Estimations of sample activation

(p,n) Reactions:

	Parent Abundance	Daughter Half-life	Cross Section (b)	Which database	Abundance*Cross Section (b)
64-Ni to 64-Cu	0.0093	12.7 h	0.0331	ENDF/B-VII.1	3.08E-4
~~Cr-53 to Mn-53~~	~~0.095~~	~~3.74E6 y~~	~~0.0907~~	~~ENDF/B-VII.1~~	~~8.62E-3~~
Cr-54 to Mn-54	0.0236	312.3 d	0.0791	ENDF/B-VII.1	1.87E-3
Fe-57 to Co-57	0.0212	271.79 d	0.0455	JENDL/HE-2007	9.65E-4
Mo-95 to Tc-95	0.1587	61 d 20h for m	5.99E-4	TENDL-2015	9.51E-5
~~Mo-98 to Tc-98~~	~~0.2429~~	~~4.2E6 y~~	~~6.54E-4~~	~~TENDL-2015~~	~~1.59E-4~~
~~Mo-100 to Tc-100~~	~~0.0974~~	~~15.8 s~~	~~0.00578~~	~~JENDL/HE-2007~~	~~5.63E-4~~
Mn-55 to Fe-55	1.0	2.73 y	0.0761	JENDL/HE-2007	7.61E-2

Notes:

1. The thresholds of Ni-61 to Cu-61, Fe-58 to Co-58 are right at 3 MeV
2. No yields are taking into consideration
3. The isotope marked with yellow color has multiple decay reactions
4. Tc-95: based on the calculation, the difference between using 20h as half-life versus 61d is really small. Since 20h has a bigger impact upon the initial waiting time, so 20h is chosen for a conservative reason.

(p, alpha) Reactions:

	Parent Abundance	Daughter Half-life	Cross Section (b)	Which database	Abundance*Cross Section (b)
~~Ni-61 to Co-58~~	~~0.0114~~	~~70.86 d~~	~~5.87E-8~~	~~TENDL-2015~~	~~6.69E-10~~
Ni-64 to Co-61	0.0093	1.65 h	3.179E-7	JENDL/HE-2007	2.96E-9
Fe-57 to Mn-54	0.0212	312.3 d	1.19E-6	JENDL/HE-2007	2.52E-8
~~Mo-94 to Nb-91~~	~~0.0919~~	~~60.86 d~~	~~7.90E-6~~	~~JENDL/HE-2007~~	~~7.26E-7~~
Mo-95 to Nb-92	0.01587	10.15d for m	1.343E-5	JENDL/HE-2007	2.13E-7
Mo-98 to Nb-95	0.2429	86.6 h	2.952E-6	JENDL/HE-2007	7.17E-7
Mo-100 to Nb-97	0.0974	1.2h	5.78E-4	JENDL/HE-2007	5.63E-5

Notes:

1. The thresholds of Ni-58 to Co-55, Ni-60 to Co-57 are right at 3 MeV
2. No yields are taking into consideration
3. The isotope marked with yellow color has multiple decay reactions
4. The number of activation reactions to Co-58 is so small that there is no need to include this at all, same is also true for Nb-91,
5. Nb-95: based on the calculation, the difference between using 34.975 d as half-life versus 86.6 h is really small. Since 86.6 h has a bigger impact upon the initial waiting time, so 86.6 h is chosen for a conservative reason.

Exclude reactions based on half-life and cross section

1. Any product half-life longer than 1E6 years and shorter than 1 min are excluded. These are Cr-53 to Mn-53, Mo-98 to Tc-98, Mo-100 to Tc-100.

Calculation Assumptions and Simplifications

1. Atomic weight of each isotope is rough (assumed to be the atomic number)
2. Calculation was done in way to assume 100% pure element material for each isotope, and then when alloys are involved, the atomic ratio of each element was multiplied directly to the calculation made to pure element without considering the density change of the materials.

Calculation Equations Used

Beam Current: $400 \times 10^{-9} A = 4 \times 10^{-7} \frac{C}{s} = 4 \times 10^{-7} \frac{C}{s} \times 6.24 \times 10^{18} \frac{\#}{C} = 2.496 \times 10^{12} \frac{\#}{s}$

Beam Flux: $BF = {2.496 \times 10^{12} \frac{\#}{s}} \Big/ {\pi 0.25^2 cm^2} = 1.27 \times 10^{13} \frac{\#}{cm^2 \cdot s}$

Density: $\rho \frac{g}{cm^3}$

Abundance: A

Atomic weight: AW

Density of atoms: $N = {\rho \cdot A \cdot 6.02 \times 10^{23}} \Big/ {AW} \; [\frac{\#}{cm^3}]$

Volume of sample: $V = \pi 0.25^2 cm^2 \times 30 \times 10^{-4} cm = 5.89 \times 10^{-4} cm^3$

Cross Section: $B[cm^2]$

Reaction Rate: $1.27 \times 10^{13} \frac{\#}{cm^2 \cdot s} \times Density\ of\ atoms \left[\frac{\#}{cm^3}\right] \times B\ [cm^2] = RR \left[\frac{\#}{s \cdot cm^3}\right]$

Irradiation Time: $t = 8h = 28800s$

Decay Constant: $DC \left[\frac{\#}{s}\right]$

Atoms activated: $AA = V \cdot N \cdot B \cdot BF \cdot \frac{1 - e^{-DC \cdot t}}{DC}$

Radioactivity in μCi at the end of the irradiation: $R = DC \cdot AA \cdot \frac{10^6}{3.7 \times 10^{10}} \; [\mu Ci]$

Gamma Constant: $GC@1m \; [\frac{mSv}{MBq * hr} @1m]$

Conversion: $GC@1cm \left[\frac{mrem}{uCi * hr} @ \, 1cm\right] = GC@1m \; \times 3.7 \times 10^4$

Dose Rate in mrem/h at the end of the irradiation: $DR = R \cdot GC@1cm$

Then decay process just follows exponential decay.

Results from Simulation

Please input the time in days: 4
The radioactivity of SS316L after 4 days is 0.0198 uCi.
The radioactivity of Hastelloy_N after 4 days is 0.0134 uCi.
The radioactivity of Incoloy_800HT after 4 days is 0.0142 uCi.
The radioactivity of Ni20Cr after 4 days is 0.0125 uCi.
The radioactivity of Ni10Cr after 4 days is 0.0112 uCi.
The radioactivity of Ni201 after 4 days is 0.0098 uCi.

As a conservative estimation, let's assume after 4 days of cooling time, we have at most 0.02 uCi for the whole sample.

How Much is Removed using CSP

We will have at most 20 samples. On each sample, we want to mill 3 spots. But only 1 spot is in the irradiation area (has radioactive isotopes). That is 20 spots in total.

$$Volume\ Ratio = Area\ Ratio = \frac{Milling\ area}{Irradiated\ area} = \frac{0.05mm \times 1mm}{\pi \times 2.5^2 mm^2} = 0.0025$$

$$Radioactivity\ removed\ per\ spot = 0.0025 \times Total\ Radioactivity = 0.0025 \times 0.02\ \mu Ci = 50\ pCi$$

We will have at most 20 samples. On each sample, we want to mill 3 spots. But only 1 spot is in the irradiation area (has radioactive isotopes). That is 20 spots in total.

$$Radioactivity\ removed\ in\ total\ = 50\ pCi \times 20\ spots = 1\ nCi$$

(The radioactivity of the whole sample was calculated in a conservative way. The spot size is also mean to be bigger than actual. This assumes we don't implement any enclosure around to catch the atoms.