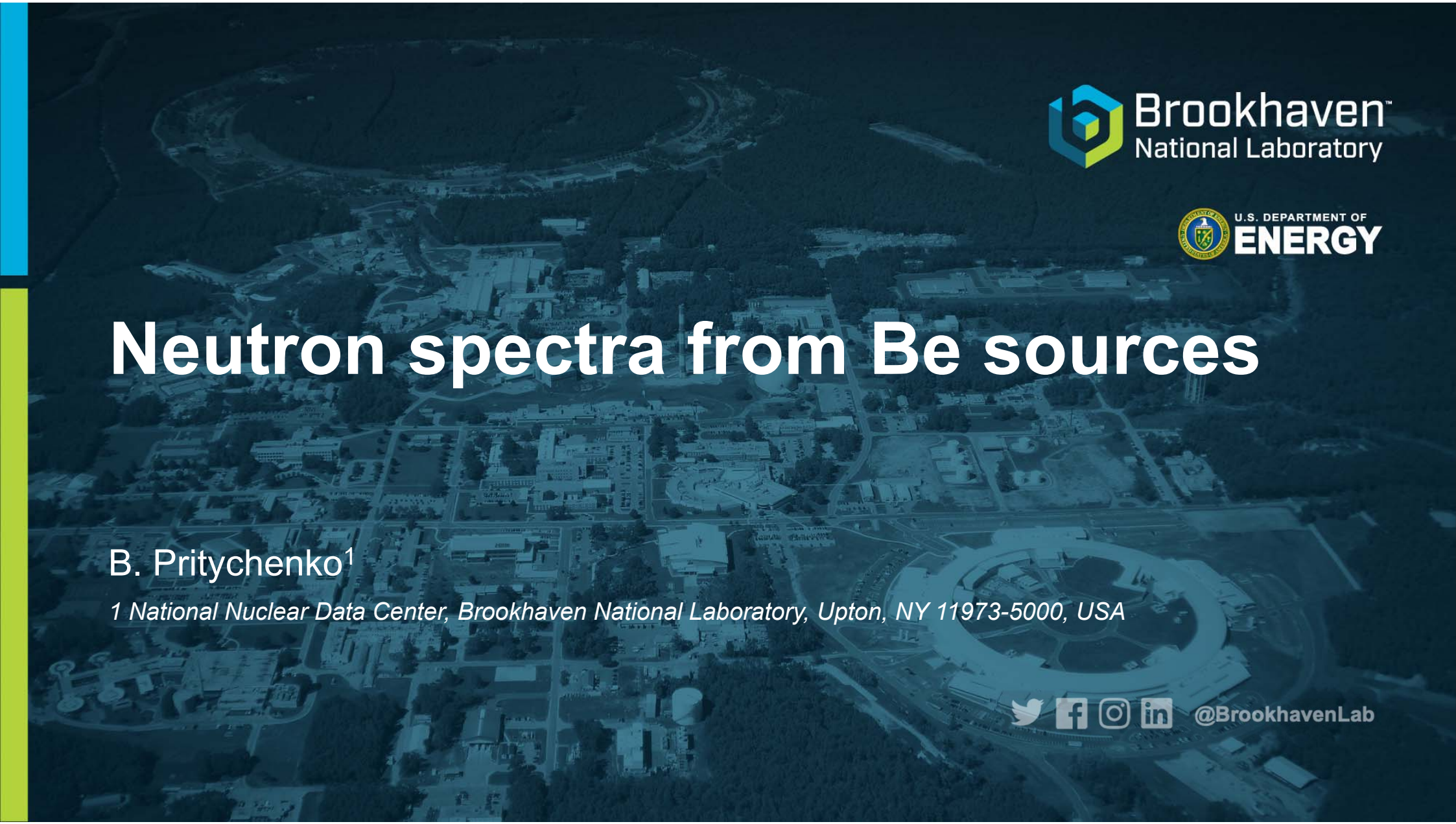


# Neutron spectra from Be sources

B. Pritychenko[1]

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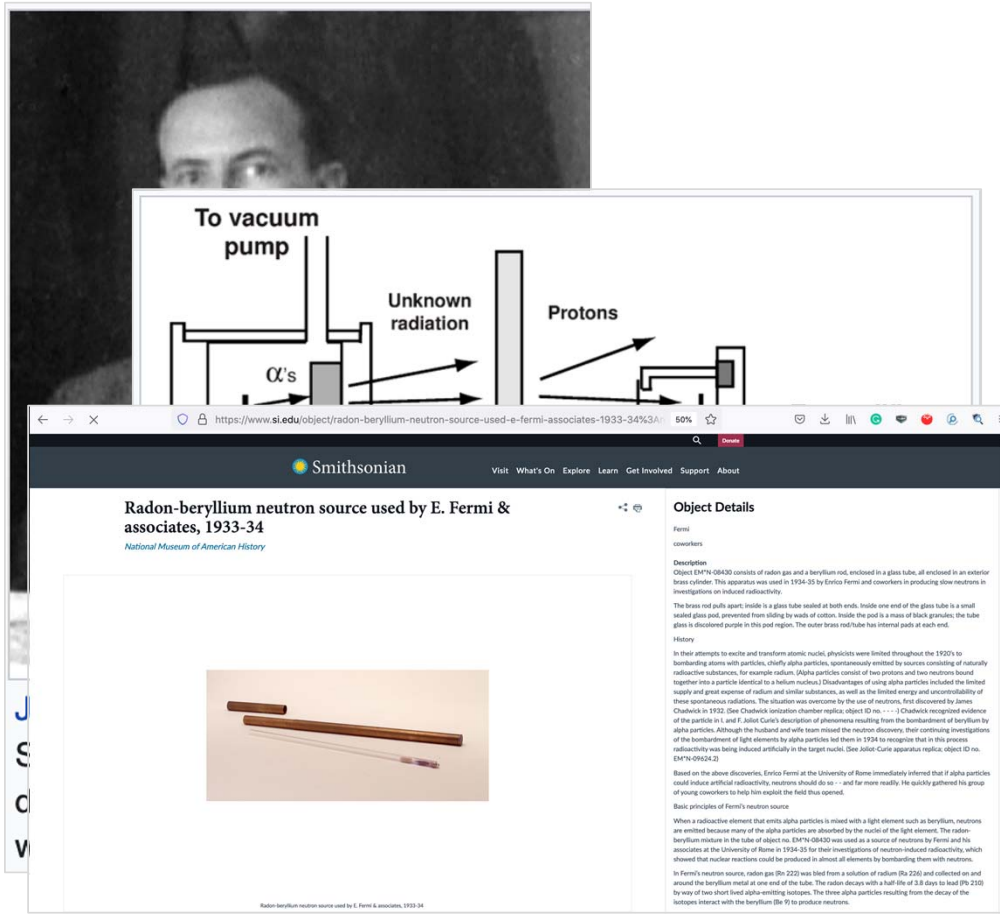
# Discovery of the Neutron

- Neither Rutherford nor James Chadwick at the Cavendish Laboratory believed the Paris gamma ray hypothesis.
- Chadwick repeated the creation of the radiation using beryllium to absorb the alpha particles: $^{9}Be + {}^{4}He\ (\alpha) \rightarrow {}^{12}C + {}^{1}n$.
- Chadwick measured the range of these protons, and also measured how the new radiation impacted the atoms of various gases. He found that the new radiation consisted of not gamma rays, but uncharged particles with about the same mass as the proton.
- National Museum of American History: Object EM*N-08430 consists of radon gas and a beryllium rod, enclosed in a glass tube, all enclosed in an exterior brass cylinder. This apparatus was used in 1934-35 by Enrico Fermi and coworkers in producing slow neutrons in investigations on induced radioactivity.

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# RnBe and RaBe Neutron Sources

- Early neutron measurements used RnBe and RaBe neutron sources.

| | | | | | | |
|---|---|---|---|---|---|---|
| 14703 | 4/21/2021 | D.C.Grahame | J,PR,53,795,1938 | Boris | | Elastic and Inelastic Scattering of Fast Neutrons, RaBe |
| 14702 | 4/21/2021 | G.T.Seaborg | J,PR,52,408,1937 | Boris | | Inelastic Scattering of Fast Neutrons, RaBe |
| 14701 | 4/21/2020 | G.E.Gibson | J,PR,51,370,1937 | Boris | | On the Interaction of Fast Neutrons with Lead, RaBe |
| 14700 | 4/20/2021 | A.C.G.Mitchel | J,PR,50,133,1936 | Boris | | Scattering of Slow Neutrons. II, RaBe |
| 14699 | 4/20/2021 | J.G.Hoffman | J,PR,52,1228,1937 | Boris | | The Neutron Absorption Limit in Cadmium, RnBe |
| 14698 | 3/26/2021 | J.Burggraf | J,PR/C,102,014612,2020 | s.h. | | Neutron-neutron correlations in the photofission of 238U |
| 14697 | 3/17/2021 | J.A.Shusterman | J,PR/C,103,024614,2021 | s.h. | | Aqueous harvesting of $_{88}$Zr at a radioactive-ion-beam facility for cross-section measurements |
| 14696 | 3/10/2021 | J.R.Dunning | J,PR,45,586,1934 | Boris | | The Emission and Scattering of Neutrons, RnBe |

- EXFOR compilations require neutron energy.
- J.R. Dunning, The Emission and Scattering of Neutrons, J,PR,45,586,1934.
- Neutron groups: A, B, C, D, E, F, G, H, J in RnBe source.
- Other neutron sources: AmBe, PuBe, PoBe, ….
- How to resolve neutron energy issues???

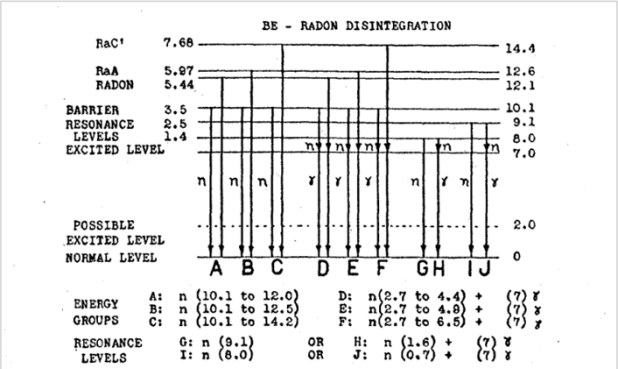
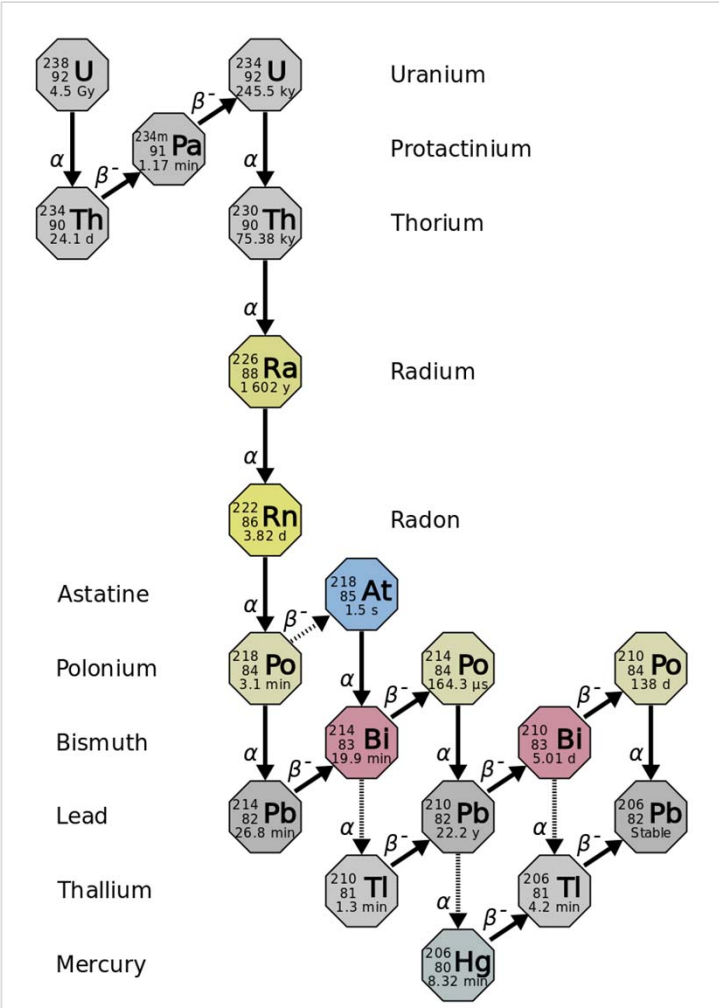


FIG. 5. Possible energy relations for Be-radon reaction.

# RnBe Source

- $^{238}U$ decay chain
- Radon-222, $^{222}Rn$
- Alpha decay energy 5.5904 MeV, *Wang, M.; Audi, G.; Kondev, F. G.; Huang, W. J.; Naimi, S.; Xu, X. (2017). "The AME2016 atomic mass evaluation (II). Tables, graphs, and references" (PDF). Chinese Physics C. **41** (3): 030003-1–030003-442. doi:10.1088/1674-1137/41/3/030003*
- RnBe source is based on (α,n) reaction with alpha particle energy 5.5904 MeV.
- RnBe neutron spectra are needed.




**Radon-222, $^{222}Rn$**

| General | |
|---|---|
| **Symbol** | $^{222}Rn$ |
| **Names** | radon-222, Rn-222, Radium emanation |
| **Protons** (*Z*) | 86 |
| **Neutrons** (*N*) | 136 |
| **Nuclide data** | |
| **Natural abundance** | Trace |
| **Half-life** ($t_{1/2}$) | 3.8215 d[1] |
| **Isotope mass** | 222.0175763[2] Da |
| **Spin** | 0 |
| **Parent isotopes** | $^{226}Ra$ (α) |
| **Decay products** | $^{218}Po$ |
| **Decay modes** | |
| **Decay mode** | **Decay energy (MeV)** |
| Alpha decay | 5.5904[2] |
| Isotopes of radon | |
| Complete table of nuclides | |

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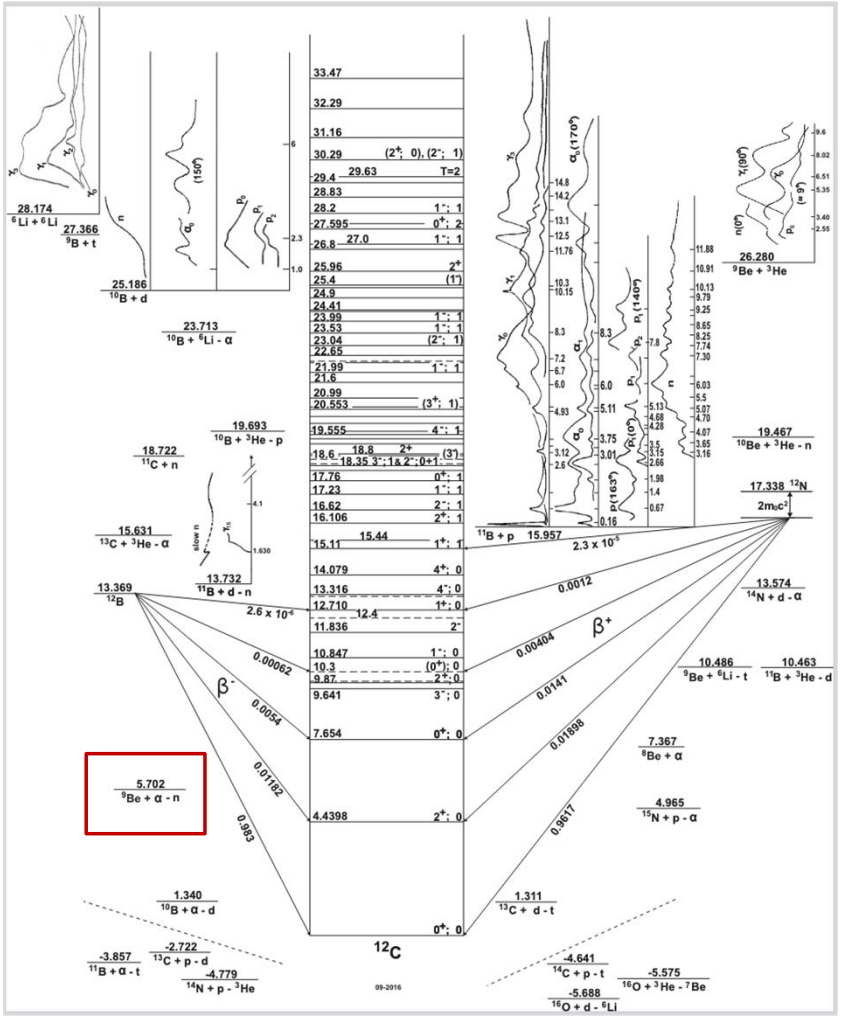
# $^{9}Be(\alpha,n)^{12}C$ Reaction

- What is the q value for the reaction 9Be + α → 12C + n ? A 57 MeV B 84 MeV C 42 MeV D 73 M: https://www.youtube.com/watch?v=Cnr0pnWm2HI
- Q-value is 5702.0 keV.
- https://nucldata.tunl.duke.edu/nucldata/figures/12figs/12_03_2017.pdf

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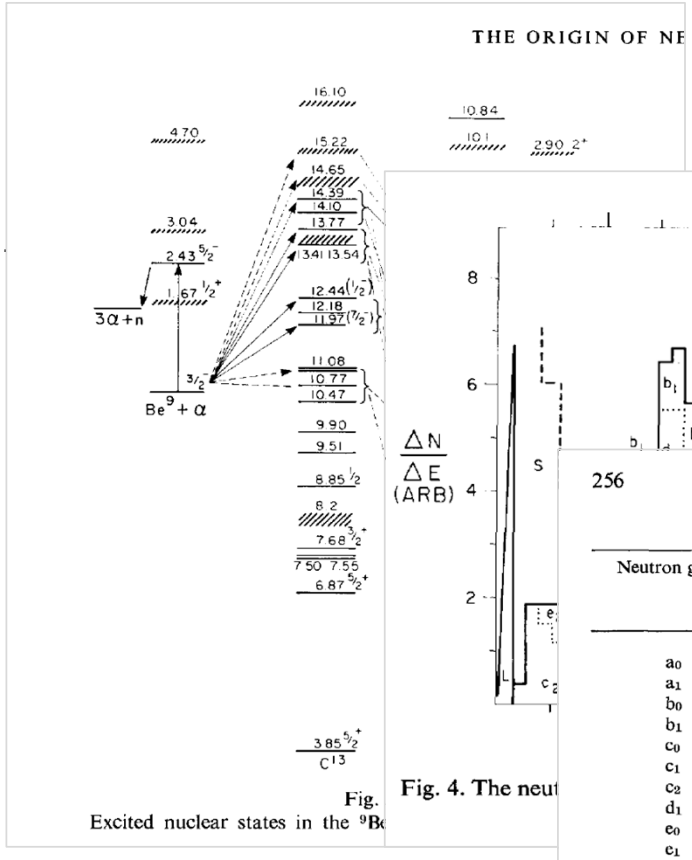
# The Origin of Neutron Groups

| | | | | |
|---|---|---|---|---|
| TITLE | The origin of neutron groups in Be(alpha,n)sources | C2761 | 1 | 3 |
| AUTHOR | (R.L.Lehman) | C2761 | 1 | 4 |
| REFERENCE | (J,NIM,60,253,1968) | C2761 | 1 | 5 |
| | #doi:10.1016/0029-554X(68)90128-6 | C2761 | 1 | 6 |



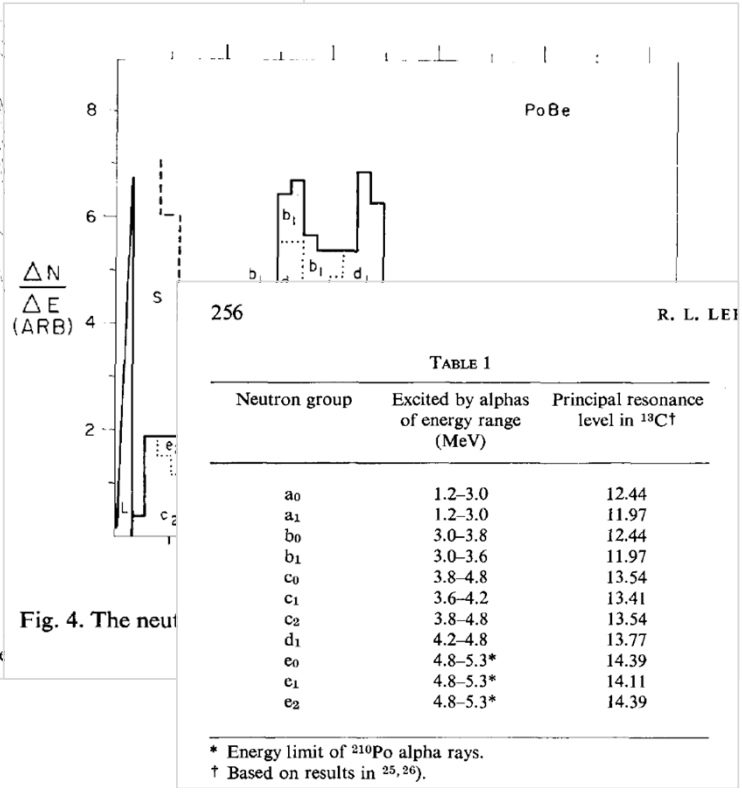




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TABLE 1

| Neutron group | Excited by alphas of energy range (MeV) | Principal resonance level in $^{13}C$† |
|---|---|---|
| $a_0$ | 1.2–3.0 | 12.44 |
| $a_1$ | 1.2–3.0 | 11.97 |
| $b_0$ | 3.0–3.8 | 12.44 |
| $b_1$ | 3.0–3.6 | 11.97 |
| $c_0$ | 3.8–4.8 | 13.54 |
| $c_1$ | 3.6–4.2 | 13.41 |
| $c_2$ | 3.8–4.8 | 13.54 |
| $d_1$ | 4.2–4.8 | 13.77 |
| $e_0$ | 4.8–5.3* | 14.39 |
| $e_1$ | 4.8–5.3* | 14.11 |
| $e_2$ | 4.8–5.3* | 14.39 |

* Energy limit of $^{210}Po$ alpha rays.
† Based on results in [25, 26].

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# Be Neutron Sources Compilations

- Practical compilations of C2761 (PoBe), C27

| | | | | |
|---|---|---|---|---|
| C2763 | 5/19/2022 | M.E.Anderson+ | R,MLM-1874,1972 | Boris |
| C2762 | 5/19/2022 | M.E.Anderson+ | J,NIM,99,231,1972 | Boris |
| C2761 | 5/19/2022 | R.L.Lehman | J,NIM,60,253,1968 | Boris |

- Other compilations may follow.

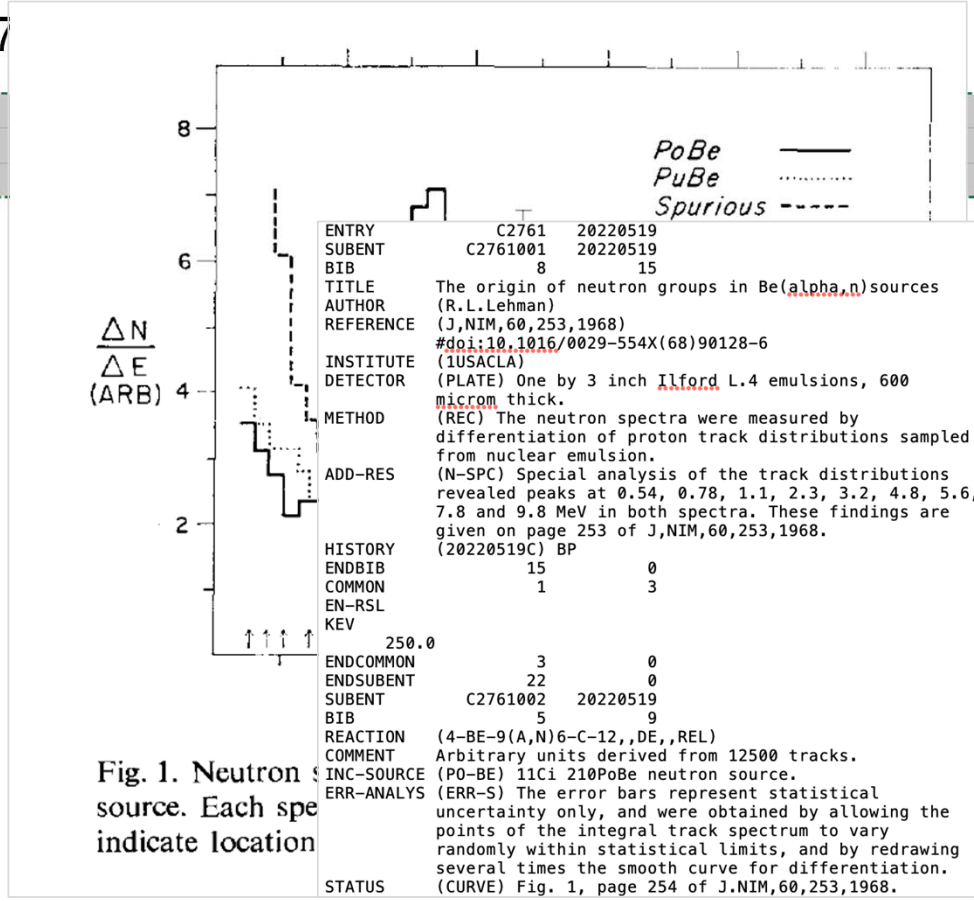


Fig. 1. Neutron
source. Each spe
indicate location

```
ENTRY            C2761   20220519                                  C2761  0    1
SUBENT        C2761001   20220519                                  C2761  1    1
BIB                  8         15                                  C2761  1    2
TITLE      The origin of neutron groups in Be(alpha,n)sources      C2761  1    3
AUTHOR     (R.L.Lehman)                                            C2761  1    4
REFERENCE  (J,NIM,60,253,1968)                                     C2761  1    5
           #doi:10.1016/0029-554X(68)90128-6                       C2761  1    6
INSTITUTE  (1USACLA)                                               C2761  1    7
DETECTOR   (PLATE) One by 3 inch Ilford L.4 emulsions, 600         C2761  1    8
           microm thick.                                           C2761  1    9
METHOD     (REC) The neutron spectra were measured by              C2761  1   10
           differentiation of proton track distributions sampled   C2761  1   11
           from nuclear emulsion.                                  C2761  1   12
ADD-RES    (N-SPC) Special analysis of the track distributions     C2761  1   13
           revealed peaks at 0.54, 0.78, 1.1, 2.3, 3.2, 4.8, 5.6,  C2761  1   14
           7.8 and 9.8 MeV in both spectra. These findings are     C2761  1   15
           given on page 253 of J,NIM,60,253,1968.                 C2761  1   16
HISTORY    (20220519C) BP                                          C2761  1   17
ENDBIB               15          0                                 C2761  1   18
COMMON                1          3                                 C2761  1   19
EN-RSL                                                             C2761  1   20
KEV                                                                C2761  1   21
      250.0                                                        C2761  1   22
ENDCOMMON             3          0                                 C2761  1   23
ENDSUBENT            22          0                                 C2761  199999
SUBENT        C2761002   20220519                                  C2761  2    1
BIB                  5          9                                 C2761  2    2
REACTION   (4-BE-9(A,N)6-C-12,,DE,,REL)                            C2761  2    3
COMMENT    Arbitrary units derived from 12500 tracks.              C2761  2    4
INC-SOURCE (PO-BE) 11Ci 210PoBe neutron source.                    C2761  2    5
ERR-ANALYS (ERR-S) The error bars represent statistical            C2761  2    6
           uncertainty only, and were obtained by allowing the     C2761  2    7
           points of the integral track spectrum to vary           C2761  2    8
           randomly within statistical limits, and by redrawing    C2761  2    9
           several times the smooth curve for differentiation.     C2761  2   10
STATUS     (CURVE) Fig. 1, page 254 of J.NIM,60,253,1968.          C2761  2   11
```

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# The International Atomic Energy Agency: (https://www.iaea.org/about/mission)

is an independent intergovernmental, science and technology-based organization, in the United Nations family, that serves as the global focal point for nuclear cooperation;

**assists its Member States**, in the context of social and economic goals, in planning for and using nuclear science and technology for various peaceful purposes, including the generation of electricity, and facilitates the transfer of such technology and knowledge in a sustainable manner to developing Member States;

develops nuclear safety standards and, based on these standards, promotes the achievement and maintenance of high levels of safety in applications of nuclear energy, as well as the protection of human health and the environment against ionizing radiation;

verifies through its inspection system that States comply with their commitments, under the Non-Proliferation Treaty and other non-proliferation agreements, to use nuclear material and facilities only for peaceful purposes.

# EXFOR - Experimental Nuclear Reaction Data

The largest experimental nuclear reaction database (*www.nndc.bnl.gov/exfor*)

- 24,225 experiments (multiple publications are grouped into a single measurement).
- 182,512 data sets as of May 31, 2022.
- Essential for Evaluated Nuclear Data File (ENDF) libraries worldwide.
- Presently run by the Nuclear Reaction Data Centres (NRDC), internationally. This is an IAEA network which is coordinated by the IAEA.
- Two largest contributors: NNDC & NEA-Databank.
- Every second, third and sixth data points in the library were contributed by the NNDC, NEA-Databank and the rest of NRDC network, respectively.

*EXFOR philosophy is to compile data as they were published (in consultation with authors) unless obvious errors are found.* Published nuclear reaction data contain outliers and discrepancies.