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Title: **Protecting the Public Water Supply from Cryptosporidium using Ultrafiltration Membrane Technology: A Case Study at Bristol Water, in the UK**

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Abstract

The UK Drinking Water Inspectorate (DWI) introduced Cryptosporidium legislation in 1999, which established a final treated water standard of 1 oocyst/10 litre. The DWI also specified that a Risk Assessment needed to be carried out for all water sources; any that were deemed to be High Risk either had to be continuously monitored by an approved auditable procedure, or had to be treated by an approved membrane process; this paper describes a case study at Bristol Water in which the Kalmem™ HYDRAcap™ UF system has been installed at a series of 7 groundwater sources in response to this legislation.

The Bristol Water sites range in flow rate from 2 mld to 15 mld, and have used a generic process design, layout, etc. The first of the 7 sites, a 5 mld installation at Frome, has been in operation for 5 months, with stable performance at a permeability of 250 lmh.bar. The feed has normally been <0.2 NTU, with occasional spikes to 5 NTU.

Membrane integrity has been monitored daily using a pressure hold test. This test is sufficiently sensitive to readily identify a single fibre break in the largest of the Bristol Water racks, which contains 24 modules. For the 5 plants which have been taken into supply so far, no broken fibres have been identified whilst the plants have been in supply, and only 2 broken fibres were found during commissioning.

Following the success of the first 7 sites, Bristol Water have extended the original contact to include an 8th site, an 18 mld installation at Chelvey.

1. Introduction

Cryptosporidium is commonly found in a variety of source waters. Normally, the concentration of cryptosporidium oocysts in surface waters is relatively low, and conventional treatment systems reduce oocyst concentrations to an acceptable level. However, exceptional circumstances may increase the risk of significant contamination of the final water, for example, in times of flood, or high rainfall following drought.

Groundwaters influenced by surface water are also at risk from cryptosporidial contamination since, historically, many of these sources will have received no treatment other than chlorination, which is ineffective against cryptosporidium oocysts; significant contamination of these sources can occur during high rainfall. This type of source provides the subject for the Bristol Water case study described in this paper.

Regulation is progressively being implemented in different parts of the world to control the risk posed by cryptosporidium. In the USA, treatment systems have to achieve a specified log removal of organisms such as viruses, cryptosporidium, and giardia. Different treatment technologies are credited with log removal ratings which can be added together to demonstrate compliance. For example, the Hydranautics Ultrafiltration (UF) membrane HYDRAcap™ is credited with a removal rating of 4 log for both viruses and cryptosporidium (which is the maximum credit that can be allocated).

In the UK, an absolute final water standard of 1 oocyst / 10 litre has been set. A risk assessment of each source together with an assessment of the current treatment system then indicates the appropriate level of additional treatment required. Under Drinking Water Inspectorate (DWI) regulation introduced in 1999, high risk groundwater sources require continuous monitoring for cryptosporidium, or treatment by a 1 micron absolute barrier process. This level of removal efficiency requires membrane technology, and manufacturers need to have their technology tested before inclusion on an approved list. The Hydranautics UF membrane is included on this list under the Kalmem™ trademark.

This paper describes the application of UF membrane technology, which has been implemented in the UK to assist municipal operators in meeting the enhanced standards for cryptosporidium removal. A case history at Bristol Water will be described to illustrate the use of the Kalmem™ HYDRAcap™ UF membrane system in meeting the requirements of the UK cryptosporidium regulations.

The Bristol Water case history comprises a series of 7 sites in the South West of England treating groundwaters influenced by surface water. Operational data will be provided for the first of the 7 sites during the initial 5 month operating period, summarising key benefits of the technology and operational experience.

2. Cryptosporidium Risk Assessment

In 1999, the DWI introduced a new regulation in response to the potential threat of contamination of water courses by cryptosporidium. The regulations required Water Undertakers (i.e. companies responsible for the public water supply) to carry out a risk assessment of all of their water sources to assess the potential for the contamination of those sources by cryptosporidium. In this assessment, there was a particular focus on groundwater influenced by surface water, since some of these sources in the UK are untreated other than by chlorination.

As a result of the risk assessment, Bristol Water identified a series of 7 groundwater sites, which the DWI agreed were high risk, and required either treatment by an approved process, or a less effective treatment combined with continuous monitoring by an approved auditable system. The DWI have announced their intention to prosecute any water undertaker that breaches the new statutory cryptosporidium standard following such a risk assessment, on the grounds of supplying water unfit for human consumption.

In accordance with DWI regulatory requirements for cryptosporidium protection, Bristol Water decided to implement a series of membrane schemes for the 7 sites, rather than simply institute a less effective treatment with a continuous monitoring scheme. There were three reasons for installing membrane equipment:

2.1 Installation of a membrane barrier provides a Public Health benefit, and eliminates the risk of potentially breaching cryptosporidium standards; this benefit is not provided by a less effective treatment and continuous monitoring, which indicates a problem after the event has passed.
2.2 A membrane barrier ensures security of supply in the event of contamination of the source. 3 of the 7 Bristol sites are essential to the local distribution network; at these 3 sites, there are no alternative supply options.
2.3 The costs of the approved continuous monitoring schemes are expensive; by avoiding these monitoring costs and the costs of a less effective treatment system, the membrane plant costs have been mitigated.

Details of the 7 sites are provided in ***Table 1.***

3. Process Design

In the summer conditions that have applied during the first 5 months of operation, the groundwater feeds on the 7 Bristol Water sites are normally of excellent quality. The turbidity has usually fallen in the range of 0.1 – 0.2 NTU, but with occasional spikes following rainfall to 5 NTU. These spikes are often short lived, eg 60 minutes; however on some of the sites, the spikes decline more slowly. Sites with longer turbidity events tend to have higher TOC. Particulate counts in the feed at low turbidity (<0.2 NTU) are 500-1000 counts/ml >2 micron.

During winter months, frequent increases in turbidity occur to between 7 and 20 NTU dependent on the site. These can last for several hours, sometimes declining slowly over several days.

The Kalmem HYDRAcap membrane is a hydrophilic polyethersulphone (PES) capillary membrane, developed to resist fouling from organic constituents found in surface waters, and minimise chemical cleaning requirements. The capillary has an internal diameter of 0.8 mm, which optimises the surface area of the module without restricting the hydrodynamics. The capillary membrane is utilised in modules, 1.5 m in length.

The standard operational sequence of the modules is based on an 80 minute cycle. An example of the operating sequence at Frome (a 50 module system split into 5 racks of 10 modules) is illustrated in ***Table 2.***

The normally low feed turbidity enables a directflow operational sequence to be used with a relatively long interval between backwashes. Each rack experiences 4 cycles with a normal permeate backwash, followed by a Chemically Enhanced Backwash (CEB) using 20 ppm H_2O_2 , with a 10 minute soak period. This ensures that bacterial colonies cannot become established on the permeate side of the membrane which would give rise to plate counts in the permeate. The CEB is followed by a rinse utilising 4 times the normal backwash volume, which gives <0.1 ppm H_2O_2 in the permeate during the subsequent filtration cycle.

H_2O_2 was chosen for disinfection via the CEB at the Bristol Water sites, rather than Cl_2, since the spent CEB effluent could be disposed of more easily to the nearby watercourse. A CEB comprising spent Cl_2 is far slower to degrade. Measurements on the H_2O_2 CEB effluent showed that, after a short residence time, the residual H_2O_2 concentration declined to a level acceptable for direct discharge to the watercourse. Any chemicals for cleaning purposes, such as Cl_2, caustic or acid, have to be tankered away from all of the 7 sites, since none of them has a sewer connection. Minimising cleaning chemicals other than H_2O_2 was therefore an important part of the cost assessment for the project.

The complete operational sequence takes 80 minutes. For the 4 racks receiving a normal backwash, the filtration times is 79 minutes; for the rack receiving a CEB the filtration time is approximately 64 minutes. This means that in every 24 hour period, each rack receives 4 CEBs.

A high TMP override is included in the control system, so that for a sustained period of high turbidity, the filtration time can be automatically reduced. During the first 150 days of operation at Frome, the TMP override has not operated despite occasional feed spikes.

The standard backwash sequence removes backwash effluent first from the top of the modules (to the concentrate manifold), then the bottom (to the feed manifold); this ensures that no accumulation of particulate can occur at the dead end of the fibre (the opposite end to the feed manifold).

A simplified Process Flow Drawing for the 7 installations, is shown in ***Figure 1.*** The plant comprises membrane racks, backwash tank and pump with chemical injection system, flow control, instrumentation, and integrity monitoring system.

4. System Design

In May 2000, Bristol Water awarded the contract for the 7 groundwater sites to the consortium of Kalsep, Mott MacDonald and Hydranautics. The site details, listed in ***Table 1***, show the number of modules required, and commissioning and supply dates.

Each site required a substantial new infrastructure for the membrane system, including a building, access road etc. As much standardisation as possible was used for both the design of the UF system, and the design and layout of the building, and the ancillary equipment. In each case, the new membrane system had to link in with an existing chlorination system, and in most cases, existing pumping systems. The building programme was further complicated by the requirement at some of the sites, such as Frome, of maintaining supply, whilst bringing the new membrane plant on-line, and of the additional complication of the supply being obtained from more than one borehole supply.

The common design approach enabled a cost effective generic design to be developed, which could be applied to all of the sites, and reduced the implementation timescale as much as possible.

In order to provide flexibility in operation, each of the systems was designed so that it could be split into 4,5 or 6 sub units, termed racks. Backwashing, chemical cleaning, or any other shutdown would therefore result in a loss capacity of just 15 – 25%, which occurs 20% of the time when the disinfection CEB is used 4 times a day.

The three standard rack sizes contained 5, 10 or 24 modules. An example drawing of a 24 module rack is shown in ***Figure 2***. A photo of the installation at Frome, the first of the 7 sites, is shown in ***Figure 3***, with 5 racks each containing 10 modules.

The modules are vertically mounted in the racks, with a single line of modules connected in parallel to a central feed manifold. Each module is therefore easily accessible. For larger systems, double lines of modules can be used to reduce footprint.

5. System Performance

The fist of the 7 sites to be commissioned was at Frome, in March 2001, with water fed into supply from May.

The design flux for the required productivity of 5 mld was 110 lmh; at 110 lmh, the backwash usage is 2.4% of the productivity. The average operational flux for the first 150 days of operation has been 91 lmh, with an average daily output of 4 mld. The TMP at 91 lmh is 0.36 bar, with a backwash recovery of 2.9% (since the backwash recovery is not reduced with reduced flux).

Figure 4 shows membrane permeability for the first 150 days of operation at Frome. The initial permeability of 270 lmh bar declined by approximately 8% during the first 20 – 30 days of operation before reaching a plateau of 250 lmh bar which has since been stable, though permeability appears to increase slightly at lower flux. Permeabilities are quoted at the actual feed temperature, which has been 10 – 12 ºC.

Permeate quality on each of the Bristol Water sites has been monitored by a particle counter (GLi). The particle count directly after backwash is approximately 10 counts >2 µm / ml for the first 1 – 2 minutes (dependent upon proximity of the counter and sample flowrate), subsequently falling to 0 – 1 counts > 2 µm / ml. Turbidity, which is continuously monitored by the Scada system, is typically 0.06 NTU.

At start up, each of the systems was disinfected with Cl_2; subsequently, 20 ppm H_2O_2 CEB have been used up to 4 times per day to control plate counts in the permeate (since there is no Cl_2 residual in the feed). Initial problems with the peroxide dosing illustrated the importance of this procedure in controlling permeate plate counts. Although the UF membrane itself is a >5 log barrier to viruses and bacteria, the system is not designed to be sterile. In the absence of disinfection, bacterial colonies will become established on the permeate side after a period of time, dependent on feed and system design characteristics. Using a disinfectant, either on an intermittent basis in the backwash, or on a low level continuous basis in the feed, will prevent colonies from becoming established, and ensure that the permeate quality complies with regulation (< x plate counts / ml).

Downstream of the UF, the original superchlorination and dechlorination system has been retained at Frome. The requirement to retain this system will be reviewed, once the long term bacteriological removal performance of the UF membrane in the field has been confirmed.

Since start up, the system at Frome has not required any chemical cleaning, which has saved the cost of occasional tankering spent cleaning chemical from site.

6. Integrity Monitoring

In order to ensure that the UF system continues to provide a barrier against cryptosporidium it is necessary to monitor the integrity of the membrane. Particles counters are used to measure permeate quality, but they are not sensitive enough to assure complete integrity, since the level of particulates in the feed is not high enough.

Accordingly, a Pressure Hold Test (PHT) is used to measure integrity. This is sufficiently sensitive to easily identify a single fibre break in a rack of 24 modules. ***Figure 5*** illustrates the steps involved in the test.

The PHT is based on the fact that a wetted membrane does not allow air to pass through its pores at pressures below the bubble point, other than by diffusion through the water filled pore.

The bubble point for the Kalmem™ HYDRAcap™ membrane is > 2 bar. At a test pressure of 0.7 bar, the rate of decline of pressure by diffusion for a 10 module rack with full integrity is 20 mbar $\pm$ 5 mbar.

A test was carried out at Frome, replacing one of the modules with a module with a known break of a single fibre. The rate of pressure decay increased to significantly greater than 50 mbar in 5 minutes, a substantial increase in comparison with a fully intact system. A theoretical analysis of a 10 module system with a single fibre break shows that the removal efficiency of cryptosporidium would still significantly exceed 4 log removal.

For the Bristol Water sites, a decay rate of >50 mbar in 5 minutes is used to indicate an integrity breach requiring attention. Of the 5 sites commissioned so far, a single fibre break has been detected during commissioning on two of the plants, with no further breaks in subsequent operation.

7. Conclusions

7.1 The Kalmem™ HYDRAcap™ UF membrane has been successfully installed on a series of 7 sites at Bristol Water to treat groundwater influenced by surface water, in compliance with DWI Cryptosporidium legislation (1999).

7.2 The common process design, layout, and operating philosophy has enabled Bristol Water to achieve a cost effective solution, rapidly implemented, in response to a demanding timetable from the DWI.

7.3 The first site to be commissioned, the 5 mld installation at Frome, has been in operation for 5 months, and has quickly reached a permeability performance plateau of 250 lmh.bar. At the maximum design output of 5 mld, the operating flux is 110 lmh, and the recovery 97.6%; average output for the plant has been 4 mld, with an average flux of 91 lmh.

7.4 Chemical waste has to removed from all of the sites by tanker since none of the sites has a sewer connection. Wastes have been minimised by using H2O2 for disinfection, which degrades naturally before disposal to local water course. Chemical cleaning has not been required so far at Frome during the first 5 months of operation.

7.5 Membrane integrity is measured by a Pressure Hold Test, which is sufficiently sensitive to readily identify a single fibre break in the largest rack at Bristol Water, containing 24 modules. For the 5 plants which have been fed into supply so far, only 2 broken fibres were found during commissioning, and no broken fibres have been found whilst the plants have been in supply.

7.6 The UF membrane contract has now been extended to include an 8th site, an 18 mld installation at Chelvey, which is currently under construction.

Table 1

The Bristol Water UF Programme

Site	**Flowrate (mld)**	**No of modules**	**No of racks**	**Commissioning Date (2001)**	**Into supply (2001)**
Frome	5	50	5 (x 10)	March	May
Alderley	5	50	5 (x 10)	April	May
Forum	2	20	4 (x 5)	July	Aug
Sherborne	4	40	4 (x 10)	June	Aug
Charterhouse	2	20	4 (x 5)	Aug	Sept
Banwell	6	60	6 (x 10)	Sept	Oct
Oldford	15	144	6 (x 24)	Nov	Dec

Table 2

Operational Sequence at Frome

Time, mins / Rack no.	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
1	B	B	B	B	B	B	G	B	B	B	B	B	B	B	R	G	B	B	B
2	B	B	B	B	B	B	G	B	B	B	B	B	B	B	B	G	B	B	B
3	B	B	B	B	B	B	G	B	B	B	B	B	B	B	B	G	B	B	B
4	B	B	B	B	B	B	G	B	B	B	B	B	B	B	B	G	B	B	B
5	B	B	B	B	B	B	G	R	B	B	B	B	B	B	B	G	B	B	B

Blue (B) - *filtration*
Green (G) - *b/w from concentrate, followed by b/w from feed - downtime 1 min*
Red (R) - *CEB (20 ppm H_2O_2 with 10 min soak) followed by an extended b/w rinse–downtime 15min*

Figure 1

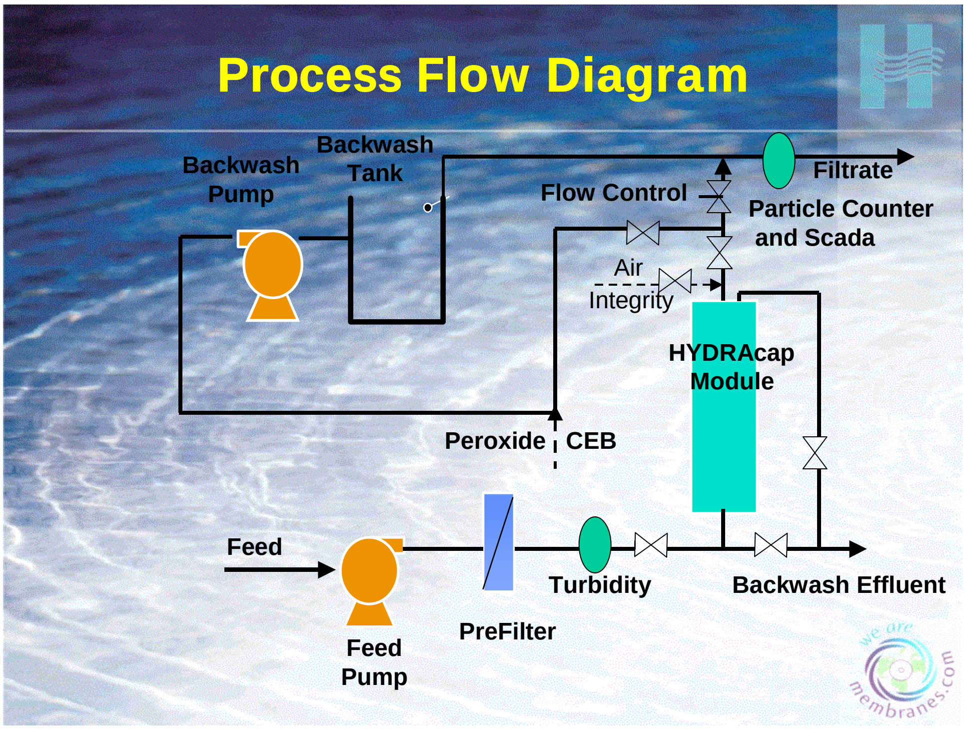


Figure 2

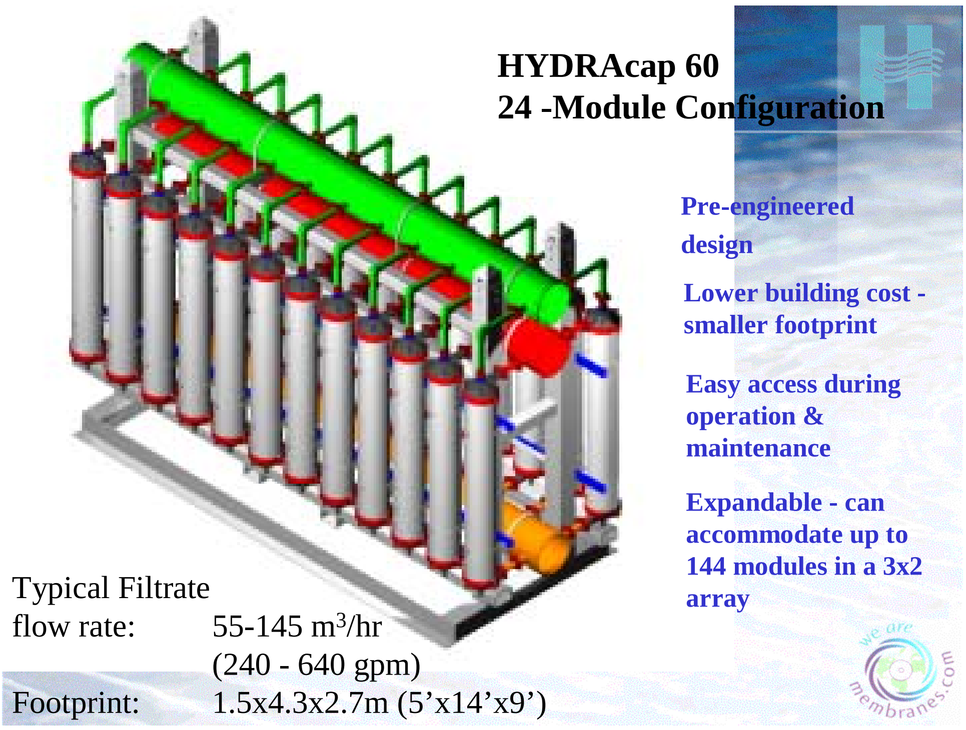


Figure 3
Photograph of the Installation at Frome

Figure 4
Permeability vs Time for the first 5 months of Operation at Frome

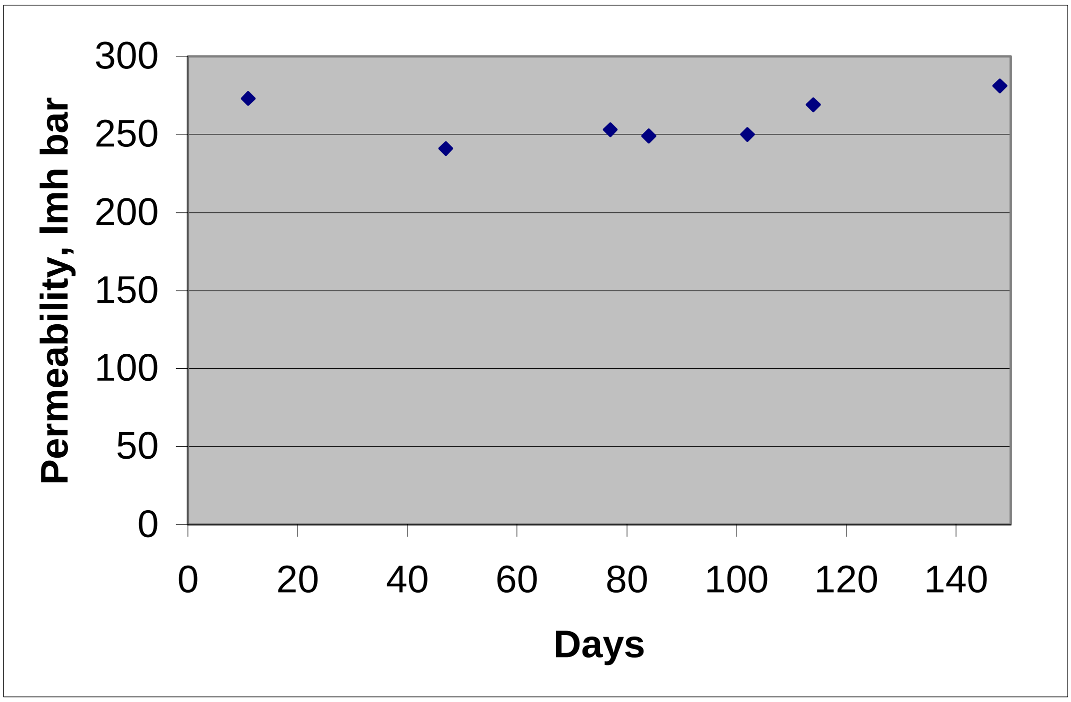
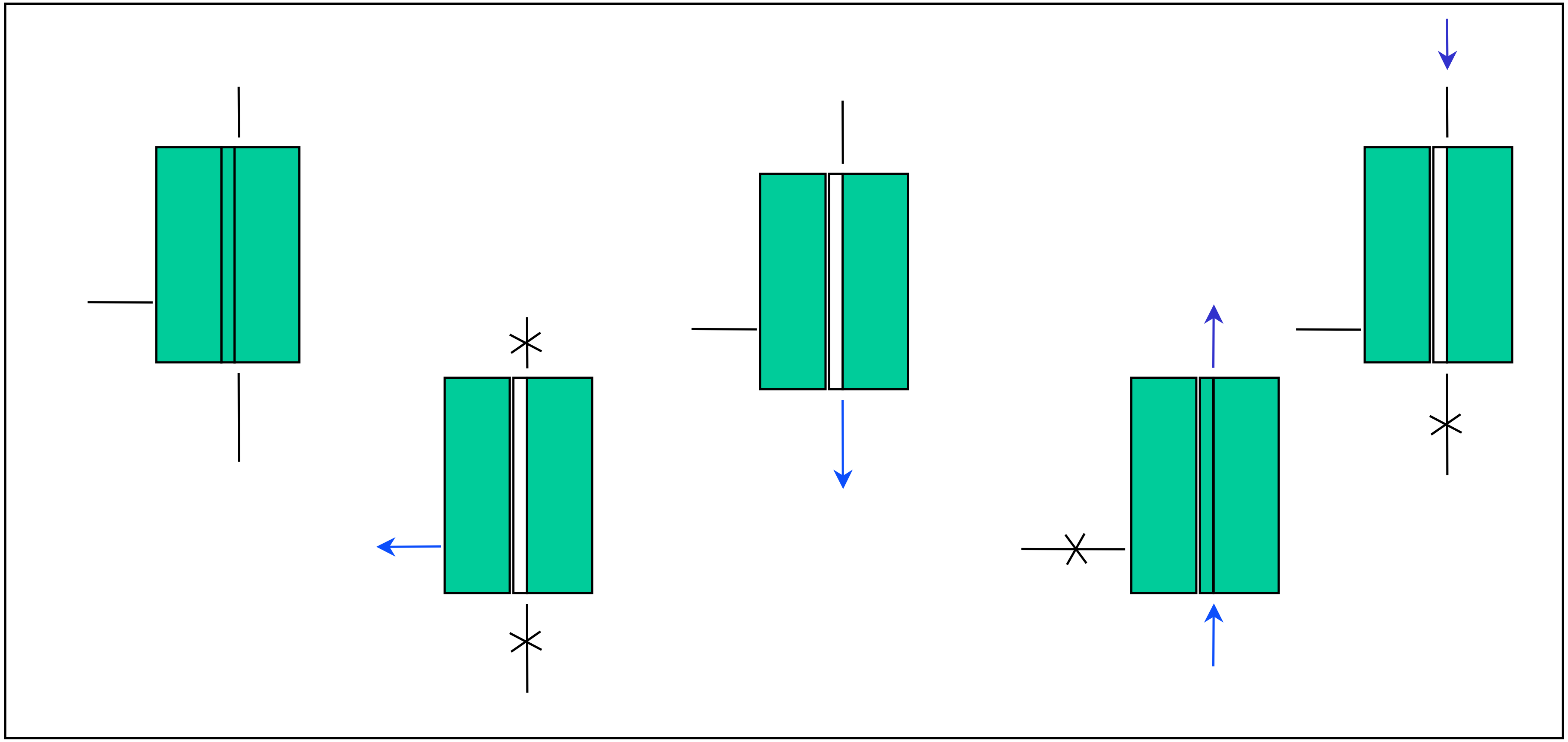


Figure 5 Operating Sequence for the Pressure Hold Integrity Test



• Pressure Hold

-detects one broken fibre in standard 24 module rack