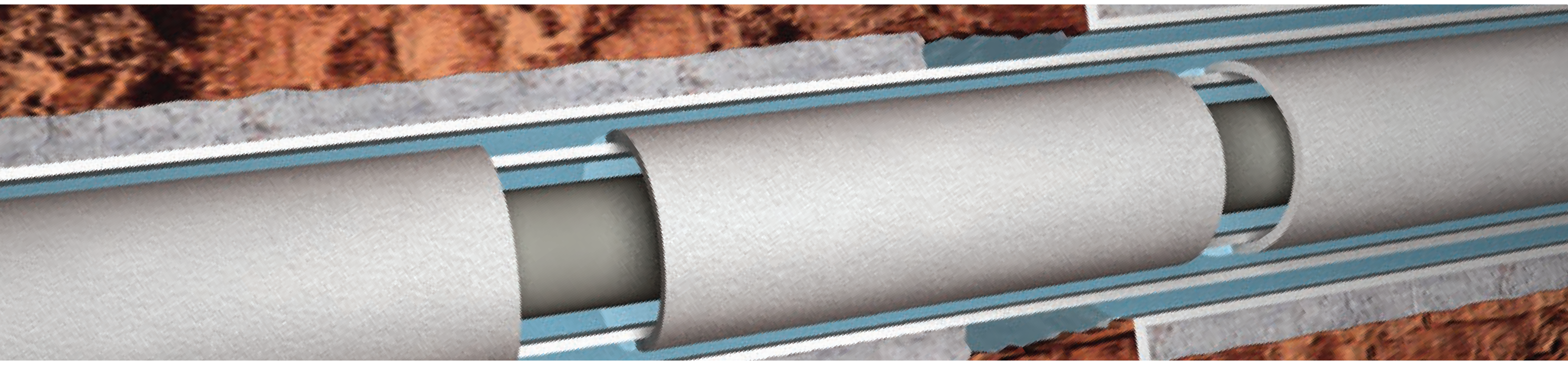
Balmoral Offshore Engineering

Buoyancy, insulation and elastomer products



Balmoral Casing Guard™

APB mitigation system

THE QUEEN'S AWARDS FOR ENTERPRISE: INTERNATIONAL TRADE 2010

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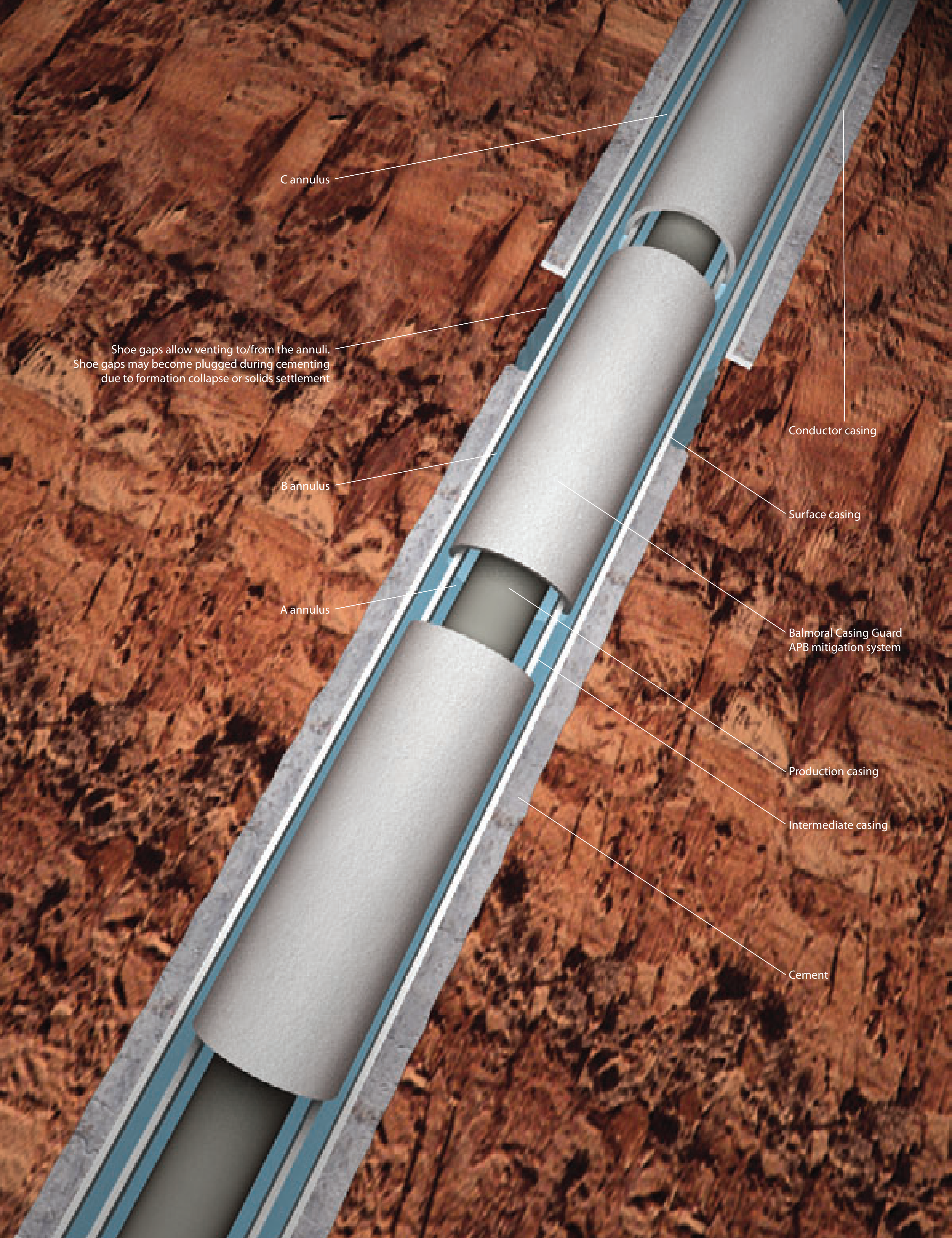
Balmoral Casing Guard™



Annular pressure build-up (APB)

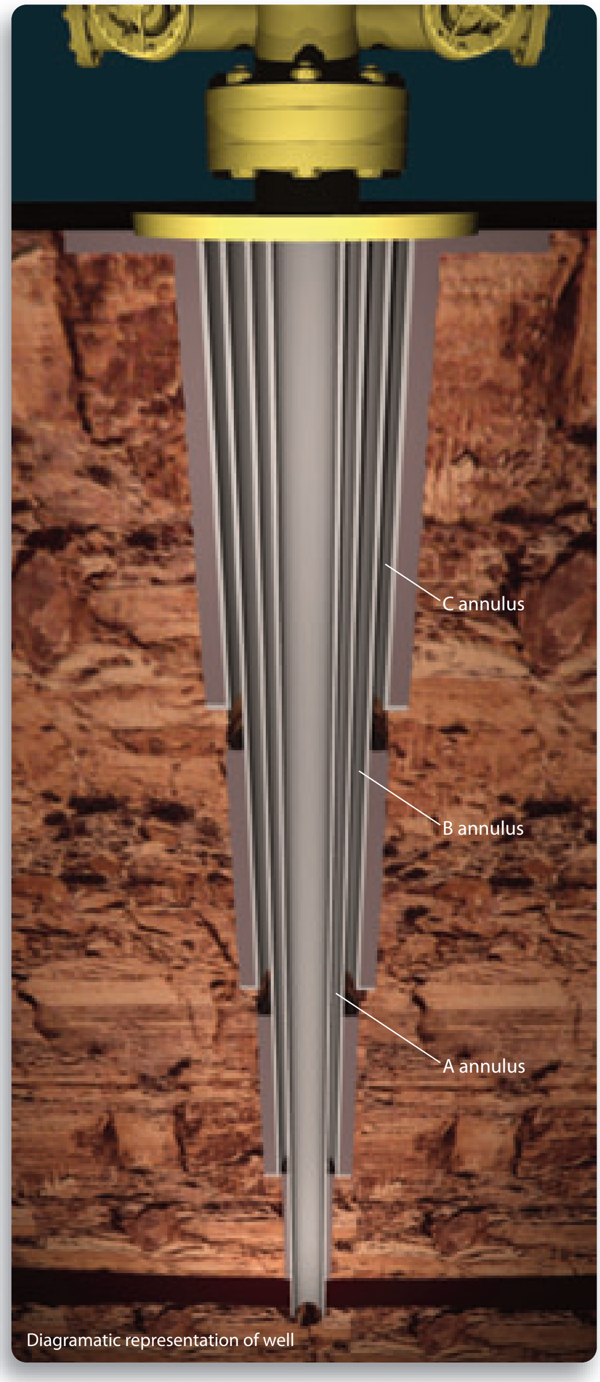
As a subsea well is drilled, successively smaller casings are introduced creating a number of fluid-filled annular spaces. Only the inner-most annulus (A) can bleed off through the subsea tree. The outer annuli (B and C) may be open to fluid movement through open shoes but, in practice, these annuli frequently get plugged off during cementing by formation collapse or solids settlement.

Due to the combination of extreme water depths and hole depth in many modern offshore wells, HP/HT reservoir fluids can reach temperatures as high as 350ºF while flowing. When a well is brought on line these hot fluids rise up the casing string, elevating the temperature of the casings and annular fluids during flow.

If thermal expansion of the annular fluids is restricted by plugging, a major pressure increase, known as annular pressure build up (APB), occurs. Pressure increases of 80-150psi/ºF are typical, meaning that even a relatively modest temperature increase of 100ºF can result in pressures approaching 15,000psi.

It is not generally cost effective and, in many cases, impractical to design the casing string to tolerate the potentially massive APB's in modern wells. Engineered APB mitigation systems are therefore required to accommodate such expansion.

APB is known to have caused the rupture of intermediate and production casings on several wells over the last 10 years. The financial impact and recovery implications of such failures are enormous.



Diagramatic representation of well

The theory of APB mitigation

Recognised APB mitigation systems include precision-engineered bursting discs and nitrogen fluid spacers. Potentially, however, the most simple mitigation system is that of syntactic foam elements with designed collapse performance located within the casing annuli.

The annular volume increase resulting from this engineered foam collapse accommodates the thermal expansion of the trapped fluid and significantly reduces APB.

Balmoral is acknowledged as an innovative and proactive developer in the fields of advanced syntactic foam systems for subsea buoyancy and insulation use. The company has now developed a family of unique syntactic foam systems that provide protection against excessive APB in casings during the start-up of subsea wells.

Known as Balmoral Casing Guard (BCG), in-house technologists developed the materials by applying behaviour patterns for syntactic foams, originally established for more traditional buoyancy and insulation systems, to the unique requirements of APB mitigation.

Pure syntactic foams comprise hollow glass microspheres (HGMS) suspended in a thermoset resin matrix. HGMS grades are available with collapse pressure ratings ranging from 250-28,000psi; these collapse pressures are not temperature sensitive. Discrete steps in collapse pressure mean that, in the absence of other factors, protection against APB could only be provided at those specific pressures determined by the glass microsphere pressure ratings.

However, the collapse pressure of each microsphere grade can be enhanced by the selection of a matrix resin system with appropriate mechanical performance. By careful selection, syntactic foams with a continuum of collapse pressures from 250-28,000 psi can therefore be created.

As the mechanical performance of the matrix resin system is temperature dependant so too is the collapse pressure of the syntactic foam even though the collapse pressure of the glass microspheres is not temperature dependant in isolation. It is therefore possible to formulate a syntactic foam which will suffer hydrostatic collapse (HCP), and thus APB mitigation, at effectively any combination of pressure and temperature.

The effects on HCP of microsphere grades of temperature and resin matrix Tg are illustrated in Figures 1 and 2.

The amount of foam volume contraction upon hydrostatic collapse - known as the 'collapse percentage' - is a function of the volume fill of the foam by microspheres. Contractions of 30-40% are routinely available.

The volume contraction behaviour of a typical medium Tg grade of Balmoral Casing Guard is given in Figure 3.

Figure 1: HCP vs Temperature
Effect of HGMS pressure rating
High Temperature Systems (Tg 120ºC)

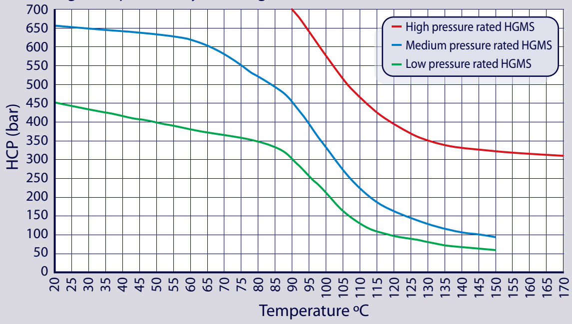


Figure 2: HCP vs Temperature
Effect of Matrix Tg
High Pressure-rated HGMS

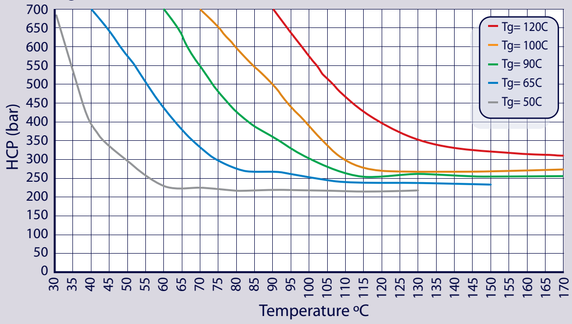
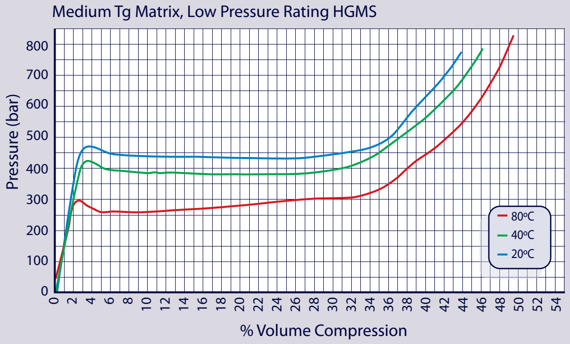


Figure 3: Effect of Temperature on Volume Compression Behaviour
Medium Tg Matrix, Low Pressure Rating HGMS



Balmoral APB mitigation system

When specifying APB mitigation requirements the operator's well design engineers will normally declare:

1. **The temperature and annular pressure range at which pressure mitigation is likely to take place**
2. **The 'collapse volume' required. Collapse volume is the additional volume in the casing annulus required to be created by foam collapse and is based on the anticipated fluid thermal expansion and the residual annular pressure build-up that the casings are able to accommodate.**

The volume of Balmoral Casing Guard required to achieve APB mitigation is dictated by the collapse volume for the particular annulus, based on the annular volume and temperature rise, and the collapse percentage of the selected foam for the specified collapse pressure band. Standard practice is to allow a modest excess of foam, typically 20-25%, as a safety margin should the collapse volume be underestimated.

In the majority of cases the APB is linked directly to annular fluid temperature increase upon well start-up. In this situation, the standard design practice for BCG is to select a foam grade where the matrix Tg is close to or less than the temperature at which the APB mitigation is to take place.

This ensures that BCG collapse pressure is highly sensitive to temperature change and collapse is guaranteed once the design APB mitigation temperature is reached.

The effect of temperature upon the volume compression behaviour of a BCG system based on a low pressure-rated HGMS and matrices of varying Tg is shown in Figure 4.

In certain circumstances APB may occur across a range of operating temperatures. In order to mitigate APB in these circumstances the foam performance is completely different, the requirement being for a system with a collapse pressure which is largely insensitive to temperatures across the range of interest.

This is achieved by selecting a foam matrix with a Tg far above the temperature range of interest. The only significant means of collapse pressure control for these systems is now through HGMS grade selection. The behaviour of such systems is illustrated in Figure 5.

Figure 4: Effect of Tg Matrix on Volume Compression Behaviour
High, Medium/High and Medium Tg Matrix
Low Pressure Rating HGMS, Tested 80ºC

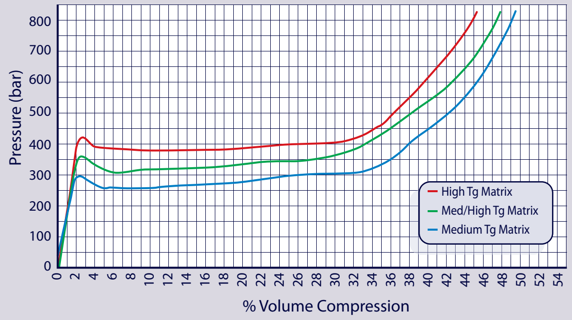
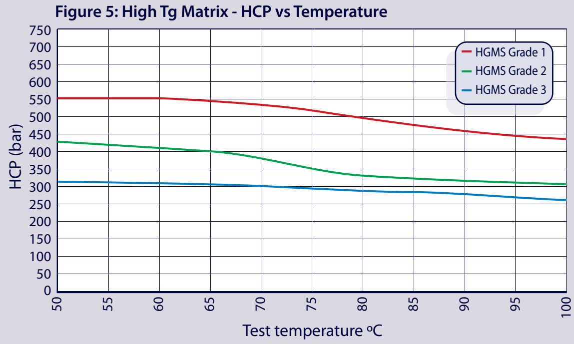


Figure 5: High Tg Matrix - HCP vs Temperature

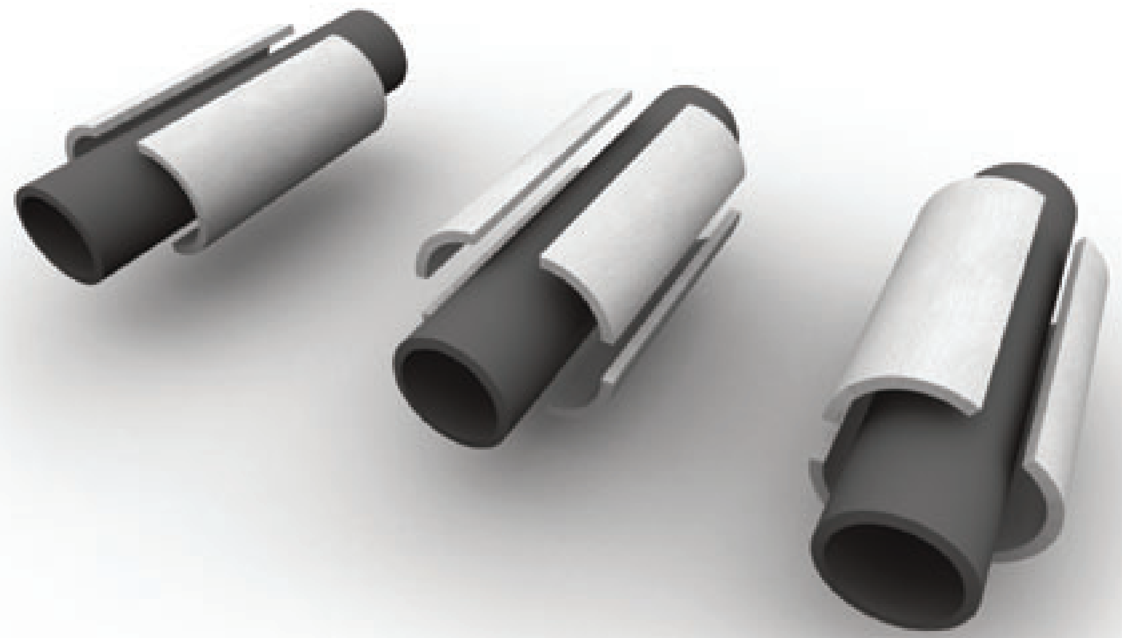


Application and operation of Balmoral Casing Guard

Balmoral Casing Guard is supplied as an easy-to-install kit for site application. It is routinely supplied as foam quadrants, typically 0.5–1.5m in length. These quarter cylinders are bonded to the outside diameter to create a continuous cylindrical section or, where a complete cylinder could later result in restricted fluid flow, in two or three sections around the casing outside diameter. The effective outside diameter of the installed BCG quadrants is restricted to minimise damage to the foam during casing deployment.

The complete BCG kit comprises the quadrant sections, adhesive system, powered adhesive dispensing equipment, banding and full HSE and installation documentation.

Once installed and the coated casing run, BCG has no detectable effect upon normal well operations and remains passive. When the design collapse conditions are reached, BCG responds immediately to provide the degree of APB mitigation specified by the engineering design team.



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