Thermal Annealing Calorimeter Design for Super Bigbite

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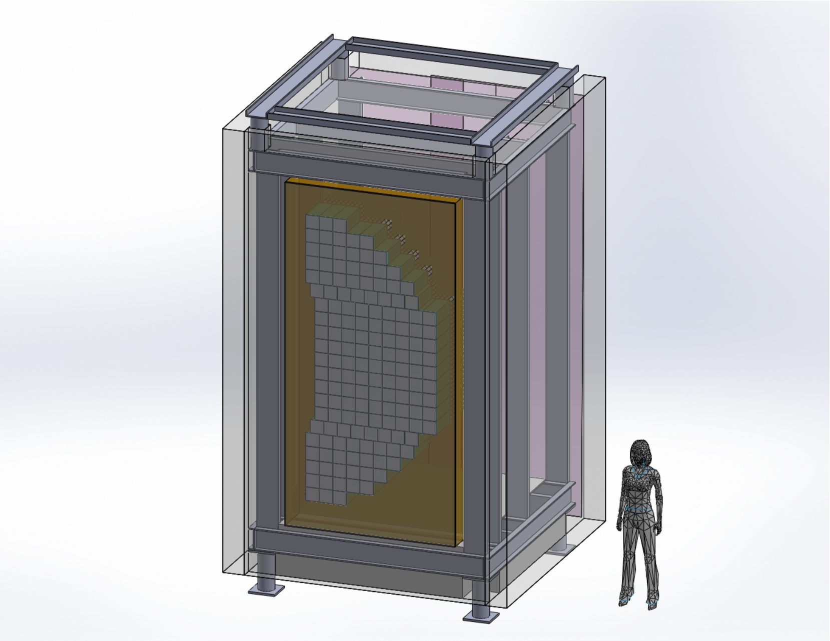


1 ECal and the Thermal Annealing Concept

The Super Bigbite (SBS) ECal is a large acceptance, moderate resolution lead glass electromagnetic calorimeter which serves as the primary electron trigger for the Super Bigbite GEp experiment. It consists of ∼1700 modules contained within in a 3×2 m^2 arrangement designed to match the acceptance of the hadron arm for the experiment. To meet this goal, approximately half of the area is designed to be inactive "filler" material to provide structural support for the lead glass blocks. Due to the large radiation dose rates for the experiment, thermal annealing will be continuously employed to maintain optical transparency of the blocks.

The important physics considerations for the SBS ECal are the energy and position resolution. For the SBS GEp highest Q^2 kinematics, a Geant4 simulation of the single and coincidence trigger rates was done which showed that a ECal trigger threshold of 90% is needed to keep the coincidence trigger rate below 5 kHz. This 5 kHz limit to the trigger rate is set by data rate limitations by the GEM readout pipeline in a coincident hadron detector stack.

The minimum ECal trigger threshold is set by the ECal energy resolution to minimize the loss of elastic events due to the trigger threshold and suppress lower energy electrons from inelastic scattering. ECal will also measure the position of the electron with a resolution of approximately 8 mm, and the position is matched in coincidence against corresponding blocks in the parallel hadronic arm. By imposing elastic kinematics, this becomes a primary cut to identify elastic events in the offline analysis. Continuous thermal annealing of the lead glass blocks will constantly repair the radiation damage over the entire length of the block. Studies were done to determine the operating temperature needed to produce an annealing rate that would compensate for the rate of radiation damage and leave the lead glass with resolution of 5% for 4 GeV electrons.

In this report, we specify the design requirements for such a calorimeter based upon operational experiences with two prototypes. The heating and cooling subsystem implementation is presented. The general mechanical structure and assembly is discussed along with proposed materials.

1.1 ECal Physics Requirements for Super Bigbite

As the primary trigger of GEp, the calorimeter must have sufficient position and energy resolution to allow for optimal coincidence triggering of elastically scattered electron-proton events. Degradation in the resolution decreases the rejection of inelastic events which would quickly overwhelm the data acquisition rate capabilities. In addition, given the rectangular aperture of the hadron arm, the calorimeter is configured for the acceptance-matched scattered electrons profile, Fig. 1.

The calorimeter blocks and PMTs have been employed in previous Jefferson Lab experiments, such as GEp-III and Real Compton Scattering, but were deployed in lower radiation dose environments which allowed for periodic UV curing to maintain optical transparency. The blocks were stacked in a row-column fashion in a rectangular shape.

For SBS GEp, a row column structure is proposed in groups of 3×3 modules, Fig. 2. The mechanical structure of the modules is described in Sec. 1.4. There are 1710 blocks total, 1053 of dimension $4.2 \text{ cm} \times 4.2 \text{ cm}$ and 657 $4.0 \text{ cm} \times 4.0 \text{ cm}$. In areas where fewer than 9 blocks will be active, inactive blocks or possibly filler material of a matched size will be supplemented.

A conceptual mechanical design for the full calorimeter is shown in Fig. 3. This design has been scaled from the working C200 design (documented in a separate report). It consists of a profile to support the modules layout

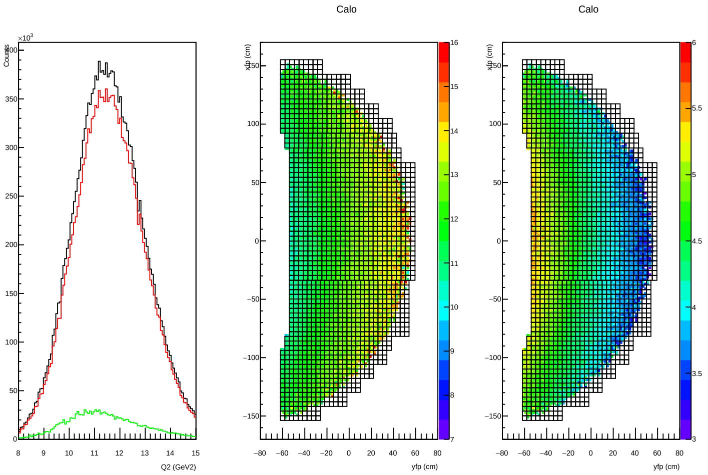


Figure 1: ECal Q^2 coverage (left, center) and momentum coverage (right) for the Super Bigbite GEp highest Q^2 point.

shown in Fig. 2 in a monolithic design, a thermally separated support and work platform, and crane attachment. Five sides are covered by hollow panels which can be filled with several inches of insulating material. The internal enclosure is required to be light tight for PMT operation and must allow for PMT high voltage and signal cabling, which are external to the enclosure, and for ducts to carry forced air. This design is for conceptual purposes and has not been evaluated by engineers.

1.2 Thermal Properties of Lead glass

To provide adequate continuous transparency given the radiation profile, a thermal gradient of 225°C for the upstream (front) part of the block and 185°C downstream (back) is sought. Cooling to operational temperatures for the PMT is done along the light guide.

TF1 lead glass with glued borosilicate light guides were assumed as fixed parameters for the full design. The dimensions and thermal and mechanical properties from the manufacturers are given in Table 1.2, Appendices A and B.

Large thermal gradients can damage the lead crystals due to internal

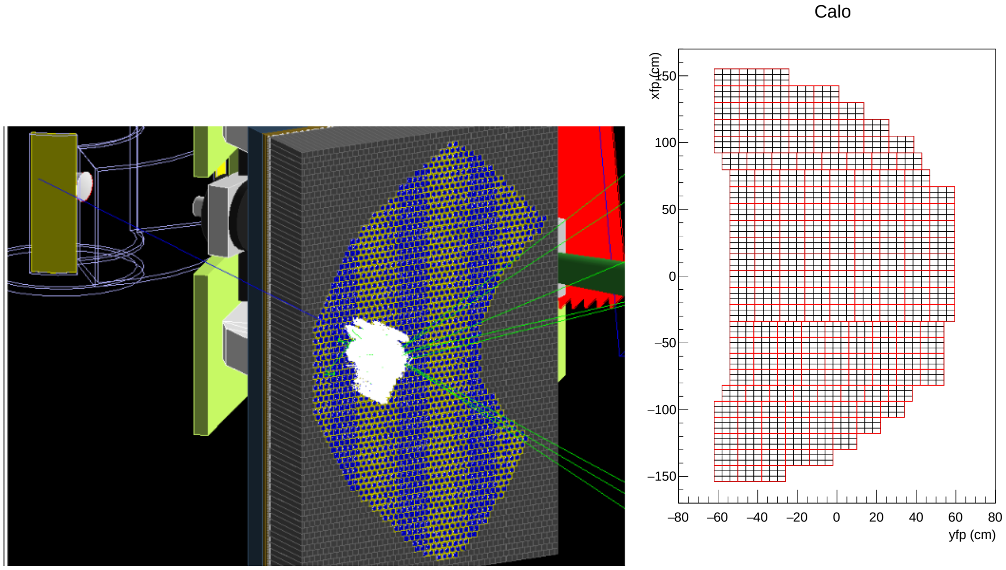


Figure 2: ECal layout for SBS GEp with a Geant4 simulation (left) and a proposed block layout (right). Approximately half the material is inactive filler material while the active lead glass is in a crescent acceptance-matching shape.

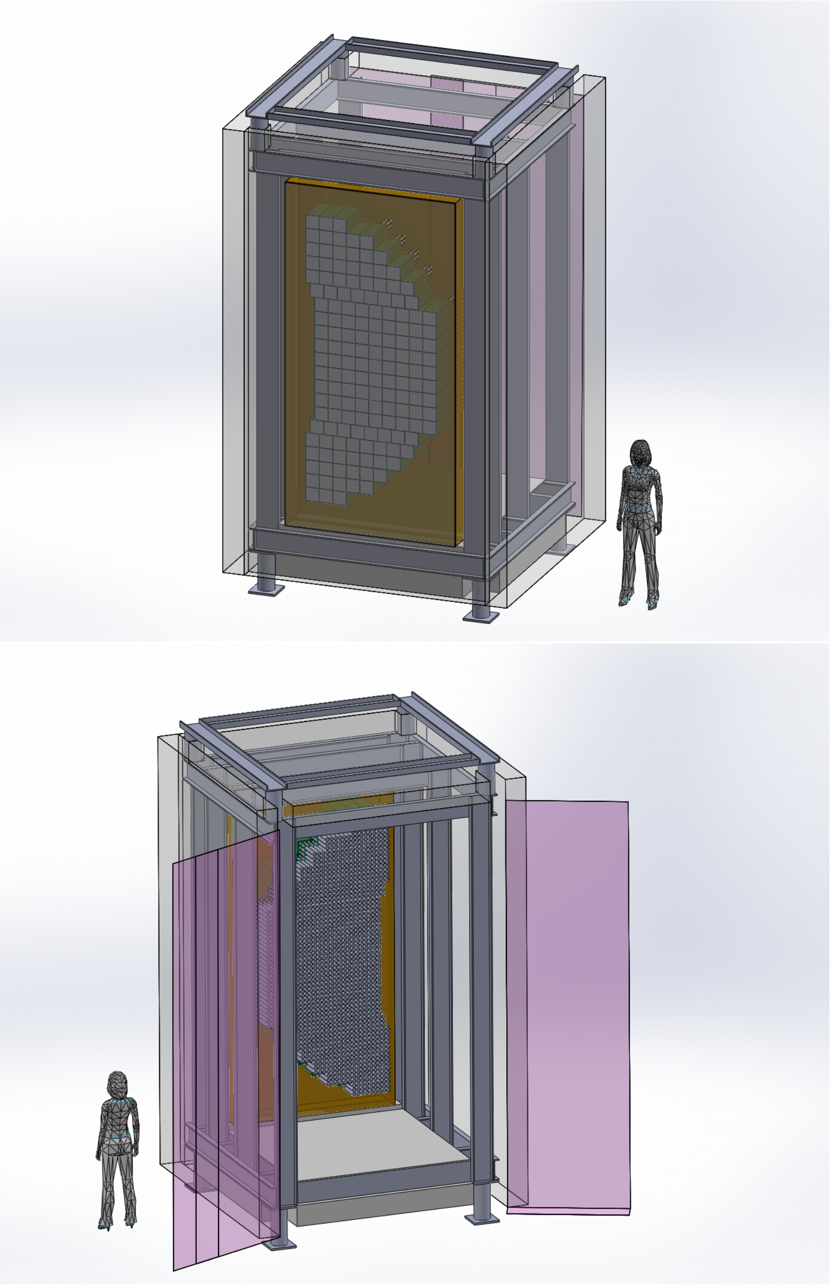


Figure 3: Conceptual structure for SBS GEp ECal

Lead glass Block Properties	
Material	TF1 Lead glass [App. A]
Width/Height	40 or 42 mm
Length	40 or 34 cm
Weight	2.2 kg (4.8 lbs)
Density	3.9 g/cm^3
Coefficient of Linear Expansion	8.6×10^{-6}/K
Thermal Conductivity	0.65 W/m $\cdot$ K
Heat Capacity	0.4 J/g $\cdot$ K
Thermal Diffusivity	0.4 mm^2/s
Young's Modulus	55 GPa
Maximum compressive strength	50 GPa
Light guide Properties	
Material	Borosilate-33 [App. B]
Diameter	30 cm
Length	15 cm
Density	2.2 g/cm^3
Coefficient of Linear Expansion	3.3×10^{-6}/K
Thermal Conductivity	1.2 W/m $\cdot$ K
Heat Capacity	0.83 J/g $\cdot$ K
Thermal Diffusivity	0.7 mm^2/s

Table 1: Parameters of the lead glass blocks and light guides.

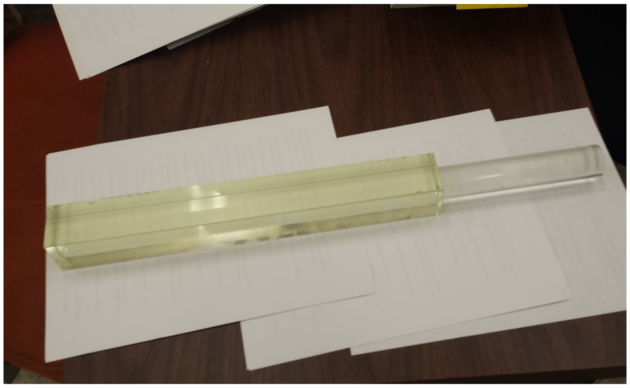


Figure 4: 42 mm×42 mm unwrapped block with glued light guide.

stress from non-uniform expansion. This stress, σ, can be given by

$$\sigma = E\alpha\Delta T \tag{1}$$

Given a maximum compressive strength of glass $\sim$ 50 MPa, an elastic modulus for lead glass of $E = 55$ GPa, $\alpha = 8 \times 10^{-6}$ and a characteristic distance of 2 cm (half the block width), an upper limit of 50K/cm is employed for this design.

The photomultiplier tubes are FEU-84, App. D, which have been used in previous deployments at Jefferson Lab. Their operation up to 50°C and 100°C for short periods (Sec. 1.6.3) has been tested and is taken as our limit.

1.3 Bulk Mechanical Structure

Primary base support for the lead glass blocks has the requirements that it must support the full load of the blocks and any additional material, be able to accommodate the required thermal gradient through additional heating, and hold the blocks in place given thermal expansion.

While a full engineering design for the support of ECal is to be completed, the bottom support should be a smooth, continuous surface. Two transverse separated aluminum plates with heating are sufficient to maintain the longitudinal thermal gradient by compensating for thermal losses from the sides. Similarly one side of the tightly packed configuration can be held using two heated vertical plates, e.g. Fig. 5. To reduce thermal conduction to the plate

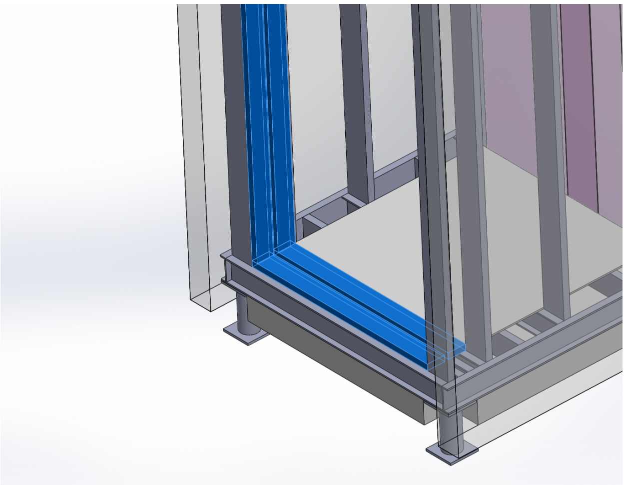


Figure 5: Conceptual ECal frame with separated aluminum plates for support. Each plate is heated separately.

1/8 in polyimide (Kapton) compression resistant board can line the surfaces. This material has a low thermal conductivity of 0.03 W/mK (compared to 40 W/mK for 6061 aluminum) and can be used at temperatures up to 280°C, and has a compression modulus of 800 psi (100 blocks applies a pressure of 23 psi) and which also provides a semi-cushioned surface.

To allow for thermal expansion, at least one side in each of the transverse directions must allow for semi-free motion and small variations in surface uniformity. Force can be applied by individual compression springs of 302 or 316 stainless steel which can operate at temperatures up to 260°C. Pressure can be distributed over a $\sim$1 in^2 area by an attached metal plate padded with polyimide board.

1.4 Scalable Modular Design

Scalability and allowance for independent mechanical expansion of the blocks is of critical importance to the design. The supermodule concept was developed, Fig. 6 to meet these requirements. It consists of a rectangular box open at the top and bottom with nine lead glass blocks set in a square. The front and rear are of 6061 aluminum and the sides of 25 gauge stainless steel (previously tested was 22 gauge galvanized G90 carbon steel). The modules

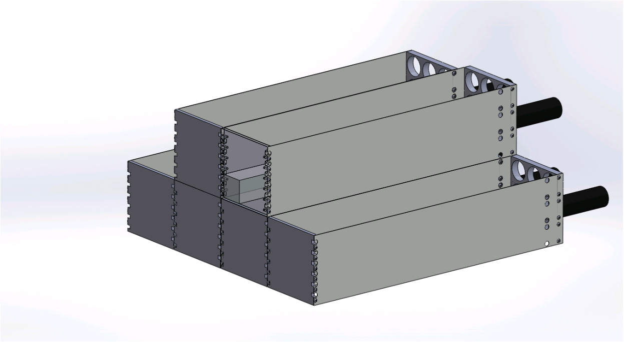


Figure 6: Supermodule stacking concept.

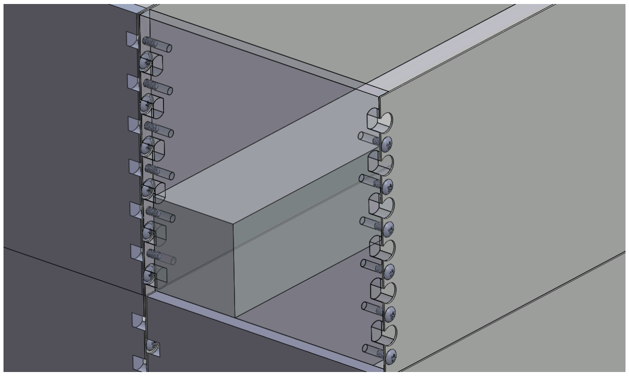


Figure 7: Supermodule front plates interlocking in tight-stack configuration.

are designed to be tightly packed by having interlocking sides of alternating screw/recess patterns in the front plate, Fig. 7. Longitudinally, two varieties of modules are constructed, “short” and “long”. The long modules are identical to the short modules except they are 1 inch longer and have an additional set of holes for neighboring short module screw heads, Fig. 8.

The heights of the plates and walls must be slightly undersized so size is driven by the bricks and does not interfere with neighboring modules. Additionally, the front plates will expand 0.3 mm over the lead glass and would cumulatively expand the stack disproportionately. Module screws must be loosened slightly in assembly to avoid bowing of the walls and stress on the block corners. These materials were simulated to have negligible impact on

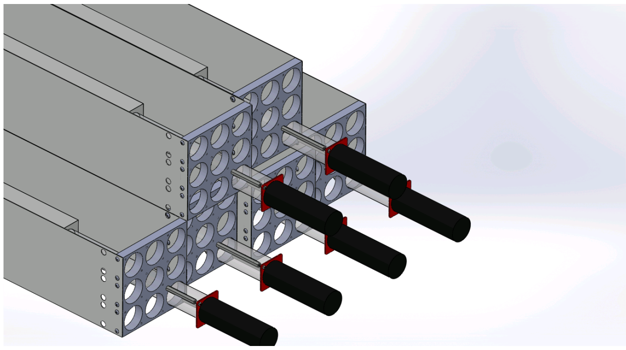


Figure 8: Supermodule rear stacking. Longer modules provide a small access gap to light guide area and holes for short module screw heads.

the light collection and physics performance of the calorimeter.

This design also has several advantages for heating by providing surfaces to potentially attach heating elements.The rear plate consists of 1/2 in thick aluminum and 9× 36 mm diameter oversized holes for PMTs Fig. 9. PMTs are held in place by existing G10 plastic holders, Fig. 8, which fit around the PMT pins and are fixed to the plate by screws into 2 or 3 in aluminum standoffs (depending on the module type).

A silicone "cookie" is placed between the light guide and PMT to improve light transmission properties. Saint-Gobain offers a version, BC-637 High Temperature Optical Interface Pad, that is rated to 200°C, App E. The PMTs and cookies are pressed into place by tensioning the screws onto the plastic piece while cold and can adjust for variations in length of the blocks (e.g. from gluing). The pieces must be slightly over-tensioned to account for longitudinal thermal expansion of the steel, approximately 2 mm.

1.4.1 Filler Material

Approximately half the mass of the calorimeter will be of inactive material to allow for matched solid angle in the GEp experiment and support the lead glass. This material should have sufficient strength for support, maintain that strength up to 200°C, a similar thermal expansion coefficient, and a similar or smaller thermal conductivity compared the lead glass. While sufficient lead glass exists to fill these spaces, they not in 42 mm dimensions and would require shimming for a tight-packing configuration. One alternative is to

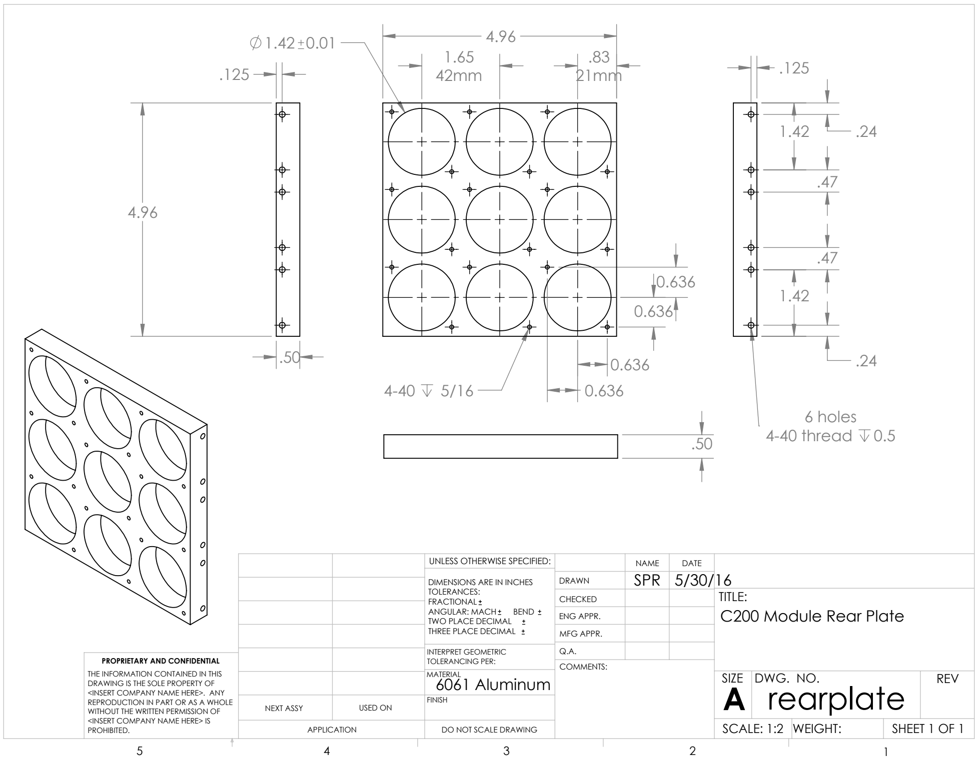


Figure 9: Supermodule rear plate drawing.

	TF1	Brick
Density [g/cm^3]	3.6	2
Coeff. of Thermal Expansion	8.2×10^{-6}	10×10^{-6}
Thermal Conductivity [W/mK]	0.63	0.9

Table 2: Comparison of thermal properties between TF1 lead glass and brick. Brick data from The Brick Industry Association.

use an inexpensive material in more practical prefabricated sizes. Common construction brick provides these properties, Table 1.4.1. In addition, a filled supermodule has a height of approximately 5 in, and 2 1/4 in (standard) and 1/2 in brick are commonly available sizes.

1.5 Heating Considerations

Heating elements must be present on all sides to establish a uniform thermal gradient and compensate for small thermal losses in the system. We consider the total required power, losses due to convection and forced air cooling, insulation and construction materials, and time required to establish and cool the system.

1.5.1 Requirements

We start with a simple one dimensional model to characterize the system, Fig. 10, which does not include convective losses or losses in the side. Heat is applied evenly per block to the front face and rear face and we assume ambient temperature externally. The total power required for the front and back is similar and requires a total of approximately 1 W/block. With similar considerations, the stainless steel walls add an additional average 0.3 W per block.

Losses from the sides of the stack are dependent on the specific implementation of insulation and scales with stack perimeter rather than number of blocks, reducing the average requirements for larger stacks. For a 3 m × 2 m stack with 8 in of FOAMGLAS, the loss is approximately 150 W total, a relatively small amount. In practice convective losses will add to this.

The thermal diffusivity of lead glass and light guides is 0.4 mm^2/s and 0.7 mm^2/s respectively. When the front and back blocks held at a constant

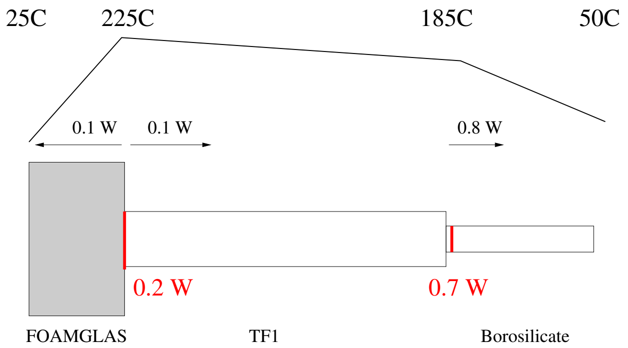


Figure 10: One dimensional schematic of heat flow based on temperature gradients.

temperature, this requires about one day for the heat to diffuse and the blocks to reach equilibrium. Raising the system to higher temperatures to increase the warm up time is difficult due to the maximum temperature limitation for the PMTs. From the heat capacity, 6 kW of applied power on 3500 blocks requires approximately 40 hours without losses.

A simplified representation of the calorimeter used in simulation is shown in Fig. 11. The calorimeter uses an approximated transverse area for the active lead glass and is embedded in brick. The detailed implementation of cooling is replaced with an effective parameter of 15 W/m^{2}K which was conservatively taken from the C200 results and fluid dynamics calculations which ranged from 8-13 W/m^{2}K. The combined effective lead glass and stainless steel conductivity is used. The inactive brick is covered in the rear by 4 in of FOAMGLAS insulation. A value of 7 W/m^{2}K was used for conductive losses to the bottom support; this value is dependent on the final design of the support frame but is not difficult to accommodate variations.

Results for the temperature profile with supplied powers in Table 3 are shown in Figs. 12 and 13. The distribution is relatively uniform to within a few K and can be modified in-situ by adjusting the insulation coverage on the rear.

Detailed temperature profiles due to the losses in the steel have variations on the 10 K level using insulated 25 gauge stainless, Fig. 14.

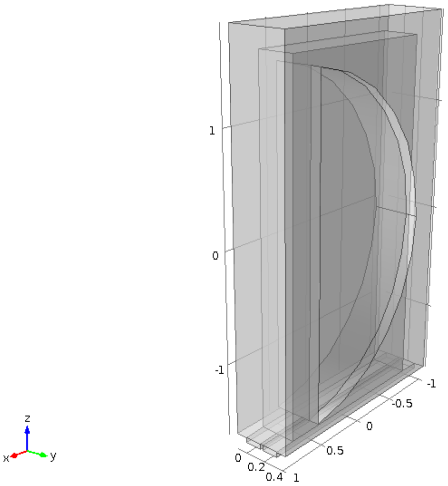


Figure 11: COMSOL representation of simplified ECal

	Power [W]
Front (full surface)	900
Rear (active surface only)	8200
Bottom	900
Top	20
Sides	120

Table 3: Power requirements for the full calorimeter

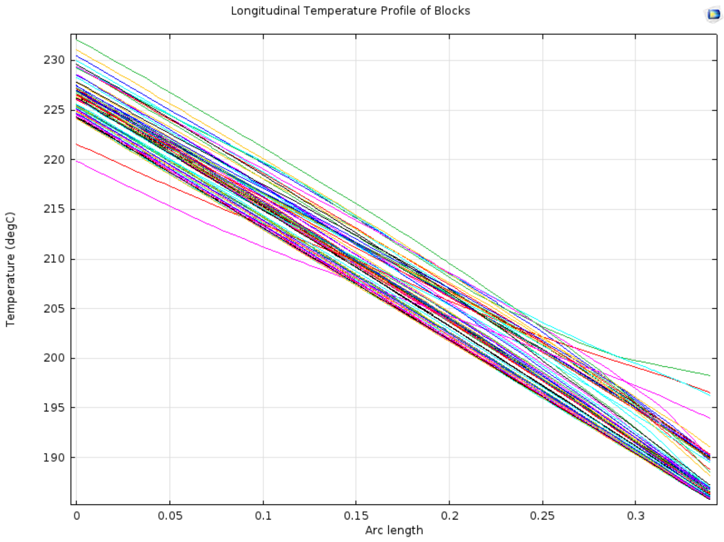


Figure 12: COMSOL representation of simplified ECal temperature gradient for several positions distributed along the calorimeter.

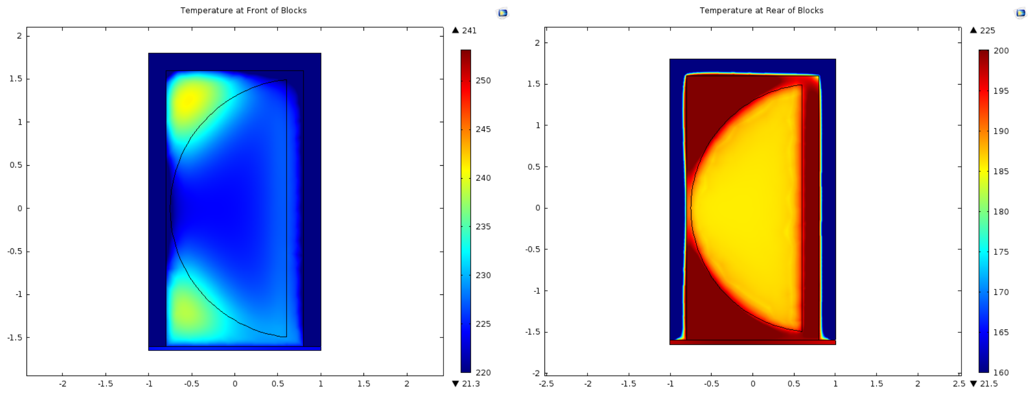


Figure 13: Simulated temperature profile for simplified ECal in COMSOL for the front block plane (left) and rear block plane (right). The temperature profile of 225°C at the front of the blocks and 185°C at teh rear of the blocks is met over the entire calorimter by the supplied power in Table 3.

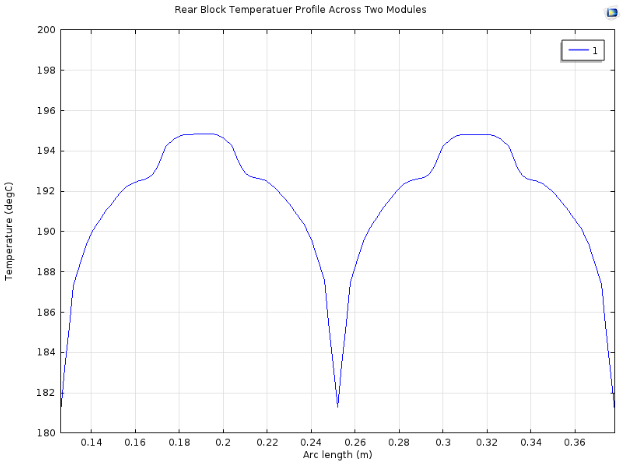


Figure 14: Temperature profile at the back of the blocks along a horizontal line at the center of the blocks across two modules. Variations on the order of 10 K due to the steel walls are present given no active compensation.

1.5.2 Element Placement

Front heating can be accomplished by stringing wire elements in a steel mesh which was pressed directly onto the front of the supermodule aluminum plates as was done in the C200 prototype. Heating from the side can be performed either by heating support plates directly in contact with the side or by attaching elements directly to the filler material.

Rear heating can be accomplished with elements placed directly on the light guides to prevent extreme local gradients on the lead glass blocks themselves, but close to the block bases to prevent unnecessary convective losses between the block and the element. This was the technique employed for the C200 prototype. A 1/8 in polyimide board partition with 33 mm holes is fitted around the light guides in the supermodule and held in place on both sides by high temperature silicon O-rings which block open airflow to the heating area, Fig. 15. O-rings are readily available for continuous operation of 200°C and have been tested in the C200 design.

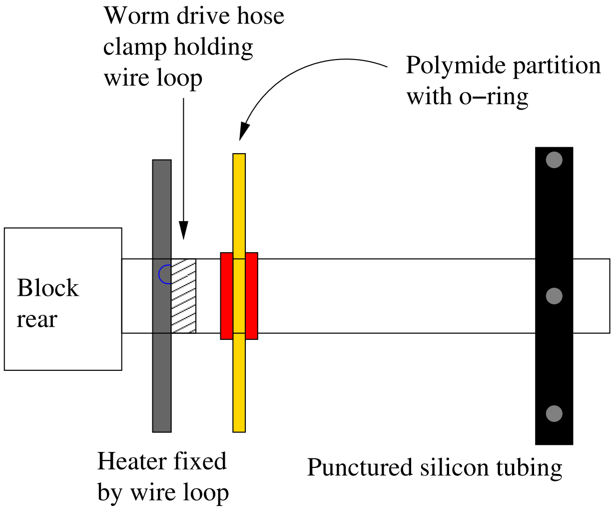


Figure 15: Rear heating/cooling organization

Figure 16: Rear heating of block stack with partition implementation in C200.

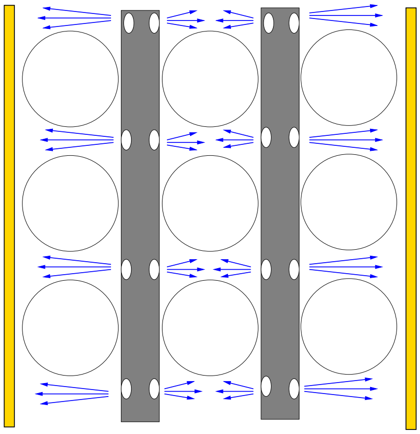


Figure 17: Cooling blowing air transverse to the light guides near the end where it meets the PMT to establish a gradual thermal gradient down the cylinder.

1.6 Cooling

Forced air cooling is required due to the restrictive volume once blocks are tightly stacked and PMTs are in place. One inch gaps due to the length differences in the supermodules allows for air to be flowed in through tubing.

1.6.1 Requirements

Approximately 0.6 W of power will be lost from the light guides per block and an additional 0.3 W on average per block from power lost to the supermodule wall. On the condition of continuously flushing air and under a 10-15 K rise from room temperature, this requires approximately 2-3 cfm of air per supermodule. Constricting this air to channels on the order of 3/8 in diameter to fit the light guide spacing is in the turbulent flow regime with $Re \sim 10^5$.

A configuration where air from a blower is forced into a flexible high-temperature silicon tubing manifold is proposed. Each tube is placed near the point of contact with the PMTs and streams air into the horizontal gap between the light guides transverse to the cylinder axis, Fig. 17. This provides sets up a gradual temperature gradient from the heating element and reduces the heat flow and therefore the power requirements.

Fluid dynamics simulations were performed to study in detail anticipated

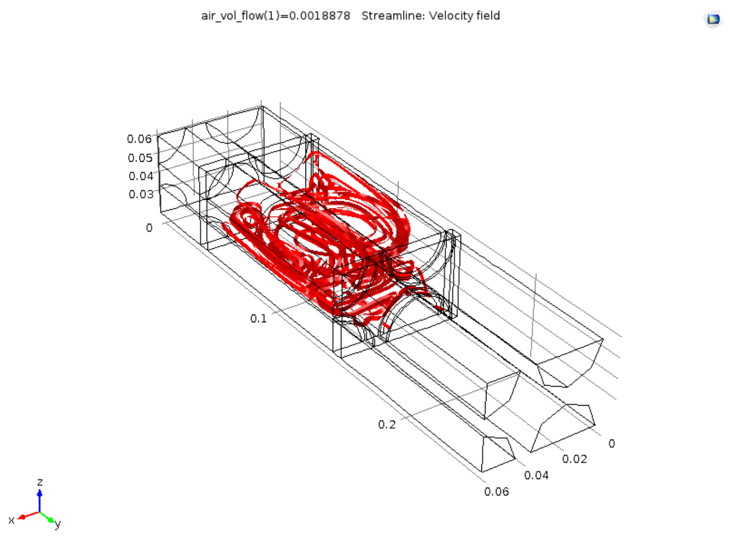


Figure 18: Surface temperatures in a forced air simulation for a single supermodule using computational fluid dynamics and heat transfer.

cooling requirements and search for situations which may be difficult to test for experimentally, Fig. 18. In particular the questions of temperature profiles for different volumes of air flow and hole diameters and if any local heating occurs were of concern.

A simulation where the rear block temperature was fixed at 185°C and symmetry and uniformity of the blocks was assumed to reduce computing requirements. The longitudinal temperature reduces with airflow rate as expected, Fig. 19, and the temperature across light guides is relatively uniform at the point of contact with the PMT, Fig. 20. The outlet radius does not appear to have significant impact on the cooling profiles, Fig. 21, likely due to airflow quickly diffusing to laminar conditions which occur on an inch length scale.

1.6.2 Configuration

High temperature polysilicon tubing of 3/8 in inner diameter, 1/2 in outer diameter (1/16 in wall thickness) and hardness of 70A on a durometer scale is proposed to be routed between the light guides and plugged at one end. Each supermodule requires two tubes with six holes punched for each tube.

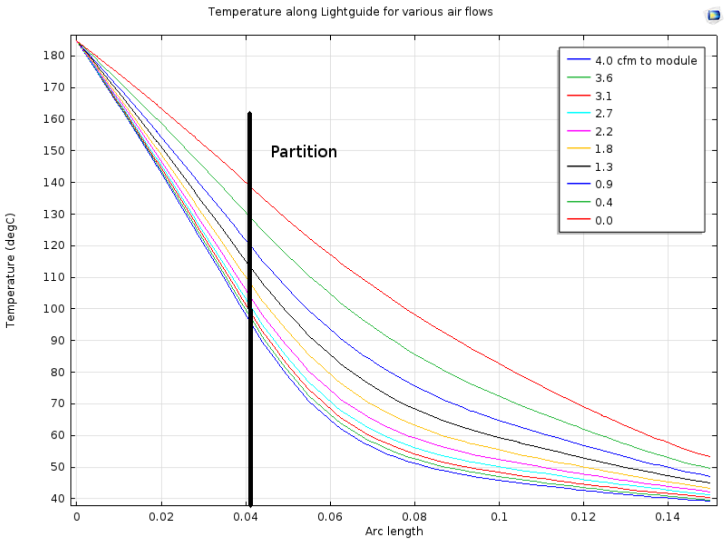


Figure 19: Light guide temperature down the axis of a block near the edge for different flow rates with 3/32 in outlet radius.

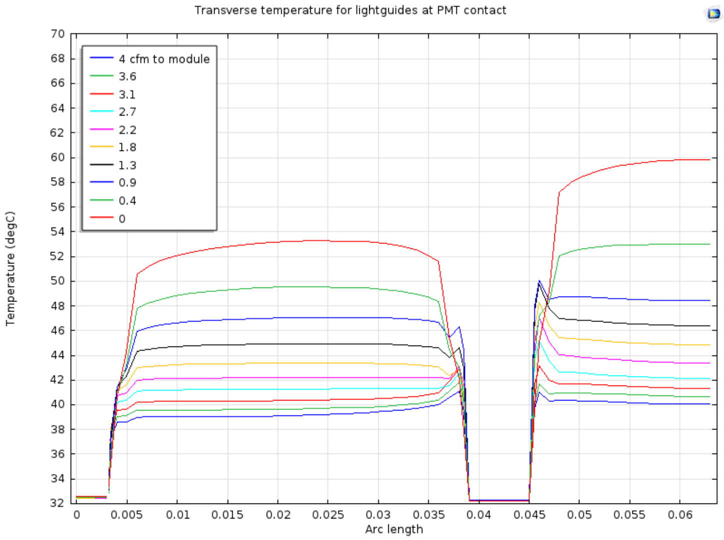


Figure 20: Temperature transverse to light guides at point of PMT contact for different flow rates with 3/32 in outlet radius..

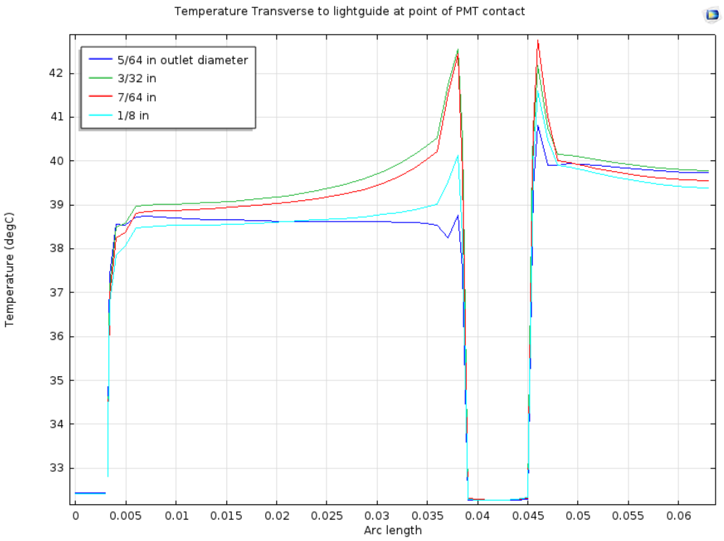


Figure 21: Temperature transverse to light guides at point of PMT contact for different outlet diameters (controlling velocity) for 4 cfm flow to the module.

Given the cross section of the tube, Three modules (18-20 holes) with 2 mm diameter can be supported to supply air flow. For approximately 4 cfm to each module, the air velocity in the tube is at least 17 m/s with $Re \sim 10^5$ and airflow can be treated as incompressible but turbulent. For 5 ft of tubing with this inner diameter and flow rate, the frictional pressure drop is estimated to be 3 in H_2O.

To support the full calorimeter, an array of manifolds will be required to divide flow of $\sim$ 600 cfm evenly. Breaking down the supply into manifolds of 4 outlets (which serves 16 modules), approximately 12 manifolds will be required. The inlets must be at least 3/4 in in size. For a single blower, it should be capable of $\sim$100 inH_2O pressure or $\sim$50 inH_2O if multiple blowers are used.

In addition, approximately 200 cfm of air should be actively flown around the rear of the modules and bases (this should be approximately twice the open volume in the back) to promote cooling. This does not need precision direction can be done with several fans, but open air paths of sufficient volume must be incorporated into the light-tight design.

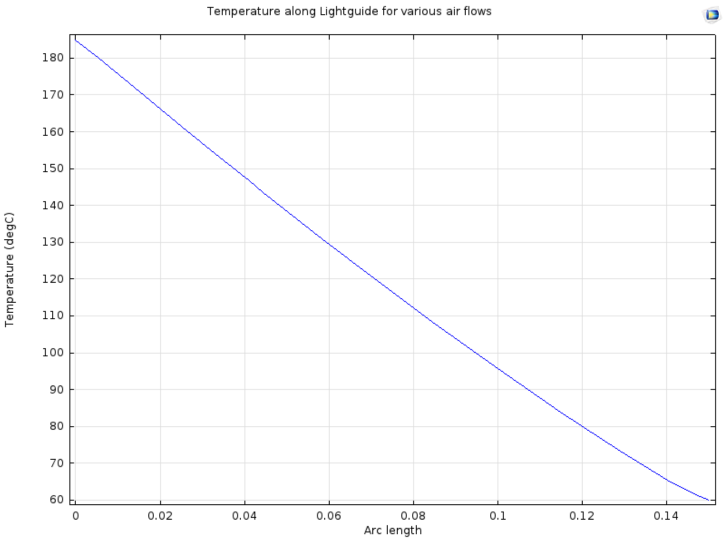


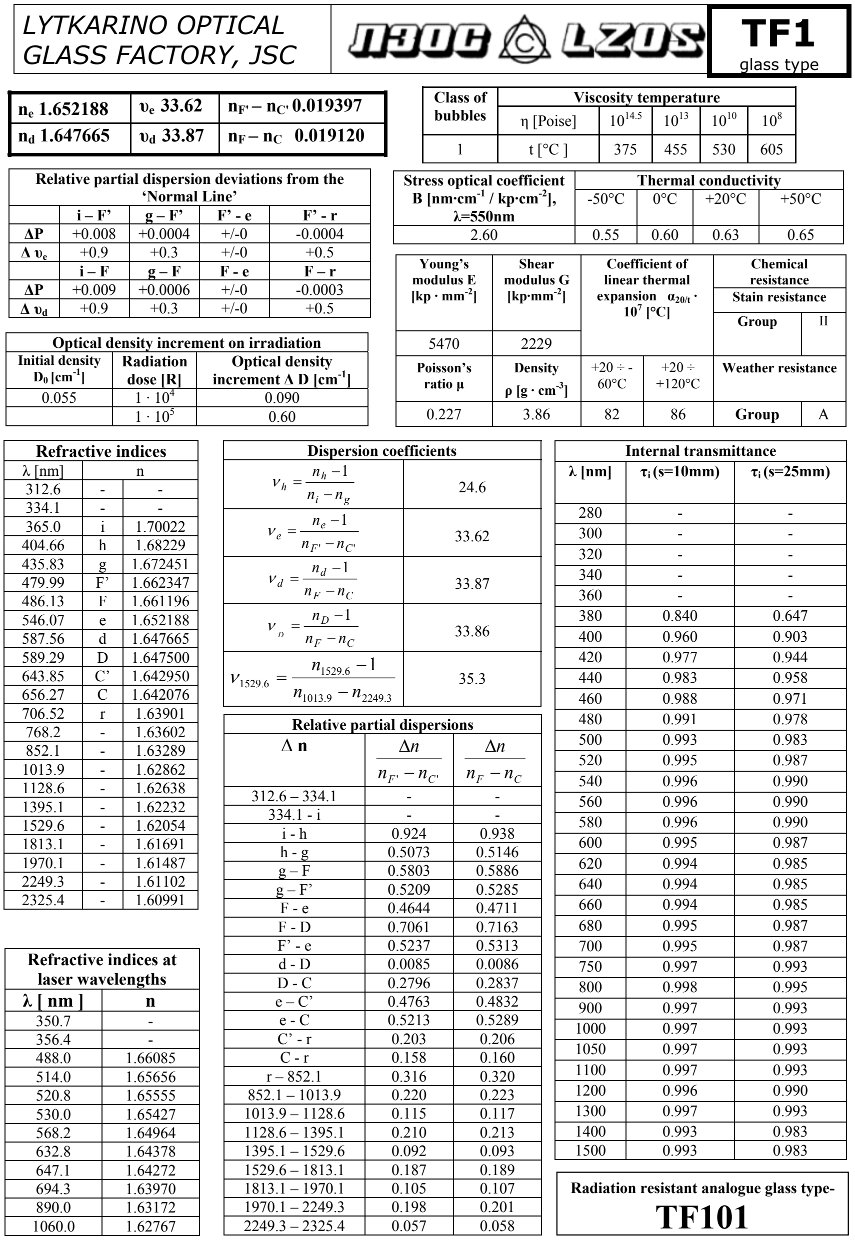
Figure 22: Light guide temperature down the axis of a block near under the extreme condition of sustained heating but no air flow.

1.6.3 Cooling Interruption

Steady state CFD calculations show the PMTs reach 60°C or below in the absence of cooling with sustained heating, Fig. 22. This calculation was done under a more constrictive condition ignoring the gaps due to the supermodule length differences. In the event of an cooling interruption, heating should be immediately discontinued and if possible the front panel should be removed to expose the front of the blocks to air and reduce the temperature. The response time for such a failure should occur within about one hour to minimize any unnecessary heating of the PMTs.

Tests were performed on 40 PMTs by raising their temperature to 100°C for 1 hour. Comparisons of the quantum efficiency before and after the heating showed that the quantum efficiency was the same within the 10% level. For temperatures well below this, the PMTs and materials should be robust against such a failure.

A TF1 Lead glass Data sheet



LYTKARINO OPTICAL GLASS FACTORY, JSC

ЛЗОС LZOS

TF1
glass type

n_e 1.652188	**υ_e 33.62**	**$n_{F'} - n_{C'}$ 0.019397**
n_d 1.647665	**υ_d 33.87**	**$n_F - n_C$ 0.019120**

Class of bubbles	**Viscosity temperature**				
	η [Poise]	$10^{14.5}$	10^{13}	10^{10}	10^{8}
1	t [°C]	375	455	530	605

Relative partial dispersion deviations from the 'Normal Line'

	i – F'	**g – F'**	**F' - e**	**F' - r**
ΔP	+0.008	+0.0004	+/-0	-0.0004
Δ υ_e	+0.9	+0.3	+/-0	+0.5
	i – F	**g – F**	**F - e**	**F – r**
ΔP	+0.009	+0.0006	+/-0	-0.0003
Δ υ_d	+0.9	+0.3	+/-0	+0.5

Stress optical coefficient B [nm·cm^{-1} / kp·cm^{-2}], λ=550nm	**Thermal conductivity**			
	-50°C	0°C	+20°C	+50°C
2.60	0.55	0.60	0.63	0.65

Young's modulus E [kp · mm^{-2}]	**Shear modulus G [kp·mm^{-2}]**	**Coefficient of linear thermal expansion $\alpha_{20/t} \cdot 10^7$ [°C]**		**Chemical resistance**	
				Stain resistance	
				Group	II
5470	2229				
Poisson's ratio μ	**Density ρ [g · cm^{-3}]**	+20 ÷ -60°C	+20 ÷ +120°C	**Weather resistance**	
0.227	3.86	82	86	**Group**	A

Optical density increment on irradiation

Initial density D_0 [cm^{-1}]	**Radiation dose [R]**	**Optical density increment Δ D [cm^{-1}]**
0.055	$1 \cdot 10^4$	0.090
	$1 \cdot 10^5$	0.60

Refractive indices

λ [nm]	n	
312.6	-	-
334.1	-	-
365.0	i	1.70022
404.66	h	1.68229
435.83	g	1.672451
479.99	F'	1.662347
486.13	F	1.661196
546.07	e	1.652188
587.56	d	1.647665
589.29	D	1.647500
643.85	C'	1.642950
656.27	C	1.642076
706.52	r	1.63901
768.2	-	1.63602
852.1	-	1.63289
1013.9	-	1.62862
1128.6	-	1.62638
1395.1	-	1.62232
1529.6	-	1.62054
1813.1	-	1.61691
1970.1	-	1.61487
2249.3	-	1.61102
2325.4	-	1.60991

Refractive indices at laser wavelengths

λ [nm]	**n**
350.7	-
356.4	-
488.0	1.66085
514.0	1.65656
520.8	1.65555
530.0	1.65427
568.2	1.64964
632.8	1.64378
647.1	1.64272
694.3	1.63970
890.0	1.63172
1060.0	1.62767

Dispersion coefficients

$\nu_h = \frac{n_h - 1}{n_i - n_g}$	24.6
$\nu_e = \frac{n_e - 1}{n_{F'} - n_{C'}}$	33.62
$\nu_d = \frac{n_d - 1}{n_F - n_C}$	33.87
$\nu_D = \frac{n_D - 1}{n_F - n_C}$	33.86
$\nu_{1529.6} = \frac{n_{1529.6} - 1}{n_{1013.9} - n_{2249.3}}$	35.3

Relative partial dispersions

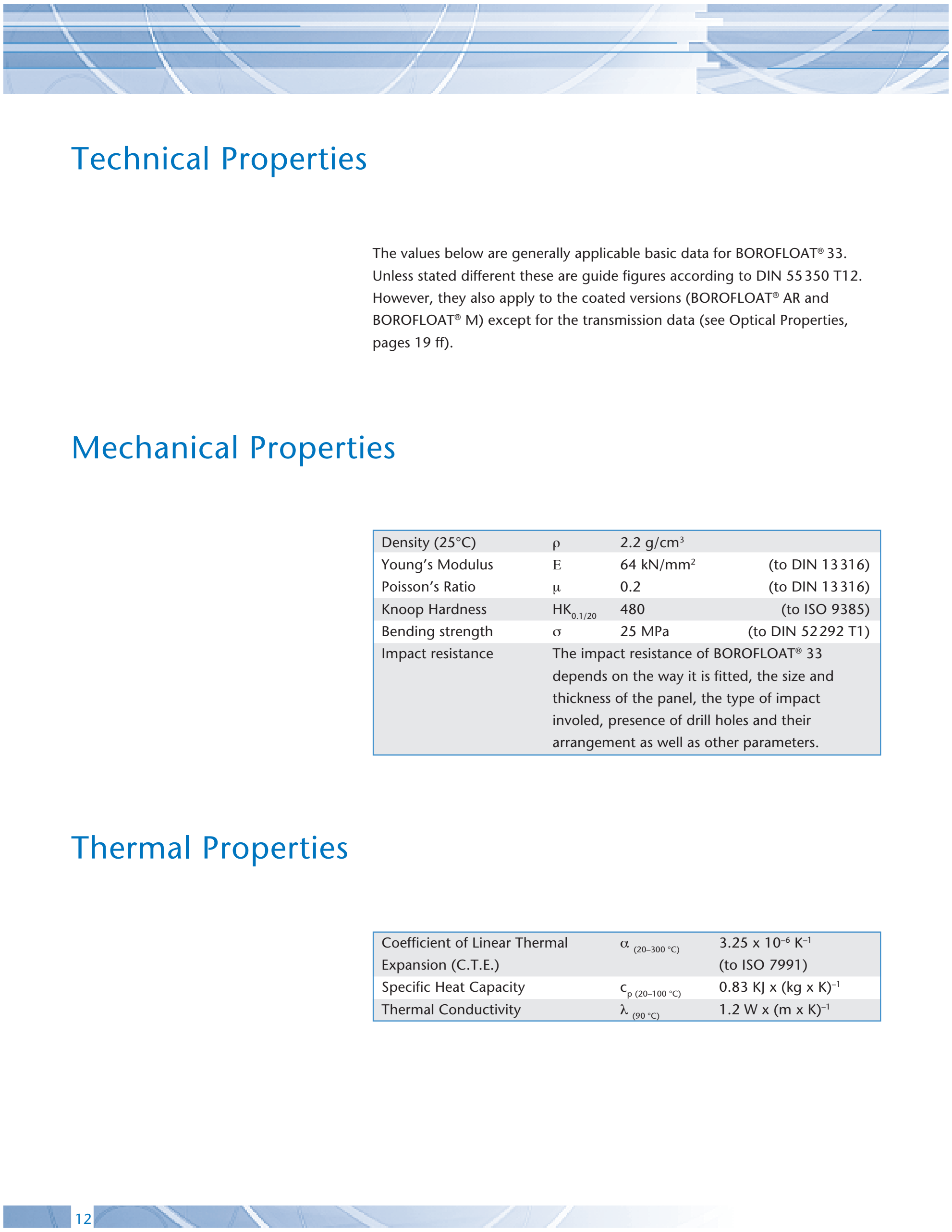
Δ n	$\frac{\Delta n}{n_{F'} - n_{C'}}$	$\frac{\Delta n}{n_F - n_C}$
312.6 – 334.1	-	-
334.1 - i	-	-
i - h	0.924	0.938
h - g	0.5073	0.5146
g – F	0.5803	0.5886
g – F'	0.5209	0.5285
F - e	0.4644	0.4711
F - D	0.7061	0.7163
F' - e	0.5237	0.5313
d - D	0.0085	0.0086
D - C	0.2796	0.2837
e – C'	0.4763	0.4832
e - C	0.5213	0.5289
C' - r	0.203	0.206
C - r	0.158	0.160
r – 852.1	0.316	0.320
852.1 – 1013.9	0.220	0.223
1013.9 – 1128.6	0.115	0.117
1128.6 – 1395.1	0.210	0.213
1395.1 – 1529.6	0.092	0.093
1529.6 – 1813.1	0.187	0.189
1813.1 – 1970.1	0.105	0.107
1970.1 – 2249.3	0.198	0.201
2249.3 – 2325.4	0.057	0.058

Internal transmittance

λ [nm]	**τ_i (s=10mm)**	**τ_i (s=25mm)**
280	-	-
300	-	-
320	-	-
340	-	-
360	-	-
380	0.840	0.647
400	0.960	0.903
420	0.977	0.944
440	0.983	0.958
460	0.988	0.971
480	0.991	0.978
500	0.993	0.983
520	0.995	0.987
540	0.996	0.990
560	0.996	0.990
580	0.996	0.990
600	0.995	0.987
620	0.994	0.985
640	0.994	0.985
660	0.994	0.985
680	0.995	0.987
700	0.995	0.987
750	0.997	0.993
800	0.998	0.995
900	0.997	0.993
1000	0.997	0.993
1050	0.997	0.993
1100	0.997	0.993
1200	0.996	0.990
1300	0.997	0.993
1400	0.993	0.983
1500	0.993	0.983

Radiation resistant analogue glass type-
TF101

B Borosilicate-33 Data sheet



Technical Properties

The values below are generally applicable basic data for BOROFLOAT® 33. Unless stated different these are guide figures according to DIN 55 350 T12. However, they also apply to the coated versions (BOROFLOAT® AR and BOROFLOAT® M) except for the transmission data (see Optical Properties, pages 19 ff).

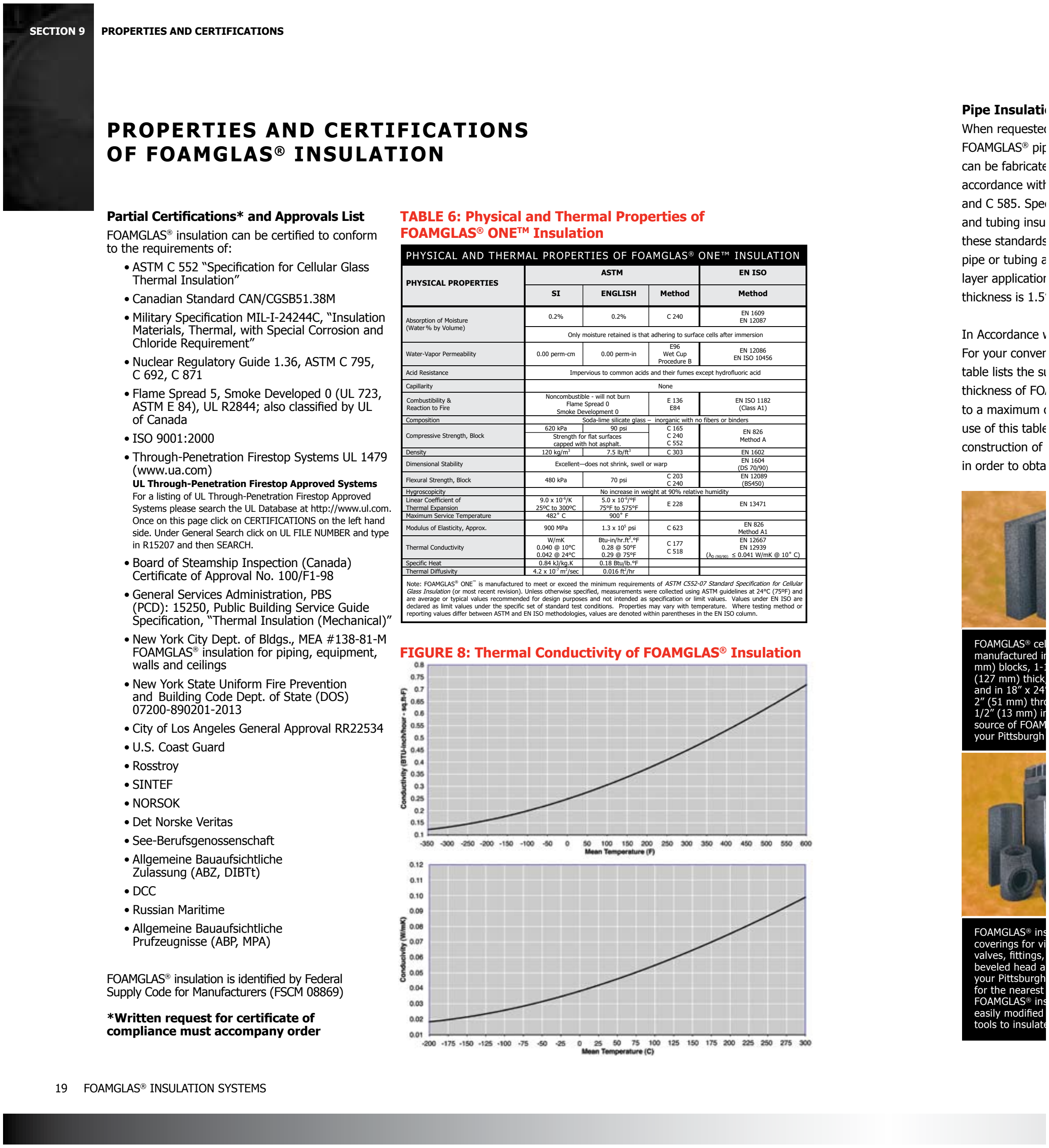
Mechanical Properties

Density (25°C)	ρ	2.2 g/cm^3	
Young's Modulus	E	64 kN/mm^2	(to DIN 13 316)
Poisson's Ratio	μ	0.2	(to DIN 13 316)
Knoop Hardness	$HK_{0.1/20}$	480	(to ISO 9385)
Bending strength	σ	25 MPa	(to DIN 52 292 T1)
Impact resistance	The impact resistance of BOROFLOAT® 33 depends on the way it is fitted, the size and thickness of the panel, the type of impact involed, presence of drill holes and their arrangement as well as other parameters.		

Thermal Properties

Coefficient of Linear Thermal Expansion (C.T.E.)	$\alpha_{(20\text{–}300\,°C)}$	3.25 x 10^{-6} K^{-1} (to ISO 7991)
Specific Heat Capacity	$c_{p\,(20\text{–}100\,°C)}$	0.83 KJ x (kg x K)$^{-1}$
Thermal Conductivity	$\lambda_{(90\,°C)}$	1.2 W x (m x K)$^{-1}$

C FOAMGLAS Data sheet



PROPERTIES AND CERTIFICATIONS OF FOAMGLAS® INSULATION

Partial Certifications* and Approvals List

FOAMGLAS® insulation can be certified to conform to the requirements of:

- ASTM C 552 "Specification for Cellular Glass Thermal Insulation"
- Canadian Standard CAN/CGSB51.38M
- Military Specification MIL-I-24244C, "Insulation Materials, Thermal, with Special Corrosion and Chloride Requirement"
- Nuclear Regulatory Guide 1.36, ASTM C 795, C 692, C 871
- Flame Spread 5, Smoke Developed 0 (UL 723, ASTM E 84), UL R2844; also classified by UL of Canada
- ISO 9001:2000
- Through-Penetration Firestop Systems UL 1479 (www.ua.com)

UL Through-Penetration Firestop Approved Systems
For a listing of UL Through-Penetration Firestop Approved Systems please search the UL Database at http://www.ul.com. Once on this page click on CERTIFICATIONS on the left hand side. Under General Search click on UL FILE NUMBER and type in R15207 and then SEARCH.

- Board of Steamship Inspection (Canada) Certificate of Approval No. 100/F1-98
- General Services Administration, PBS (PCD): 15250, Public Building Service Guide Specification, "Thermal Insulation (Mechanical)"
- New York City Dept. of Bldgs., MEA #138-81-M FOAMGLAS® insulation for piping, equipment, walls and ceilings
- New York State Uniform Fire Prevention and Building Code Dept. of State (DOS) 07200-890201-2013
- City of Los Angeles General Approval RR22534
- U.S. Coast Guard
- Rosstroy
- SINTEF
- NORSOK
- Det Norske Veritas
- See-Berufsgenossenschaft
- Allgemeine Bauaufsichtliche Zulassung (ABZ, DIBTt)
- DCC
- Russian Maritime
- Allgemeine Bauaufsichtliche Prufzeugnisse (ABP, MPA)

FOAMGLAS® insulation is identified by Federal Supply Code for Manufacturers (FSCM 08869)

***Written request for certificate of compliance must accompany order**

TABLE 6: Physical and Thermal Properties of FOAMGLAS® ONE™ Insulation

PHYSICAL AND THERMAL PROPERTIES OF FOAMGLAS® ONE™ INSULATION

PHYSICAL PROPERTIES	ASTM			EN ISO
	SI	ENGLISH	Method	Method
Absorption of Moisture (Water % by Volume)	0.2%	0.2%	C 240	EN 1609 EN 12087
	Only moisture retained is that adhering to surface cells after immersion			
Water-Vapor Permeability	0.00 perm-cm	0.00 perm-in	E96 Wet Cup Procedure B	EN 12086 EN ISO 10456
Acid Resistance	Impervious to common acids and their fumes except hydrofluoric acid			
Capillarity	None			
Combustibility & Reaction to Fire	Noncombustible - will not burn Flame Spread 0 Smoke Development 0		E 136 E84	EN ISO 1182 (Class A1)
Composition	Soda-lime silicate glass – inorganic with no fibers or binders			
Compressive Strength, Block	620 kPa	90 psi	C 165 C 240 C 552	EN 826 Method A
	Strength for flat surfaces capped with hot asphalt.			
Density	120 kg/m^3	7.5 lb/ft^3	C 303	EN 1602
Dimensional Stability	Excellent—does not shrink, swell or warp			EN 1604 (DS 70/90)
Flexural Strength, Block	480 kPa	70 psi	C 203 C 240	EN 12089 (BS450)
Hygroscopicity	No increase in weight at 90% relative humidity			
Linear Coefficient of Thermal Expansion	9.0 x 10^{-6}/K 25ºC to 300ºC	5.0 x 10^{-6}/°F 75ºF to 575ºF	E 228	EN 13471
Maximum Service Temperature	482° C	900° F		
Modulus of Elasticity, Approx.	900 MPa	1.3 x 10^5 psi	C 623	EN 826 Method A1
Thermal Conductivity	W/mK 0.040 @ 10°C 0.042 @ 24°C	Btu-in/hr.ft^2.°F 0.28 @ 50°F 0.29 @ 75°F	C 177 C 518	EN 12667 EN 12939 ($\lambda_{D\ (90/90)}$ ≤ 0.041 W/mK @ 10° C)
Specific Heat	0.84 kJ/kg.K	0.18 Btu/lb.°F		
Thermal Diffusivity	4.2 x 10^{-7} m^2/sec	0.016 ft^2/hr		

Note: FOAMGLAS® ONE™ is manufactured to meet or exceed the minimum requirements of *ASTM C552-07 Standard Specification for Cellular Glass Insulation* (or most recent revision). Unless otherwise specified, measurements were collected using ASTM guidelines at 24°C (75ºF) and are average or typical values recommended for design purposes and not intended as specification or limit values. Values under EN ISO are declared as limit values under the specific set of standard test conditions. Properties may vary with temperature. Where testing method or reporting values differ between ASTM and EN ISO methodologies, values are denoted within parentheses in the EN ISO column.

FIGURE 8: Thermal Conductivity of FOAMGLAS® Insulation

Pipe Insulati

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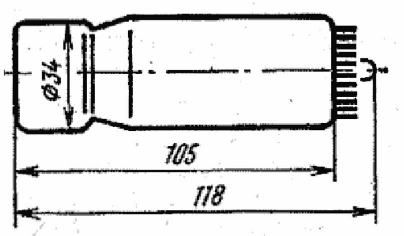
for the nearest
FOAMGLAS® ins
easily modified
tools to insulat

D PMT Data sheet

FEU-84 Specifications
Translation from Russian



Photocathode diameter	25 mm
Number of stages	12

FEU-84, FEU-84-1

Wavelengths of maximum sensitivity	420-480 nm
Cathode lumininous sensivity (300-350 V)	> 80 microA/lm
Anode luminous sensitivity (1700 V)	100 microA/lm
Cathode radiant sensitivity (694 nm)	>3 mA/W
Dark current	< 200 nA
Life expentancy	> 1500 h
Anode sensitivity after 1500 h	> 80 A/lm
Dark current after 1500 h	< 250 nA

FEU-84-3

Wavelengths of maximum sensitivity	420-550 nm
Dark current	< 50 nA
Signal to noise ratio ?	22

Maximum Ratings

Max Voltage	1900 V
Max anode current	5 micro A

E Silicone Cookie Data sheet

Detector Assembly Materials

BC-634A Optical Interface Pad –

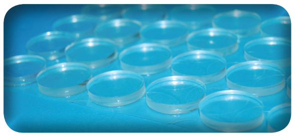
BC-634A is a self-wetting, flexible pad just hard enough to resist tearing while handling.

It is formulated for use within the temperature range of -10 to +60°C, has an index of refraction of 1.42 and an internal transmission >98% around 400nm.

If you cannot maintain sufficient interface pressure, apply a thin film of coupling grease to both sides of the interface pad.

BC-637 High Temperature Optical Interface Pad –

BC-637 interface pads are placed between the plastic and photomultiplier tube. BC-637 is rated at 200°C.



BC-638 Black Wrapping Tape –

BC-638 is a black adhesive tape 2" (50.8mm) wide by .008" (0.2mm) thick. Wrapping a plastic scintillator in one layer will give you a light-tight seal. We provide BC-638 in 36 yard (32.9m) rolls.

BC-640 Plastic Masking Paper –

This material is an adhesive-backed masking paper routinely used for protecting the surfaces of plastic scintillator during handling or storage. We supply BC-640 in rolls 12" (30.5cm) wide by 300' (91.4m) long.

BC-642 PTFE Reflector Tape –

BC-642 is a .003" (0.08 mm) thick (normal) Teflon tape and is frequently used as a reflecting material for non-hygroscopic scintillators. Three layers give you optimum reflectivity. It comes in rolls 2" (50.8mm) wide by 540" (13.7m) long.

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