ABSTRACT. The Cryogenic Solar Absolute Radiometer (CSAR) is a new primary radiometric standard for use in space traceable to the International System of Units (SI). CSAR will have the potential to measure the total irradiance of the Sun with an uncertainty of 0.01% and a resolution of 0.001%, more than a factor ten improvement over existing instruments. Since CSAR will be cooled by a mechanical cooler based upon the Stirling cycle its working lifetime is projected to be in excess of 10 years.

1. INTRODUCTION

Electrical substitution radiometers (ESRs) operating at ambient temperatures have been the traditional instruments for the precise measurement of black-body radiation. Unfortunately their performance has been limited by the thermal properties of materials at these temperatures (~ 293 K), and even with the most modern innovative design their absolute accuracy stubbornly remains in the range 0.1% to 0.3% (Gillham 1962, Boivin and Smith 1978, Wilson 1979).

During the 1980's work at NPL showed that by cooling the ESR to liquid helium temperatures significant improvements could be achieved in resolution and accuracy. The first cryogenic radiometer constructed measured the power of black-body radiation from a black body held at the triple point of water and was used to determine the Stefan-Boltzmann constant with an uncertainty of 0.02% (Quinn and Martin 1985). The value obtained agreed with the theoretical value which can be calculated using other fundamental constants and is regarded as the best experimental determination to date (Cohen and Taylor 1986).

Following the success of the first cryogenic radiometer a second radiometer was built dedicated to the measurement of optical laser power with an uncertainty of 0.005% (Martin et al 1985) and to demonstrate the validity of this uncertainty the two radiometers were successfully compared in 1990 (Fox and Martin 1990). The second radiometer has become the Primary Standard radiometer (PS radiometer) upon which all UK optical radiation scales are based.

Thus the development of cryogenic radiometry has reduced the measurement uncertainty of optical radiation by at least a factor 10. This has led to most National Standards Laboratories adopting (or proposing to adopt) a cryogenic radiometer for use as their primary standard for optical radiation.

The current position in the uncertainty of the measurement of total solar irradiance is that which existed in the measurement of optical radiation before the advent of cryogenic radiometers.

Terrestrial solar irradiance measurements are based upon the World Radiometric Reference (WRR). The WRR is established from a group of ambient temperature ESRs, known as the World Standard Group (WSG). The individual ESRs in the WSG are periodically compared with one another using the Sun as a standard source; this leads to a reproducibility of the WRR of 0.02% but an absolute uncertainty of 0.3% (Fröhlich 1991).

Irradiance measurements made using three space radiometers of similar design to the WSG, the Solar Maximum Mission Active Cavity Irradiance Monitor (SMM-ACRIM), and the solar monitors aboard the Earth Radiation Budget Satellite (ERBS) and Nimbus-7 are shown in figure 1 (Lee et al 1991). The measurements agree within their uncertainties but
there is a maximum disagreement between the instruments of 0.4%.

More recent data from ACRIM II on the Upper Atmosphere Research Satellite (UARS-ACRIM) are 0.17% lower than the data from SMM-ACRIM (just within the combined uncertainty of the instruments). This data has been adjusted to the SMM-ACRIM data by comparing them with the data from the NIMBUS-7 and ERBS experiments which have been taken in the same time-frame as the SMM and UARS flights. Comparisons have also been made with the shuttle ACRIM instrumentation flown on the ATLAS 1 and 2 missions (Willson 1993). The preliminary results from the Solar Variability experiments (SOVA 1 and 2) aboard the European Retrievable Carrier (EURECA) have been reported to fall within the overall spread of results shown in figure 1 (Romero et al 1993).

![Figure 1. Comparison of solar irradiance values from ERBS, SMM and Nimbus-7 experiments. The irradiance unit is Wm⁻² and the error bar denotes the instrument uncertainty.](image)

Although the data are the best available to date the uncertainties in their absolute accuracies can lead to difficulties in monitoring long term drifts in solar irradiance, for example, the 0.2% difference between the maximum and the minimum of the eleven year solar cycle. To overcome this problem the solar community have decided to establish a continuous database relying on measurements from overlapping satellite missions to normalise the data. This empirical approach is not ideal since it is not based on an absolute radiometric measurement standard and any break in the data chain means that data recorded before and after the break cannot be compared with sufficient accuracy. Thus this approach is very vulnerable to instrument lifetime, instrument failure, satellite malfunctions or simply delays in the launch dates, and it is unlikely that a continuous database can be generated to cover many solar cycles.

The development of a Cryogenic Solar Absolute Radiometer, CSAR, should provide the means of obtaining absolute data which negates the need of a continuous database. Any break in the data chain can be bridged by later measurements with a new absolute radiometer. In addition, if flown in the near future it would link the present data base to an absolute radiometric standard.

The objective of CSAR is to measure the total solar irradiance with at least a ten-fold improvement in the accuracy and resolution over previous measurements. If this objective can be achieved then CSAR