Gamma Ray Microcalorimeters using Superconducting Materials and Technologies

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Introduction

Currently gamma-ray spectrometry is performed with semiconductor detectors such as high purity germanium (HPGe) or scintillation detectors (e.g. NaI). Recently, novel microcalorimeters have been used to measure gamma radiation with a far superior energy resolution. This project comprised a literature review to assess the viability of two types of microcalorimeter - transition-edge sensors (TES) and metallic magnetic calorimeters (MMC) - for use in Atomic Weapons Establishment (AWE) operations, particularly nuclear forensics.

Improved energy resolution over current gold standard spectrometers

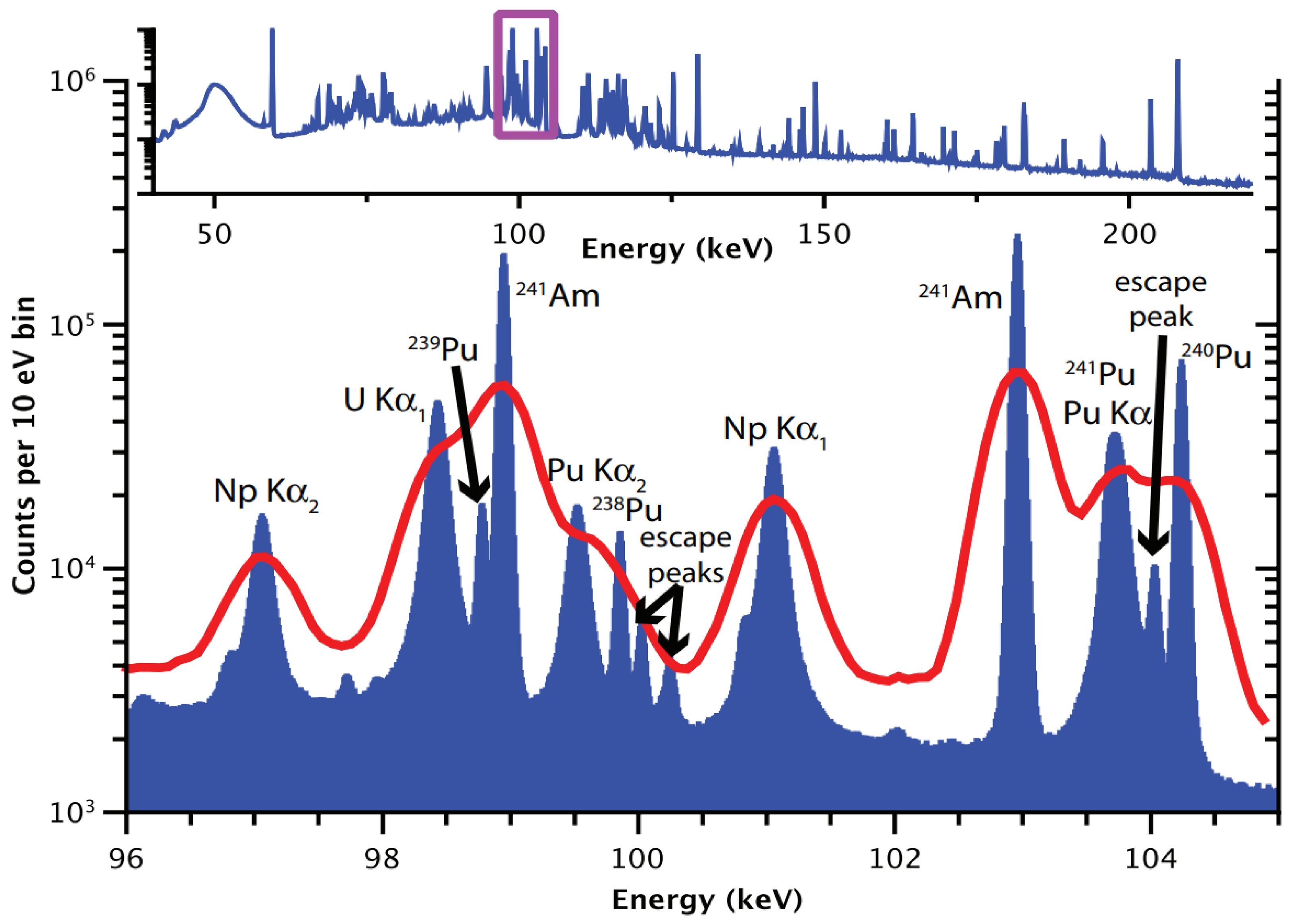

Figure 1: A measured spectrum of ~85% ^{239}Pu and 14% ^{240}Pu)comparing results with an array of microcalorimeters (blue) and a high-purity germanium detector (red). The inset shows the same spectrum over the energy range 40 keV to 220 keV. [1] The microcalorimeter is able to resolve closely spaced lines in Pu samples which HPGe cannot.

Optimal device parameters

Material	Atomic number	Superconducting?	Heat capacity (@ ~0.1K) J/K/m³
Au	79	No	7.14
Sn	50	T_c = 3.72 K	0.0469
Ag	47	No	
Ta	73	T_c = 4.47 K	0.00216
Bi	83	No	0.39
Pb	82	T_c = 7.20 K	0.09

Table 1: Properties of previously used absorbed materials for microcalorimeters [4 – 8].Low heat capacity allows for improved energy resolution. Superconducting absorbers have low heat capacity below T_c.

Energy resolution (@ ~5.9keV) eV	
TES	MMC
2.4	2.7
3.7	3.4
14	1.7

Table 2: Reported energy resolutions for microcalorimetry devices [3, 9-12]. Each case used different device and readout geometries however this table provides the range of performances reported in literature. For nuclear forensics, higher energy photons must be detected – very little research has yet been done at these energies however theoretical performance is promising.

Currently microcalorimetry for nuclear forensics is at a low TRL, however the achieved energy resolutions make it a technology worthy of further exploration. The readout technology (SQUIDs) is mature and several academic institutions in the UK have the necessary facilities to fabricate new devices. We recommend devices be designed specifically for the nuclear forensics application, manufactured, and tested with isotopes of interest.

Transition-edge sensors (TES)

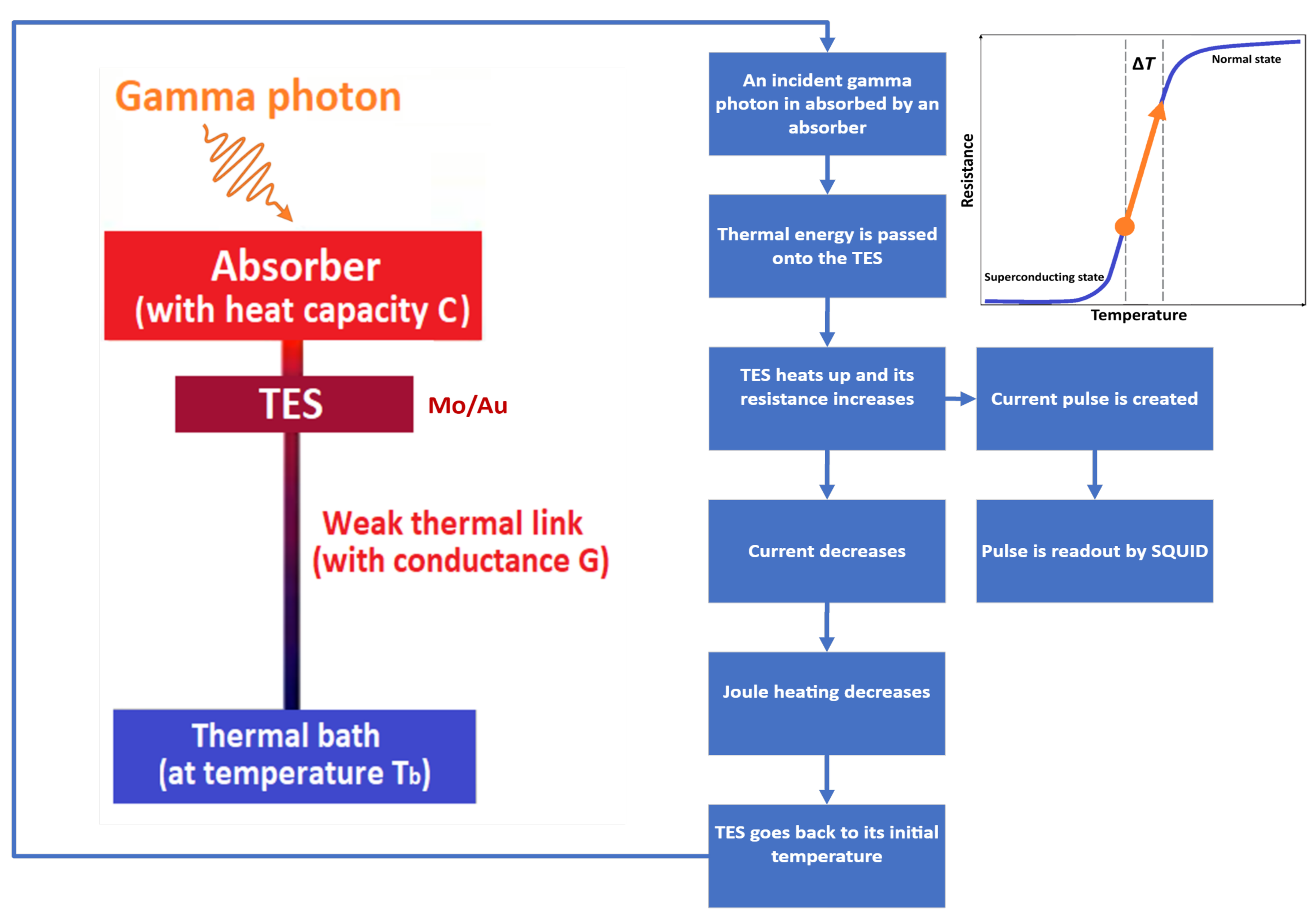

Figure 2: Schematic diagram of a TES microcalorimeter. The sensor is kept at a low temperature in its transition region. A photon incident on the sensor is absorbed by the absorber which sits atop the sensor. The photon is thermalised and the thermal energy is passed on from the absorber to the TES. This is ensured by a strong thermal link between the absorber and the TES. The TES heats which produce a resistance change, which is read out as a pulse in the TES current by an inductively coupled SQUID amplifier. Reproduced from [2].

Metallic magnetic calorimeter (MMC)

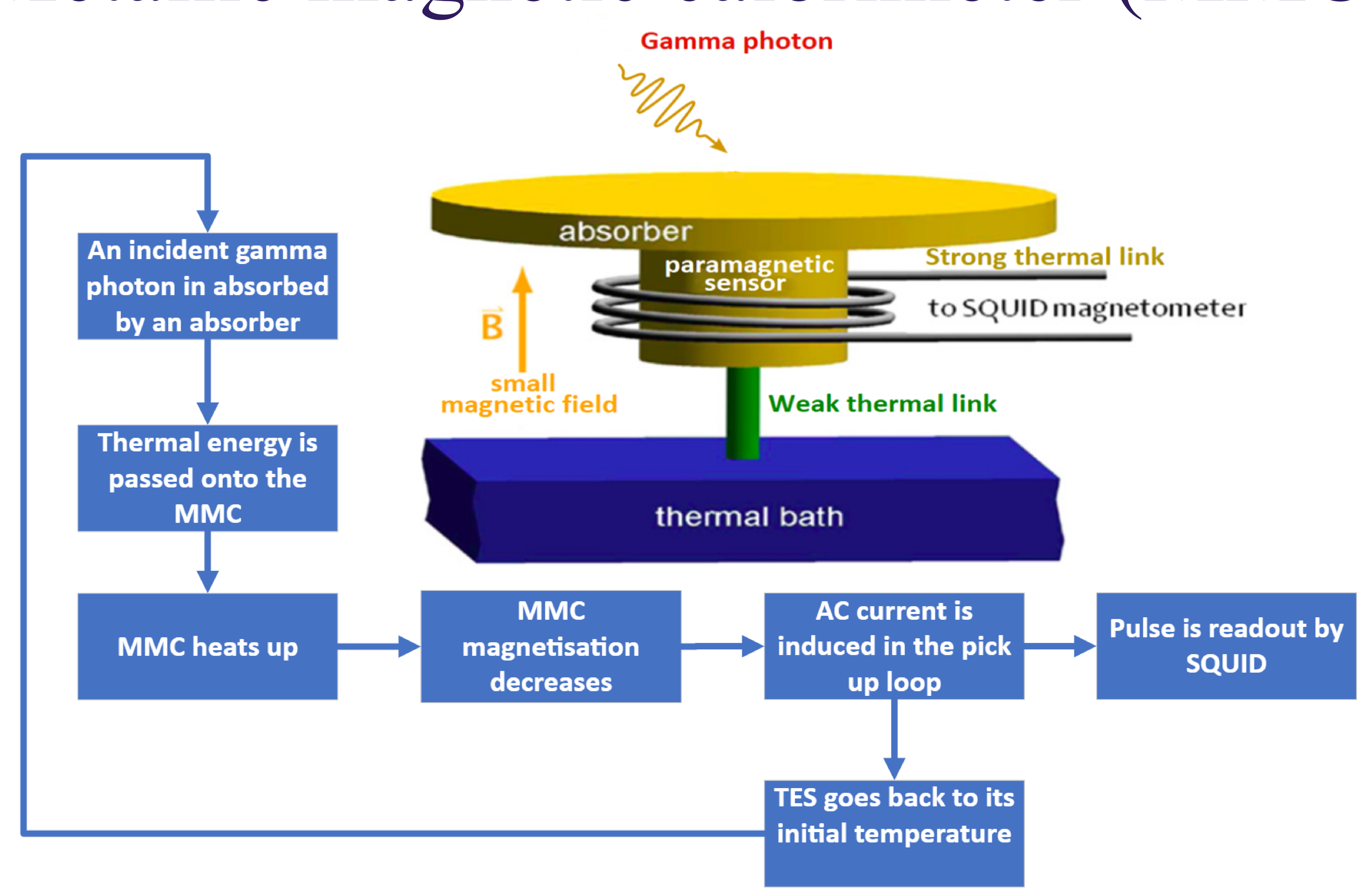

Figure 3: Schematic diagram depicting the main idea of a metallic magnetic calorimeter. The detector sits in a small magnetic field, **B**. A photon incident on the sensor is absorbed by the absorber which sits atop the paramagnetic sensor. The photon is thermalised and the thermal energy is passed on from the absorber to the paramagnetic sensor. Because the magnetisation of the sensor is temperature dependent, as the sensor's temperature increases, its magnetisation decreases inducing a current in the pick up loop of the inductively linked SQUID. The paramagnetic sensor goes back to its equilibrium temperature by transferring the heat to the thermal bath via the weak thermal link. Figure reproduced from [3]

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