection of Design 4 as the optimum radial flow filter configuration for use at WTP, Porvair began the process of up-scaling the technology implemented in the quadrant packs. A plan to build several prototype filters was established and the tools for manufacturing Porvair's new, robust radial flow HEPA were put into place. Several unique aspects of the Design 4 filter required special attention. These consisted of (1) an unconventionally deep pleat for radial flow filters, (2) the use of a heavily reinforced fibrous glass media, and (3) a novel method of pleat separation.

At the time of prototype manufacturing, the depth of pleat required for the Design 4 filter was above that of Porvair's US pleating capability and thus made necessary the use of subcontract pleating equipment. Throughout the development process, in order to meet the necessary design specifications and to improve the methods and pace of construction, the Porvair engineering team performed three separate pleating trials on subcontract equipment. However, so as to be fully prepared for higher quantity filter manufacturing, Porvair procured an additional world-class pleating machine with a capacity for pleat heights ranging from 3mm to 300mm (0.120in. to 12.0in.).

In addition to the challenges of deeper pleat heights, the use of a heavily reinforced HEPA media meant that filter construction was non-traditional when compared to existing 3400 m^3/hr (2000 cfm) radial flow HEPA filters. Several methods of potting or encapsulating the media were trialed, ultimately resulting in the selection of a traditional urethane-type adhesive for both seam and end-cap sealing.

Finally, the Design 4 filter utilized a proprietary corrugated pleat separator, which, when installed, prevented pleat collapse and allowed for continued operation of the filter through unconventionally high differential pressure ranges. The key result from Porvair testing of this novel pleat separator was an approximately 25% decrease in DP when compared with separators of a more traditional construction. Due to the unique construction of the corrugated separator, custom manufacturing equipment was developed and installed at Porvair's US manufacturing headquarters in Ashland, Virginia, USA. Figure 5 (below) is a 3D model representing the corrugated pleat separator designed by Porvair.

Full-Scale Prototype Test Results

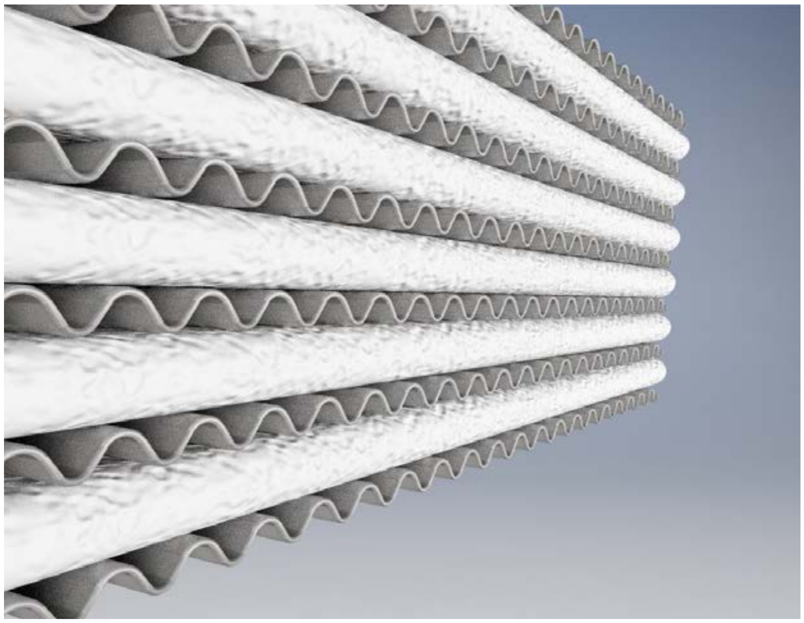

Fig. 5. 3D Model of Porvair Corrugated Separator.

The full-scale prototyping process resulted in the manufacture and testing of four safe change filters in 2015 and 2016. Three filters were required to meet the testing requirements of BNI and a fourth unit was manufactured for additional testing. Tables IX-XII summarize the DP and FE results of Porvair's factory acceptance testing on all four prototypes.

TABLE IX. Full-Scale Prototype #1 DP & FE Results.

Rated Flow (%)	Flow Rate (m^3/s)	Pipe Velocity (m/s)	DP (mm WC)	DP (in. WC)	Amb. Temp. (°C)	Atm. Press. (mBar)	Face Velocity (m/s)	FE (%)
100	0.9439	16.61	16.84	2.09	53	21	1003	99.9970
80	0.7551	13.29	13.32	1.57	40	21	1003	-
60	0.5663	9.97	10.17	0.94	24	21	1003	99.9968
40	0.3776	6.64	6.78	0.63	16	21	1003	-
20	0.1888	3.32	3.46	0.28	7	21	1003	99.9969
0	0.0000	0.00	0	0.00	0	21	1003	-

TABLE X. Full-Scale Prototype #2 DP & FE Results.

Rated Flow (%)	Flow Rate (m^3/s)	Pipe Velocity (m/s)	DP (mm WC)	DP (in. WC)	Amb. Temp. (°C)	Atm. Press. (mBar)	Face Velocity (m/s)	FE (%)
100	0.9439	16.61	16.84	2.05	52	23	1003	99.9983
80	0.7551	13.29	13.32	1.50	38	23	1003	-
60	0.5663	9.97	10.17	1.02	26	23	1003	99.9985
40	0.3776	6.64	6.78	0.59	15	23	1003	-
20	0.1888	3.32	3.46	0.28	7	23	1003	99.9989
0	0.0000	0.00	0	0.00	0	23	1003	-

TABLE XI. Full-Scale Prototype #3 DP & FE Results.

Rated Flow (%)	Flow Rate (m^3/s)	Pipe Velocity (m/s)	DP (mm WC)	DP (in. WC)	Amb. Temp. (°C)	Atm. Press. (mBar)	Face Velocity (m/s)	FE (%)
100	0.9439	16.61	16.84	1.93	49	20	1019	99.9925
80	0.7551	13.29	13.32	1.46	37	20	1019	-
60	0.5663	9.97	10.17	0.98	25	20	1019	99.9925
40	0.3776	6.64	6.78	0.55	14	20	1019	-
20	0.1888	3.32	3.46	0.28	7	20	1019	99.9914
0	0.0000	0.00	0	0.00	0	20	1019	-

TABLE XII. Full-Scale Prototype #4 DP & FE Results.

Rated Flow (%)	Flow Rate (m^3/s)	Pipe Velocity (m/s)	DP (mm WC)	DP (in. WC)	Amb. Temp. (°C)	Atm. Press. (mBar)	Face Velocity (m/s)	FE (%)
100	0.9439	16.61	16.84	2.13	54	24	1010	99.9983
80	0.7551	13.29	13.32	1.50	38	24	1010	-
60	0.5663	9.97	10.17	0.98	25	24	1010	99.9986
40	0.3776	6.64	6.78	0.59	15	24	1010	-
20	0.1888	3.32	3.46	0.28	7	24	1010	99.9986
0	0.0000	0.00	0	0.00	0	24	1010	-

The results of Porvair's DP and FE testing confirmed that the Design 4 configuration performed acceptably at the full-scale. The DP results were slightly higher than stipulated in the code on three of the four units, but some slight changes to the corrugated separator design allowed for subsequent units manufactured by Porvair to fall under the 50mm WC (2in. WC) clean DP requirement set forth in ASME AG-1. Furthermore, the filtering efficiency was quite good on all four units, with only unit 3 showing a minimal dip in efficiency, believed to have been caused by manufacturing inconsistencies. Having successfully passed Porvair factory acceptance testing, all four units were ultimately shipped to the customer for more rigorous testing at a third-party facility.

Figures 6 and 7 (below) graphically depict the results of Porvair's prototype testing, and show acceptable DP and FE results. When plotted against flow, the DP of all four units follow approximately the same trend, thus showing an inherent consistency and repeatability of the design. Furthermore, the efficiency of the Design 4 prototypes was shown to be above the 99.97% removal of all particulate above 0.3µm, with all four units showing 99.99+% efficiencies.

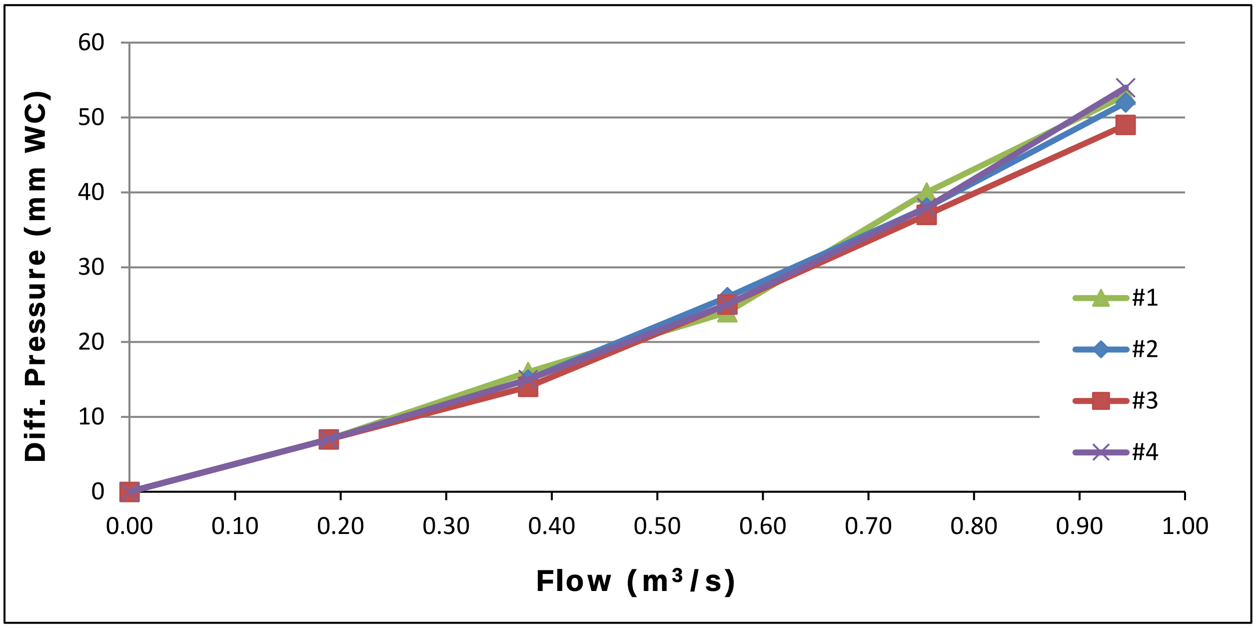

Fig. 6. Differential Pressure (Pressure Drop) Vs Flow.

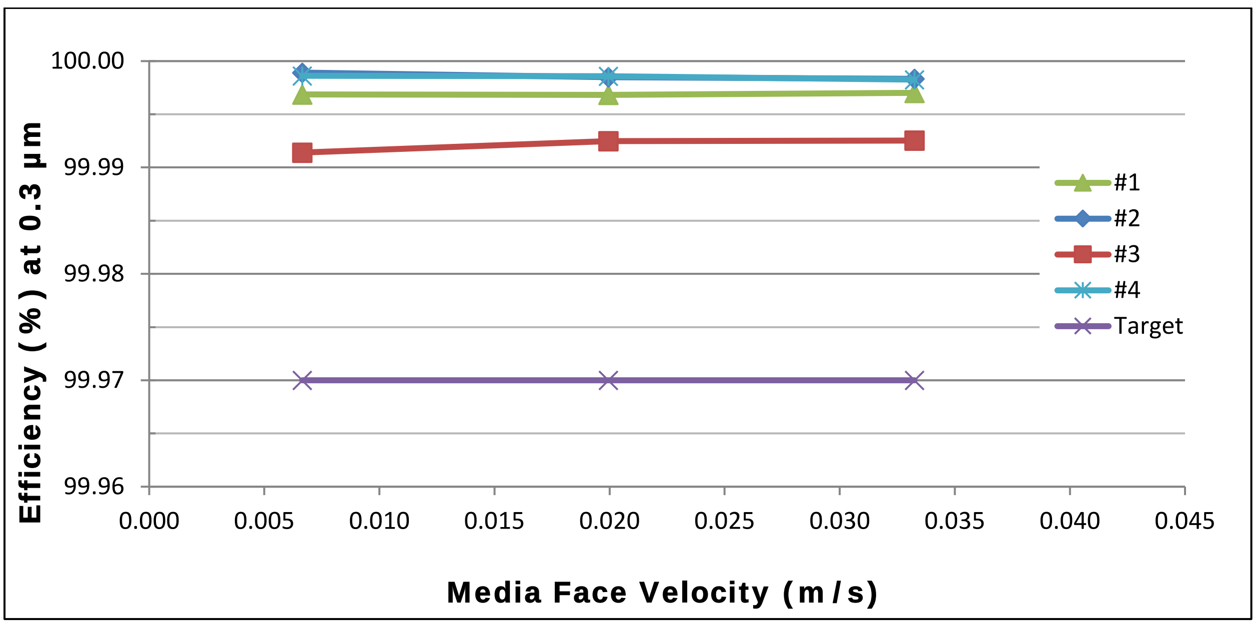

Fig. 7. Filtering Efficiency vs. Face Velocity.

CONCLUSION

During the development program that took place from 2013 to 2016, Porvair was able to produce four prototypes that went on to meet the requirements specified by BNI for use at the WTP. After completing all factory acceptance testing, the filters were subjected to differential pressures up to 1270mm WC (50in. WC), high relative humidity, and elevated dirt-loading scenarios during BNI sponsored testing, performing above expectations in all tests. Furthermore, Porvair successfully delivered two orders of the new design 3400 m^3/hr (2000 cfm) radial flow HEPA filters to BNI during the second half of 2016, which will undergo further testing through early 2017. The radial flow HEPA filter which Porvair developed with BNI, for use at the WTP, implements first-of-a-kind technologies to meet and exceed the requirements for one of the world's most demanding nuclear waste processing environments. Figure 8 (below) is an image of the Porvair 3400 m^3/hr (2000 cfm) radial flow HEPA filter.

Fig. 8. Porvair 3400 m^3/hr (2000 cfm) Radial Flow HEPA Filter

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