

NPL Calorimetry: The evolution so far

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Abstract

In this paper I will endeavour to cover the history of radiation calorimetry at NPL, from the earliest efforts up to the present day calorimeters. I hope to put all the NPL calorimeters that you are going to hear about in the workshop into context and present some interesting ideas from early calorimeters.

I. INTRODUCTION

Many people have contributed to the evolution of calorimetry at NPL - too many to mention them all. I will just mention some of the main contributors:

Lloyd Kemp - early theoretical designs.

Mike Baker - early construction and operation.

Brian Owen - project leader for photon beam therapy level graphite calorimeter.

Alan Calverd - electronics design.

Christine Cross - construction.

Alan DuSautoy - computer software.

Ian Stoker - electronics and operation.

Bob Burns - conversion from graphite to water.

Dave Burns - simple high dose electron beam calorimeter and therapy level calorimeter.

Trevor Morris - high dose calorimeter.

Malcolm McEwen - work on all electron calorimeters.

Simon Duane - theory and design of portable calorimeter.

Noria Mod Ali - low energy calorimeter.

Karen Rosser - ice calorimeter and water calorimeter.

Andy Williams - water calorimeter.

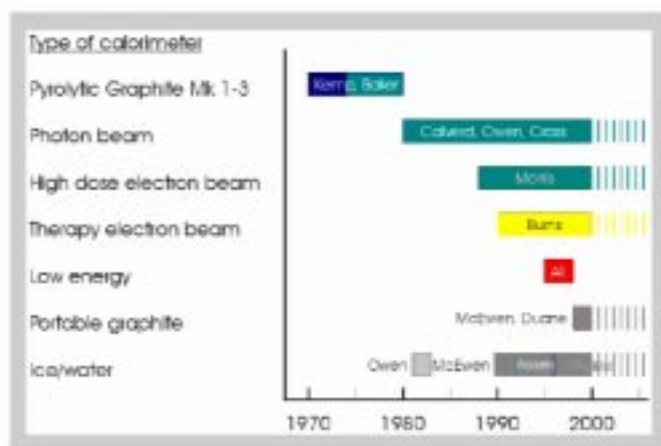


Figure 1: History of calorimetry at NPL

II. EARLY GRAPHITE CALORIMETERS UP TO 1980.

A. Principles of calorimetry

Absorbed Dose D is the energy absorbed E in an element of some specified medium divided by the mass m of that element

$$D = dE/dm$$

according to ICRU report 33 [1]. The temperature rise on irradiation is measured and the energy deposited E is equal to heat capacity multiplied by temperature rise. There are two ways to measure the heat capacity either 1. measure the heat capacity *in situ* by electrical heating; or 2. use a known (or previously measured) heat capacity.

B. The pyrolytic graphite calorimeter

Interest in calorimeters at NPL was prompted in 1969 by ICRU report 14 [2]. Initial work lead Kemp *et al* to designs for a pyrolytic graphite calorimeter [3-10]. The heat capacity was measured *in situ* and the pyrolytic graphite itself was used as the heating element. Pyrolytic graphite has a higher resistance perpendicular to the plan of the crystals (as shown in Table 1) and the calibration heating utilised this intrinsic resistance to obtain uniform heating.

Table 1: Properties of Pyrolytic graphite

	electrical conductivity / ohm cm	thermal conductivity / W m-1 K-1
a-direction:	0.4 E-3	20
c-direction:	1	0.14

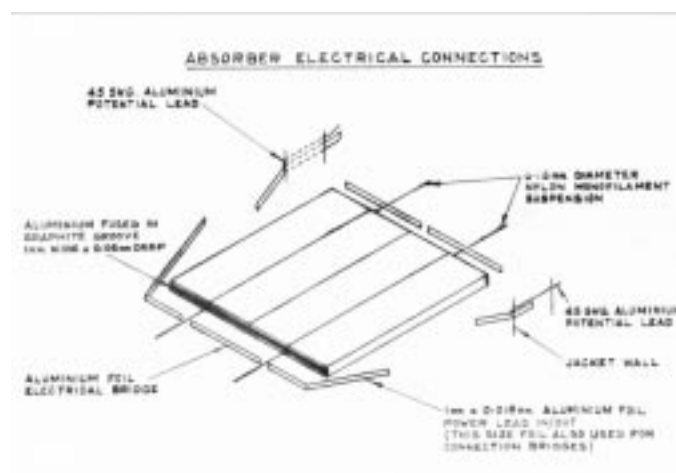


Figure 2: Pyrolytic graphite absorber (i.e. central component)

Figure 2 shows the pyrolytic graphite calorimeter absorber. Aluminium electrodes connect the heating circuits to the graphite slabs. Great effort was made to make good contact resistance and the zig zag design increased the resistance and distributed the heat more evenly.

Figure 3 shows an external view of the pyrolytic graphite calorimeter. The top is the vacuum entrance off of which is the electronics port and the front shows the temperature controlled snout.

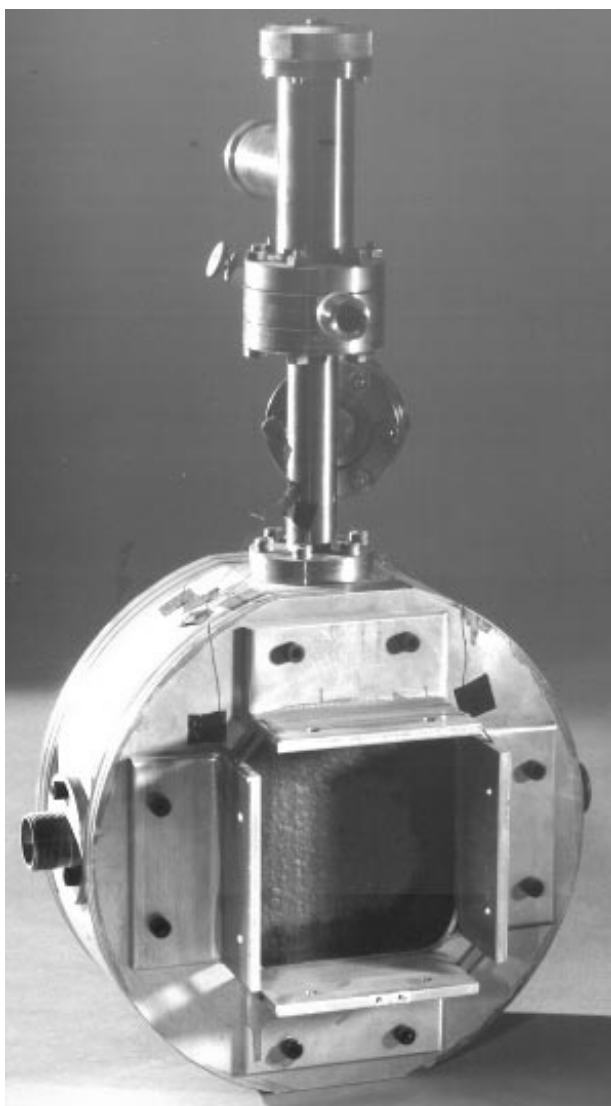


Figure 3: External view of Pyrolytic graphite calorimeter

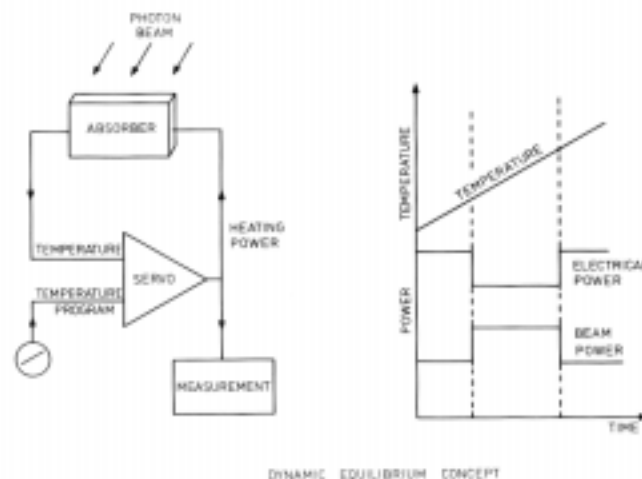


Figure 4: Dynamic equilibrium mode calibration

A novel dynamic-equilibrium mode of operation was introduced (see Figure 4). A program is sent into a servo amplifier to generate the heating required in the absorber to maintain a temperature equal to the program temperature. For example if the program is a constant temperature the servo will generate heating power to raise the temperature of the absorber until the absorber temperature equals the program temperature and then the servo would switch off. In dynamic equilibrium mode the program is a ramp in temperature. The required heating is uniform but the heating can be supplied by either irradiation or electrically. The reduction in electrical power is a measure of the beam power from which the dose absorbed can be derived. Work on this calorimeter proceeded until about 1980. A later development of the dynamic equilibrium mode was made by Joseph Witzani called the isothermal mode [11]. The dynamic equilibrium mode system requires a very high gain amplifier and was quite ambitious for the electronics of the 1970's.

A drawback of the pyrolytic graphite calorimeter was the precision with which dynamic equilibrium mode measurements could be made. Also the low resistance (relative to insulators) of the graphite heating elements made making aluminium contacts extremely difficult. However a major advance was the introduction (in the late 1970's) of A C measurement bridges.

III. THE PHOTON BEAM GRAPHITE CALORIMETER

In 1983 a homogeneous graphite therapy level calorimeter was built to a design by Steve Domen (see Figure 5)[12]. The philosophy was to measure therapy level doses in photon beams or electron beams at one gray, and one gray per minute. The system was computer controlled.

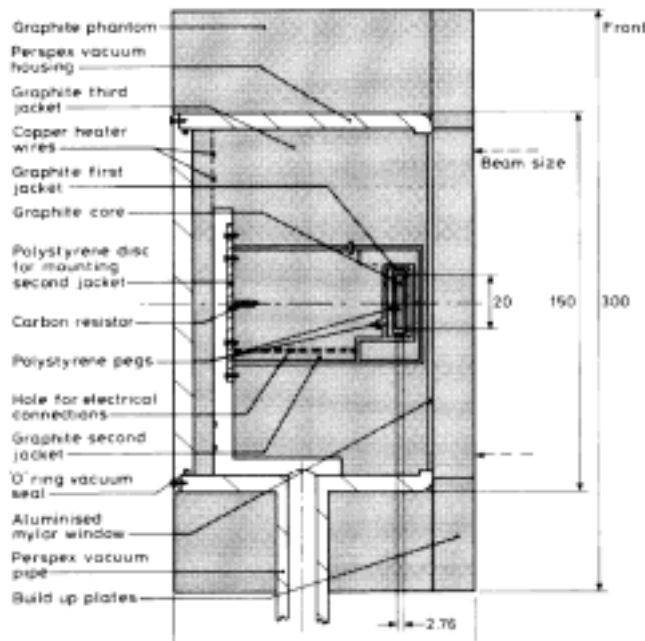


Figure 5: Homogeneous therapy-level graphite calorimeter

The therapy level calorimeter is the current primary standard for photon beam absorbed dose measurement and chemical dosimetry services. There is a later paper on the therapy level calorimeter by Simon Duane. The calorimeter was described in detail at the last calorimeter workshop in 1996 and other papers [13-19]. Absorbed dose to graphite is converted to absorbed dose to water by the scaling theorem method. This is described in detail by Bob Burns [20,21]. The UK adopted a code of practice for high energy photon therapy based on this calorimeter in 1990 [22].

IV. Electron beam graphite calorimeters.

Electron beam calorimeters were designed at NPL in the 1980s. The philosophy was to produce a simple design. The calorimeters were initially used for high dose and therefore designed for a large temperature rise. The calorimeters worked very well and are still used for high dose work [23]. Figure 6 shows the high dose electron beam calorimeter.

The electron beam calorimeter with minor design changes lead onto a therapy level electron beam graphite calorimeter [24-27], which looks very similar. The use of this calorimeter and the conversion from graphite to water is described in [28-30]. This led to the worlds first electron beam absorbed dose calibration service and had two more spin-offs.

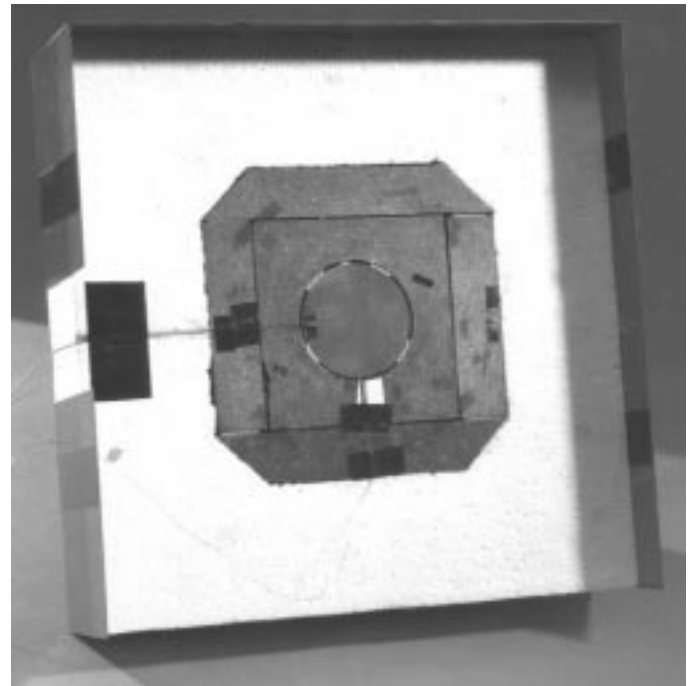


Figure 6: High dose calorimeter

First the low energy calorimeter Figure 7. Here the philosophy was to design a calorimeter for use in low energy electron beams of energy less than 500 keV. The low energy calorimeter [31] will be described later by Noriah Mod Ali.

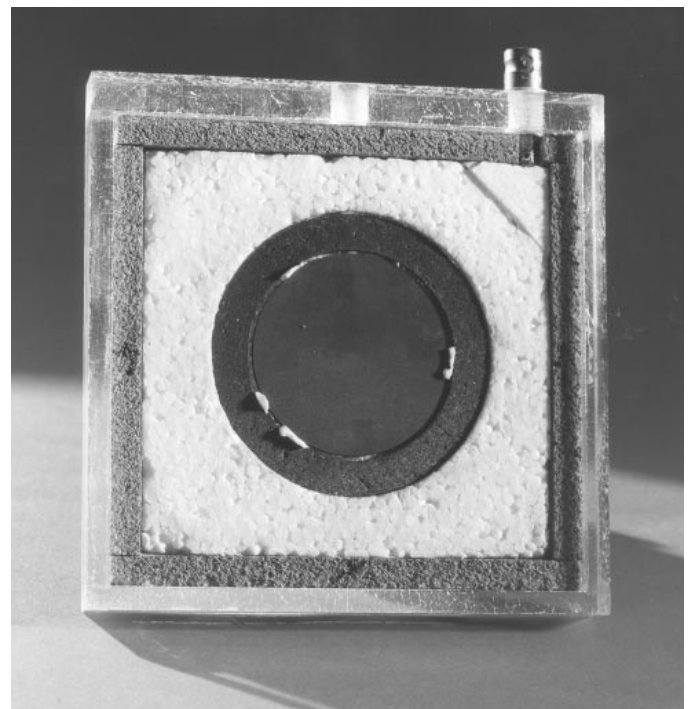


Figure 7: Low energy calorimeter

The other spin-off is a portable graphite calorimeter. Here the philosophy is to keep the calorimeter design simple but provide good temperature control. This will be described in a later paper by Malcolm McEwen.

V. WATER CALORIMETRY

Water calorimetry at NPL had three false starts. First Brian Owen produced a water calorimeter similar to NRC's stirred water calorimeter and it was used to calibrate Fricke dosimeters. His calorimeter is shown in Figure 8. Although the high purity water was contained in a quartz or glass vessel the dissolved gasses in the water were not kept under control. Therefore this calorimeter had a variable heat defect and was unsuitable as a standard.



Figure 8: Early water calorimeter

The second water calorimeter was produced by Malcolm McEwen [32] for use in electron beams but electron beams tend to give steeper depth dose gradients and therefore temperature gradients. He therefore decided to pursue the therapy graphite calorimeter in preference. Karen Rosser produced a ice calorimeter [33] for low energy X-rays. This did produce some results but they were not of sufficient precision to replace graphite calorimeters or ion chambers.

The most recent water calorimeter [34-36] has been produced by Karen Rosser and Andrew Williams (see Figure 9) and will be described by Andrew Williams later in this conference.

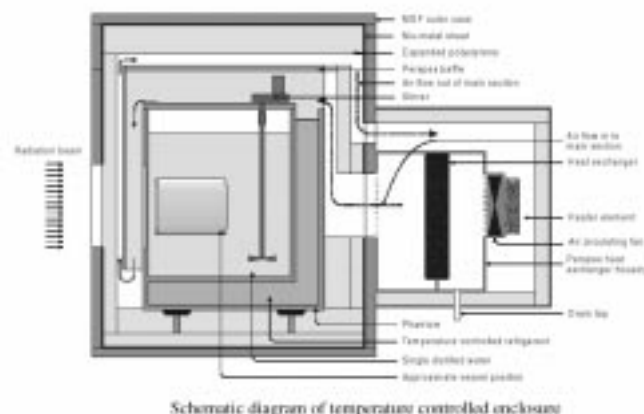


Figure 9: Recent water calorimeter

VI. CONCLUSION

In summary, I have described various types of calorimeters; early calorimeters graphite high dose, graphite therapy and water calorimeters and I hope have put the various calorimeters into context.

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