Supplementary Information

Results of linear combination analysis

Orientation	SP13 fraction	CuO fraction	Total	R-factor
80°	0.618(6)	0.370(6)	0.9879(6)	6.024×10^{-5}
45°	0.765(9)	0.230(9)	0.9949(8)	9.335×10^{-5}
10°	0.764(5)	0.231(5)	0.9944(6)	8.565×10^{-5}

Table 1: Summary of the fit parameters from the linear combination analysis. The total was allowed to vary in the fit along with the fractions of each component, but the energy scales were not permitted to shift. R-factor is a measure of goodness-of-fit and is defined as $\frac{\Sigma(data-fit)^2}{\Sigma(data)^2}$

Coated conductor details

Sample code	Manufacturer	Rare earth	Deposition method	REBCO thickness	Artificial pinning
Bruker	Bruker	Y	PLD	2.0 µm	DD
Fujikura	Fujikura	Gd	PLD	2.0 µm	No
Shanghai (Gd)	SST	Gd	PLD	1.8 µm	No
Shanghai (Eu)	SST	Eu	PLD	2.4 µm	$BaHfO_3$
SCS4050	SuperPower	Gd,Y	MOCVD	1.0 µm	No
SCS4050 AP	SuperPower	Gd	MOCVD	1.0 µm	$BaZrO_3$
SCS4050 AP 2011	SuperPower	(Gd,Y)	MOCVD	1.0 µm	$BaZrO_3$
SCS4050 AP 2013	SuperPower	Gd	MOCVD	1.0 µm	$BaZrO_3$
SCS4050 AP 2017	SuperPower	(Gd,Y)	MOCVD	1.2 µm	$BaZrO_3$
SUNAM	SUNAM	Gd	RCE-CDR	1.3 µm	No
344C	AMSC	Y	RABiTS/MOD	1.2 µm	No

Table 2: Coated conductor descriptions. PLD = pulsed laser deposition; RCE-CDR = reactive co-evaporation-cyclic deposition and reaction; MOCVD = metallorganic chemical vapour deposition; DD = double-disordered.

X-ray attenuation lengths

X-ray attenuation lengths estimated for YBCO with a density of 6.5 $\mathrm{g\,cm^{-3}}$ using the Berkeley Lab Center for X-ray Optics (CXRO) tool available at `https://henke.lbl.gov/optical_constants/` are shown in figure 5. Please note that the angles given in figure 5 are the angles of the incident X-ray beam to the surface of the sample, whereas for the orientations of the spectra we use the angle of incidence relative to the sample normal. Therefore, the 10° attenuation data is relevant for the 80° spectra.

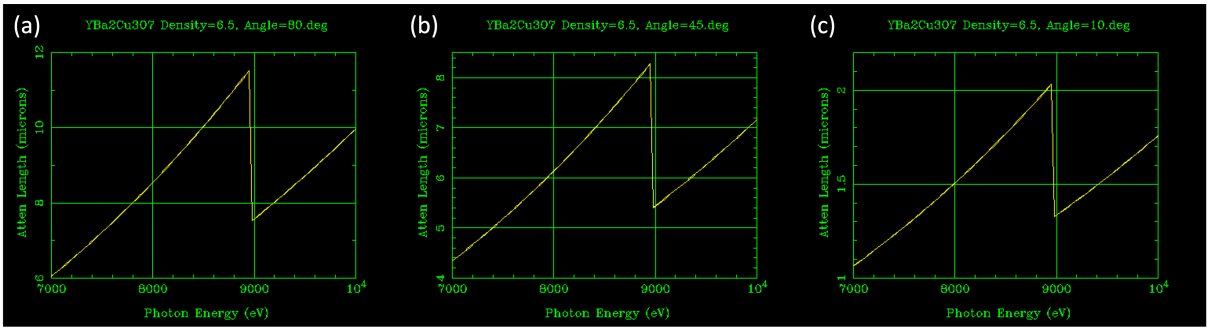

Figure 1: Attenuation lengths for X-rays in YBCO (density = 6.5 g cm^{-3} with angles of incidence to the sample surface of (a) 80°, (b) 45° and (c) 10°.

Sources of error in difference spectra

The spectral differences between the pristine and neutron-irradiated samples are very small. Therefore, it is appropriate to consider whether alternative sources of differences between the spectra could be responsible for the observed results.

Normalisation and flattening procedure

The spectra are normalised and flattened using standard protocols in the Larch software prior to calculating the difference spectra. However, it is challenging to perform this procedure with the required accuracy for the 80° spectra where the x-rays are incident at a grazing angle, owing to artefacts in the post-edge arising from an increasing interaction depth with increasing energy. The severity of this artefact depends on the precise geometry of the samples and the position of the x-ray spot on the sample. As can be seen in Figure 2, which shows normalised but unflattened spectra, this artefact is most evident in the neutron irradiated SuperPower SP13 sample that was irregular in shape, and means that the absolute values of the difference spectra are less reliable in sample SP13 than in the SUNAM or SP11 samples.

Sample-to-sample variations

It is possible that different samples taken from the same batch of coated conductor tape may not have identical spectra, owing to inhomogeneities in the material. Unfortunately, we do not have spectra taken from two nominally identical samples at the same beam time that would be needed to verify whether the irradiation-induced spectral changes reported in the manuscript are more pronounced than sample-to-sample variations taken on different pieces of the same pristine tape. However, we have measured pristine SP11 tapes at several different beam times. Figure **??**

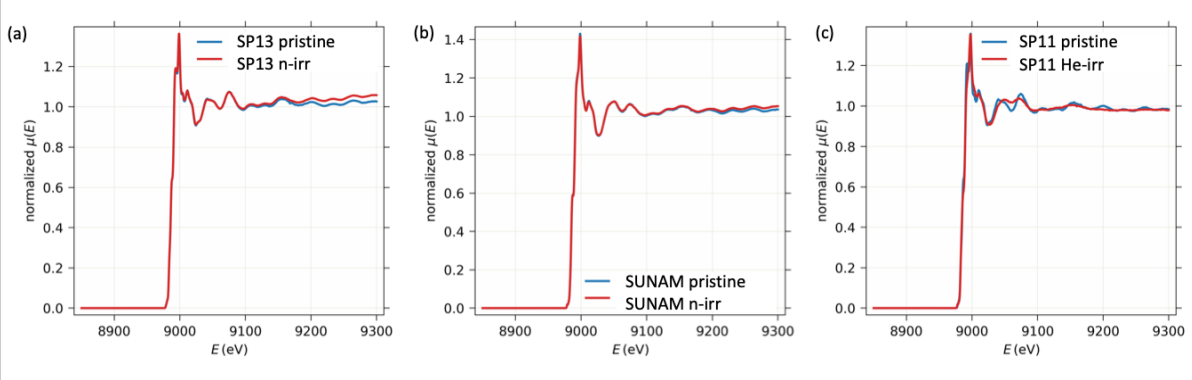

Figure 2: Unflattened normalised spectra from pristine and unirradiated samples of (a) SP13, (b) SUNAM, (c) SP11.

shows the difference spectra between two pristine SP11 samples taken at different beam times compared with the irradiation induced difference spectra, where the irradiated sample and its pristine reference have been measured in the same beam time (as is the case for all difference spectra in this manuscript). Although the magnitudes of the differences are similar for both cases, the difference spectra between two nominally identical pristine SP11 samples do not have the same general shape as the irradiated-pristine difference spectra. In addition, spectra taken at different beam times would be expected to show larger differences than if they were taken at the same beam time owing to slight changes in the calibration and instrument. Therefore, the similarity in the general shape of the difference spectra reported in Fig 4 of the manuscript gives confidence that the main differences noted are irradiation-induced.

Effect of angular alignment

Since the XANES spectra are angle dependent, it is useful to analyse the magnitude of the changes in spectral features that we might observe owing to errors in the angular alignment of the sample. The angle dependence of the intensity of the main peak in the 10° spectrum at 17 eV has been extracted from the data published in Fig. 4b of Nicholls et al [Commun Mater 3, 52 (2022). https://doi.org/10.1038/s43246-022-00272-0], and is plotted in Figure **??**. The drop in intensity follows the expected cosine function, $I(\theta) = \frac{\Delta I}{2} cos2\theta + c$, where ΔI is the difference in intensity between 0° and 90° and has the value of 0.68, and c is a constant relating to the background at this energy and has the value of 1.53. Therefore, the angle dependence near 10° is not very strong, and we calculate that a misalignment of more than 4° would be needed to lead to the observed drop in intensity of 0.02 for this peak in the neutron irradiated samples.

Since we estimate the error in uncertainty in the angle of the sample to be less than 1°, we are confident that the differences are not a result of angular misalignments of the samples.

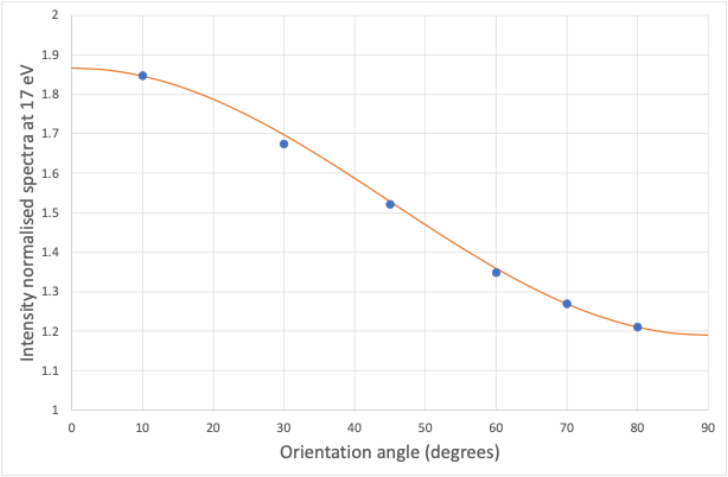

Figure 4: Angle dependence of the intensity at 17 eV. Blue data points are taken from Nicholls et al [Commun Mater 3, 52 (2022). https://doi.org/10.1038/s43246-022-00272-0], and the orange line is the cosine model.

Comparison of damage in GdBCO and YBCO

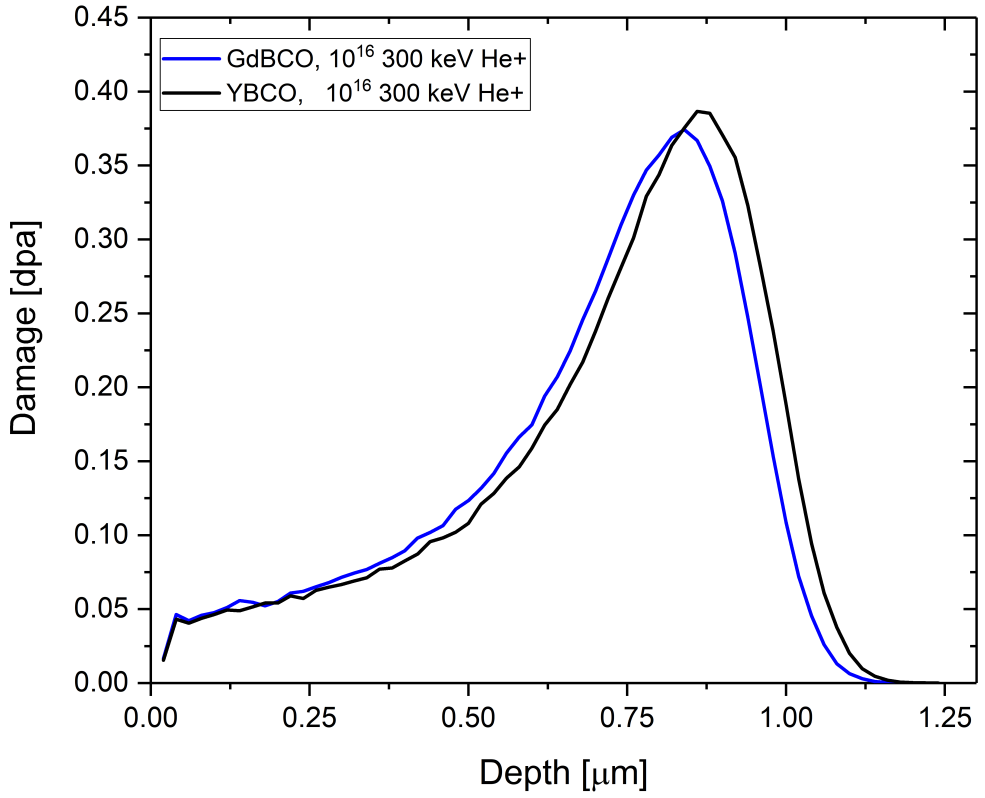

Figure 5: Comparison of GdBCO and YBCO irradiation damage. (a)Damage profile of 300 keV He^+ ions, and (b) compares calculated dpa per full power year (FPA) for YBCO and GdBCO for TRIGA CIF neutrons.