The radium-beryllium neutron source has an advantage in its half-life period being long enough to make attenuation normally negligible during any experiment or series of experiments. The usual weight ratios of Be:Ra are from 5:1 to 3:1. A freshly prepared Ra-Be source must be "aged" to allow the daughter products (Rn, RaA, etc.) to come to equilibrium. The alpha-emitters among these daughter products contribute to the neutron production so that aging for about one month increases the neutron intensity by a factor of about 6 over the initial ("fresh" Ra) value.

As may be seen by inspecting the series, in radium aged for a month there will be alphas available from Ra, Rn, RaA, and Ra (C + C′); as a consequence the neutron spectrum will be complex* with neutron energies up to 7.68 + 5.5 ≃ 13 Mev. In addition the effect of passage of the alphas through the beryllium, even in finely powdered state, and the possibility of the resultant C^{12} nucleus being left in an excited state tends to make the Ra-Be source emit neutrons with a fairly continuous distribution of energies. A distinct limitation of the Ra-Be source is the accompanying gamma radiation.

This latter limitation is not present in the polonium-beryllium source. Polonium (RaF) emits alphas almost exclusively; the few gammas present in pure Po arise from the relatively improbable emission of alphas with energies slightly below normal.† Polonium-beryllium sources have a half-life of 140 days which limits their usefulness to some extent.

Radon can be used with beryllium. The gas is placed in a beryllium capsule. The yield is substantially the same as for a Ra-Be source; however, the half-life is only 3.8 days.

The strengths of these natural (α, n) sources will vary with the details of their construction. In round numbers Ra-Be and Rn-Be sources will emit about 1 to 2 × 10^7 neutrons/second/curie; Po-Be sources will emit about 2.8 × 10^6 neutrons/second/curie. Using the technique described by H. L. Anderson and B. T. Feld in the *Reviews of Scientific Instruments*, 18:186 (1947) a neutron yield is obtained for pressed Ra-Be sources as follows:

$$\text{Fast neutrons/second/gram Ra} = 1.7 \times 10^7 \frac{M_{Be}}{M_{Be} + M_{Ra\,Br_2}}$$

Absolute measurements with this type source have been reported by F. G. P. Seidl and S. P. Harris in the *Reviews of Scientific Instruments*, 18:897 (1947). Their "Source No. 38" consisting of 504 mc Ra and 3000 mg Be yielded (5.5 ± 0.4) × 10^6 neutrons/second. G. R. Gamertsfelder and M. Goldhaber in the *Physical Review*, 69:368 (1946) report a Ra-Be source yield of 6.8 × 10^3 neutrons/second/mc Ra.

Boron bombarded with alphas yields neutrons. The reactions are $B^{11}(\alpha, n)N^{14}$ and $B^{10}(\alpha, n)N^{13}$ with the former reaction predominant. Yields are ~2 × 10^6 neutrons/sec/curie for boron-radium mixtures; BF_3 can be used with yields of ~10^5 neutrons/sec/curie.

Similarly, fluorine yields neutrons in the reaction $F^{19}(\alpha, n)Na^{22}$.

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* A. I. Alichanow, *Comptes Rendus Academie Sciences, U.S.S.R.*, 20:429 (1938). W. Y. Chang, *Physical Review*, 70:632 (1946).

† W. Y. Chang in *Physical Review* 69:60 (1946) gives Po alpha spectra. H. T. Richards, L. Speck, I. H. Perlmann in *Physical Review* 70:118 (1946) discuss neutron spectra of Po-B and Po-Be sources.

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