*Evaluation of HYLIFE-II AND SOMBRERO using 175- and 566-group neutron transport and activation cross sections**

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Abstract

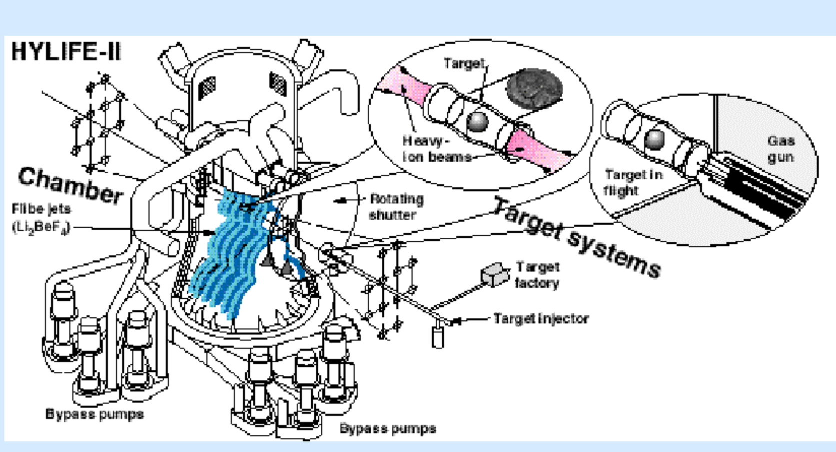
Recent modifications to the TART Monte Carlo neutron and photon transport code allow enable calculation of 566-group neutron spectra. This expanded group structure represents a significant improvement over the 50- and 175-group structures that have been previously available. To support use of this new capability, neutron activation cross section libraries have been created in the 175- and 566-group structures starting from the FENDL/A-2.0 pointwise data. Neutron spectra have been calculated for the first walls of the HYLIFE-II and SOMBRERO inertial fusion energy power plant designs and have been used in subsequent neutron activation calculations. The results obtained using the two different group structures are compared to each other as well as to those obtained using a 175-group version of the EAF3.1 activation cross section library.

New Version of TART Supports 50, 175, and 566 groups

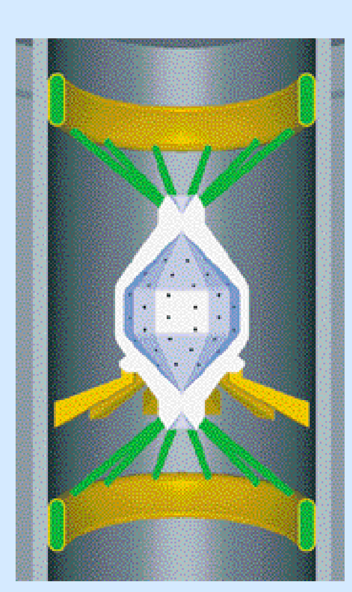
- Old versions of TART[1] supported only 50 and 175-groups in an unorganized group structure
- New version adds 650-group cross sections:
  - Energy range from 10^{-10} MeV to 1 GeV
  - Data only available to 20 MeV/566-groups active
  - 50 groups per decade in organized fashion
  - 10-20% faster due to organization (less time spent asking "what group am I in?")
- Created 175- and 566-group versions of FENDL/A-2.0 activation cross section library[2] from pointwise data:
  - LINEAR and GROUPIE[3] codes used with flat weighting spectrum
  - Activity-related indices calculations for HYLIFE-II[4] and SOMRBERO[5] designs
  - ACAB98[6] radionuclide generation/depletion code used
- Differences in 175- and 566-group results discussed
- Also compare 175-group FENDL/A-2.0 results to those obtained with 175-group version of EAF3.1

Calculational Models

- Objective is to establish whether or not use of more groups is justified:
  - Given objective, simple models are justified
  - One-dimensional HYLIFE-II and SOMBRERO models are used
- Spherical target model: r_o = 0.01 cm; ρr = 3 g/cm^2; 50-50 mix of D-T
- HYLIFE-II design:
  - Thick-liquid protection system (60-cm-thick)
  - Uses Flibe (LiF + BeF_2 in 2:1 ratio) pocket to protect first wall
  - Stainless steel 304 (SS304) first wall assumed to have 100 dpa limit/30 fpy lifetime
- SOMBRERO design:
  - Dry-wall, gas protection system
  - Uses low-activation carbon-carbon (C/C) composites
  - 75 dpa limit assumed for C/C composite/ 5 fpy lifetime



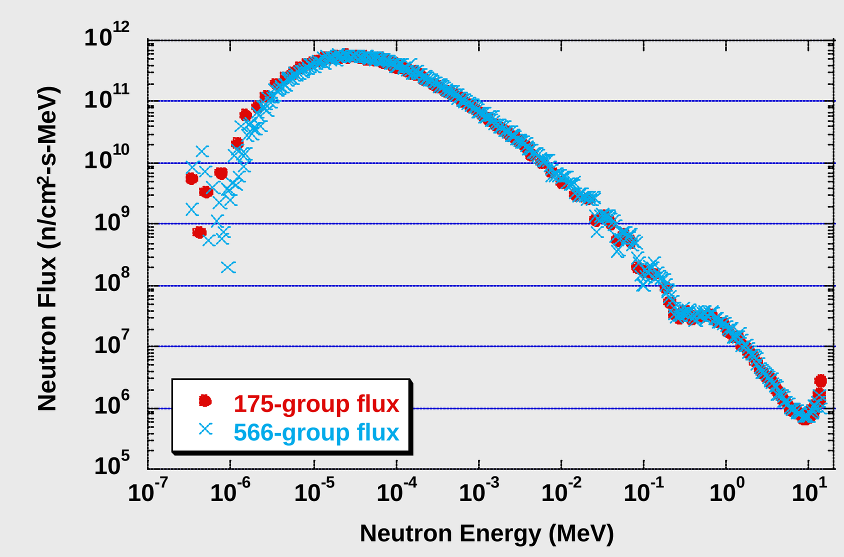
HYLIFE-II Power Plant



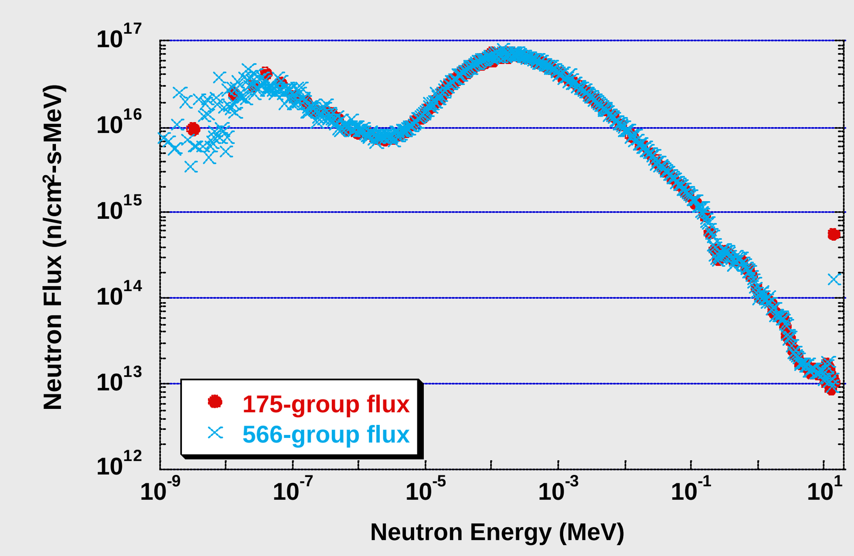
SOMBRERO Power Plant

Calculated Neutron Spectra

- HYLIFE-II neutron spectrum:
  - Large thermal neutron absorption in Flibe:
    - Few neutrons with energies < 10^{-6} MeV make it to first wall
    - Good agreement is observed between 175- and 566-group spectra
  - Scatter in data observed from 2×10^{-7} to 2×10^{-6} MeV:
    - Poor statistics due to large absorption in Flibe
    - Could be fixed with more particles or splitting of particles by energy ranges (not a feature currently available in TART)
- SOMBRERO neutron spectrum:
  - Without a thick-liquid protection scheme, many neutron with energies < 10^{-6} MeV make it to the first wall
  - Definition from 10^{-9} to 10^{-7} MeV greatly improved with the 566-group structure:
    - Old, 175-group structure only has 6 energy groups in this range
    - New structure has 100 groups in this range
  - Again, observe good agreement between 175- and 566-group spectra
  - Still observe scatter in results at lowest neutron energies



Neutron Spectrum, in the HYLIFE-II First Wall



Neutron Spectrum in the SOMBRERO First Wall

Since neutron spectra show good agreement, only might see differences due to two effects: (1) high-energy threshold reactions with non-zero cross section in small number of groups; (2) low-energy reactions where increased energy resolution of 566-group structure is important

Comparison of 175- and 566-group Activation Results

- HYLIFE-II results for SS304 first wall:
  - Activity:
    - 34 radionuclides differ by ≥ 10% at t=1 min
    - None responsible for significant portion of radioactivity
    - Accident analysis needed to determine if any important for accident doses
  - Waste disposal rating (WDR):
    - Total is nearly identical
    - ^{26}Al differs by 38% – produced entirely via ^{27}Al(n,2n) reaction; E_{thresh} = 13.54 MeV
      - 175-groups: contributions from two energy groups: 13.54-13.86 MeV and 13.86-14.14 MeV
      - 566 groups: contributions from two energy groups: 13.18-13.80 MeV and 13.80-14.45 MeV
      - Threshold in middle of group affects group-averaged value
  - Contact dose rates show similar effects:
    - ^{22}Na, ^{26}Al each differ by ~ 38%
    - ^{22}Na produced via ^{23}Na(n,2n); E_{thresh} = 12.96 MeV
- SOMBRERO results for C/C composite first wall:
  - Activity:
    - 147 radionuclides differ by ≥ 10%
    - Those potentially important for accident doses include: ^{18}F, ^{22}Na, ^{30}P, ^{35}S, and ^{45}Ti
  - WDR:
    - Good agreement: only ^{26}Al and ^{44}Ti show more than a few percent difference
    - Insignificant difference in the total WDR
  - Contact dose rates:
    - Good agreement at early times, but significant disagreement at times ≥ 1 year
    - Remote recycling appears possible after ~ 7 years
    - difference in ^{22}Na inventory injects uncertainty of ~ 1 year in this estimate

Comparison of 175-group Results Obtained with FENDL/A-2.0 and EAF3.1

- Considerable differences observed for all indices
- Activities:
  - 127 radionuclides differ by ≥ 10%
  - 25 radionuclides differ by ≥ 10×
  - These findings confirm previous work such as by Sanz, et al.[7]
- WDR:
  - Significant differences for ^{14}C and ^{26}Al
  - These isotopes dominate the total, and thus, total WDR is significantly different
  - total WDR is underestimated by ~ 3× lower with EAF3.1
- Contact dose rates:
  - As with 175- and 566-group comparisons, good agreement is obtained for early cooling times
  - ^{22}Na inventory overestimated with EAF3.1 by ~ 100×
  - Result suggests that remote recycling would be delayed from 7 years to ~ 15 years

Conclusions and Recommendations

- Neutron transport and activation calculations have been carried out using 175- and 566-group cross sections with the TART98 and ACAB98 codes
- Largely, calculations have shown that results agree quite well:
  - Radionuclides produced in high-energy threshold reactions (E_n > 10 MeV) suffer from effects related to the particular group structure
  - Total activities, waste disposal ratings, and contact dose rates for HYLIFE-II and SOMBRERO first walls have not been significantly affected, but one should carefully consider the energy group structure if radionuclides produced in high-energy threshold reactions are important
  - Good agreement is an important benchmarking of the new group structure and data sets
- Comparison of FENDL/A-2.0 results to those obtained with the older, EAF3.1 library have confirmed earlier work that identified significant differences between the cross section libraries

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