**REBCO Transmutation text for Chris’ paper**

REBCO superconducting tape consists of multiple materials, including two 20 µm thick copper layers on either side and a thick (50 µm) Hastelloy substrate that supports a 1 µm thick layer of YBa2Cu3O7-x superconductor on a Ag buffer layer. Several different nuclear reactions can take place when REBCO is subjected to a fast neutron field, causing damage to the material. These include displacement damage due to elastic scattering and hydrogen embrittlement and swelling arising from (n,p) and (n,a) reactions. In addition to damage, these reaction will cause transmutation of the elements in REBCO. The table below shows the largest transmutation products on the four constituent elements in REBCO along with the energetic threshold for the reaction that causes their formation.

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| Target | Reaction | Product (lifetime) | s14 (mb) |
| 89Y | (n,g) | 90Y (64 h) → 90Zr | - |
| 89Y | (n,2n) | 88Y (107 d) | 823 |
| 89Y | (n,p) | 89Sr (51 d) | 23 |
| 89Y | (n,pn) | 88Sr (stable) | 58 |
| 89Y | (n,a) | 86Rb (18.6 d) | 5 |
| 158Gd | (n,p) | 158Eu (45.83 min) | 2 |
| 158Gd | (n,a) | 155Sm (22.33 min) | 1 |
| 152Sm | (n, p) | 152Pm (4.12 min) | 3 |
| 152Sm | (n, p) | 149Nd (1.73 h) | 2 |
| 153Eu | (n,an) | 149Pm (2.12 d) | 1 |
| 153Eu | (n,pn) | 152Sm (stable) | 1 |
| 153Eu | (n,p) | 153Sm (stable) | 5 |
| 153Eu | (n,an) | 150Pm (2.68 h) | 1 |
| 63Cu | (n,g) | 64Cu (12.7 h) | - |
| 63Cu | (n,2n) | 62Cu (9.7 min) | 417 |
| 63Cu | (n,p) | 63Ni (101 y) | 59 |
| 63Cu | (n,pn) | 61Ni (stable) | 419 |
| 63Cu | (n,a) | 60Co (5.3 y) | 44 |
| 65Cu | (n,g) | 66Cu (5.1 min) → 60Zn | - |
| 65Cu | (n,2n) | 64Cu (12.7 h) | 837 |
| 65Cu | (n,p) | 65Ni (2.5 h) | 20 |
| 65Cu | (n,pn) | 64Ni (stable) | 36 |
| 65Cu | (n,a) | 62Co (1.5 min) | 14 |
| 16O | (n,g) | 17O (stable) | - |
| 17O | (n,np) | 16N (stable) | 1 |
| 16O | (n,p) | 16N (6 s) | 42 |
| 16O | (n,a) | 13C (stable) | 142 |
| 16O | (n,an) | 12C (stable) | 124 |

Given the limited thickness of the tape, the thin-target formula is appropriate to determine nuclear reaction rates in the constituent materials:

Where *s* is the reaction cross section, *r* is the density of the material and *x* is the thickness.

Perhaps the most concerning of these transmutations reactions are on oxygen, whose role is central to high temperature superconductors. Here, the role of 14 MeV neutrons is particularly important.

Let’s assume a tokamak geometry with inner and outer diameters of 1.0 and 2.5 m respectively and a plasma chamber with elliptical cross section with major/minor axes of 2 and 1.5 m (which is roughly that of the DIII-D experiment being run by General Atomics). If this device were to evolve 1 GW of fusion power, then the total neutron fluence would be ≈2.7x1014 n/cm2/s. Given that the total 16O(n,a) and (n,an) cross sections is 266 mb @ 14 MeV, this implies a conversion rate of:

In one year of continuous operation this equates to 0.23% of all oxygen in the REBCO. Note that the corresponding values for the transformation of yttrium into strontium and copper into zinc would be ≈0.7% respectively.

Recently, simulations conducted by Torsello et. al. explored the expected damage from fusion spectra neutrons on the toroidal field magnets of another tokamak, the ARC reactor, using SPECTRA-PKA and molecular dynamics simulation software. This analysis found that the ARC TF magnets would see a 14.1 MeV neutron flux of roughly 9.6x1013 n/cm2/s neutrons/(m^2s); the implied conversion rate of oxygen for REBCO in these magnets over a year of continuous operation is 0.0081%. Though lower than the DIII-D conversion rate, significant oxygen transmutation will occur in the REBCO tapes throughout the reactor’s lifetime, and such disparities in transmutation rates between devices demonstrates the significance of tokamak geometries and magnet shielding.

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| Target | Reaction | Product (lifetime) | s14 (mb) |
| 58Ni | (n,pn) | 57Co (271 d) | 558 |
| 58Ni | (n,an) | 54Fe (stable) | 4 |
| 58Ni | (n,p) | 58Co (70.86 d) | 354 |
| 58Ni | (n,a) | 55Fe (2.74 y) | 105 |
| 58Ni | (n,2p) | 57Fe (stable) | 28 |
| 96Mo | (n,p) | 98Nb (2.86 s) | 5 |
| 96Mo | (n,a) | 95Zr (64 d) | 5 |
| 52Cr | (n,p) | 52V (3.7 min) | 89 |
| 52Cr | (n,a) | 49Ti (stable) | 30 |
| 52Cr | (n,pn) | 51V (stable) | 40 |
| 56Fe | (n,p) | 56Mn (2.58 h) | 114 |
| 56Fe | (n,a) | 53Cr (stable) | 44 |
| 56Fe | (n,pn) | 55Mn (stable) | 44 |
| 56Fe | (n,an) | 52Cr (stable) | 1 |
| 59Co | (n,a) | 56Mn (2.58 h) | 30 |
| 59Co | (n,p) | 59Fe (44 d) | 51 |
| 59Co | (n,pn) | 58Fe (stable) | 82 |
| 59Co | (n,pn) | 55Mn (stable) | 1 |
| 55Mn | (n,p’) | 55Cr (3.5 min) | 1 |

Gas production in the various layers of REBCO tape is also of great concern to the longevity of HTS magnet systems for fusion, particularly in the Hastelloy layer (56 wt% Ni, 16 wt% Mo, 15 wt% Cr, 5 wt% Fe, 4 wt% W, 3 wt% Co, 1 wt% Mn,) that is present in most tapes. Table ??? shows the largest gas-producing neutron reactions with the major constituents of Hastelloy. With the neutron fluence expected on the ARC TF magnets, this results in XXX apm of hydrogen and XXX apm of helium to be produced over a year of continuous operations (tie back into swelling observed at different implantation levels of the solders here).