somewhat. This may be due either to experimental error in estimating the strength of the resonance or perhaps to a relaxation of rules based on isotopic spin as a good quantum number. It is known that at a lower excitation in O^{16} (13.05 Mev) considerable $T=0$ admixture is found in a $T=1$ state,[14] and it may be that our 14.7-Mev state which would be pure $T=0$ in an ideally charge-independent system may contain a substantial admixture of $T=1$ which would allow a contribution to the transition to be made by the H_1 part of the Hamiltonian. In this connection it would be interesting to investigate experimentally the isotopic spin of the 14.7-Mev level. If we are correct in our assignment, it should certainly have a large $T=0$ component and should presumably show strong alpha-particle emission to the low-lying $T=0$ states of C^{12}. The presence of a substantial $T=1$ contamination would be revealed by $E1$ transitions to low-lying $T=0$ states of odd parity in O^{16} such as the 3− state at 6.14 Mev, the 1− state at 7.12 Mev[5] or the 2− state at 8.87 Mev.[15]

[14] D. H. Wilkinson, Phys. Rev. **90**, 721 (1953).
[15] Toppel, Wilkinson, and Alburger, Bull. Am. Phys. Soc. **30**, No. 3, 32 (1955).

REACTION $N^{15}(p,\gamma)O^{16}$

There is good hope that much more detailed information on this interesting resonance, particularly with regard to its possible fine structure, may be obtained through a study of the reaction $N^{15}(p,\gamma)O^{16}$. At the peak of the resonance, the associated proton energy (in the reaction of radiative capture) is only 2.8 Mev so a 4-Mev accelerator is capable of spanning the whole of the interesting region of excitation. Much more accurate angular distributions and radiative width measurements should be possible than in the photodisintegration experiment. The investigations into the isotopic spin properties of this level, mentioned in the last paragraph, could also be most powerfully investigated through proton bombardment.

It is planned to undertake these measurements in this laboratory.

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Gamma Radiation from the Interaction of 4.4-Mev Neutrons with Fe^{54} and Fe^{56}†

ROLF M. SINCLAIR
Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania

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The gamma radiation from the interaction of 4.4±0.1 Mev neutrons with naturally occurring iron has been compared with that from a sample enriched to 34 percent Fe^{54}. The methods used for detection of gamma rays from small samples and the shielding of the NaI detector are described. The results show that the well-known 0.85-Mev gamma ray comes from Fe^{56}, and that Fe^{54} emits a gamma ray of energy 1.40±0.02 Mev. The ratio of the cross section for production of this 1.40-Mev radiation to that of the 0.85 Mev is 0.62±0.07 at 4.4 Mev neutron energy, and 0.68±0.10 at 3.9 Mev. The 1.40-Mev gamma ray is tentatively assigned to the reaction $Fe^{54}(n,n')Fe^{54*}(\gamma)Fe^{54}$, and is believed to represent the de-excitation of the first excited state.

INTRODUCTION

RECENT work in this laboratory has made possible the measurement of gamma radiation emitted by small samples of material bombarded by fast neutrons. The size of the scatterer from which gamma rays can be unambiguously detected has been reduced sufficiently so that the presently available amounts of separated isotopes can be employed. This makes possible the isotopic assignment of the gamma rays produced by the neutron bombardment of polyisotopic elements, as well as the detection of radiation emitted by the less prevalent isotopes which is usually masked by that from the more abundant ones. The isotopes Fe^{54} and Fe^{56} have been studied by this method.

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EXPERIMENTAL

Figure 1 shows the geometry of the experiment. A $1\frac{1}{2}$ in.$\times 1\frac{1}{2}$ in. cylindrical NaI(Tl) crystal detected gamma radiation from a scatterer exposed to fast neutrons produced by the deuteron bombardment of a D_2 target. The spread in neutron energy was calculated to be 100 kev. The neutron flux was monitored by a Hanson long counter at 0° to the deuteron beam, and a current integrator measuring the deuteron current incident on the target. The crystal was shielded from the neutron source and the background due to the electrostatic generator by tungsten and lead. The gas

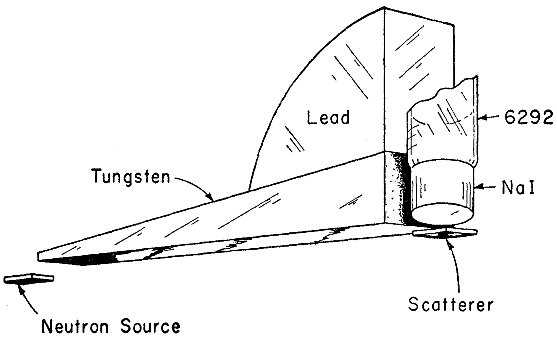

FIG. 1. Experimental arrangement used in the study of gamma radiation emitted by small samples bombarded by fast neutrons.

target was located seven feet above the floor of a thin-walled shed adjoining the generator building, and the supporting structures were kept to a minimum.

A 32.51-g sample of metallic iron electromagnetically enriched in Fe^{54} was obtained from the Stable Isotopes Division, Oak Ridge National Laboratory, and a similar sample was made from normally occurring iron. The scatterer dimensions were $1\frac{1}{4}$ in.$\times 1\frac{1}{4}$ in.$\times$0.181 in. Table I gives the isotopic compositions.

RESULTS

Figure 2 shows the pulse-height curves obtained. The gamma rays previously reported[1] from iron can be clearly seen, superimposed on the smooth curve from neutron interactions in NaI.[2] Fe^{54} emits a gamma ray of energy 1.40±0.02 Mev, measured by comparison with the 1.17- and 1.33-Mev gamma rays from Co^{60}. This is presumably the same gamma ray reported previously by other observers[3] working with lower neutron energies and normal iron. No other gamma rays could be detected from Fe^{54}.

The ratio of the 0.85-Mev gamma-ray yield from the two samples was found to be 0.77±0.05, confirming its assignment to Fe^{56}. No accurate data could be obtained on the yield of the gamma rays with energy greater than 1.4 Mev, but their assignment to Fe^{56} seems certain. The ratio of the areas under the photopeaks of the 1.40-Mev and 0.85-Mev gamma rays from the enriched sample was 0.18±0.02 at 4.4-Mev neutron energy. Correcting this for the energy-dependent photopeak efficiency of the spectrometer,[4] the isotopic abundances, and absorption in the scatterer[5] gives a ratio for the cross sections for production of these two gamma rays of 0.62±0.07. At 3.9-Mev neutron energy, this ratio was found to be 0.68±0.10.[6] No correction was made for multiple neutron scattering. Errors quoted are twice the probable errors of a number of measurements, to allow for systematic errors.

The 1.40-Mev gamma ray is tentatively assigned to the reaction $Fe^{54}(n,n'\gamma)Fe^{54}$, from the excitation of the first excited state. This agrees with the value of 1.413 ±0.005 Mev found for this state by Phillips *et al.*,[7]

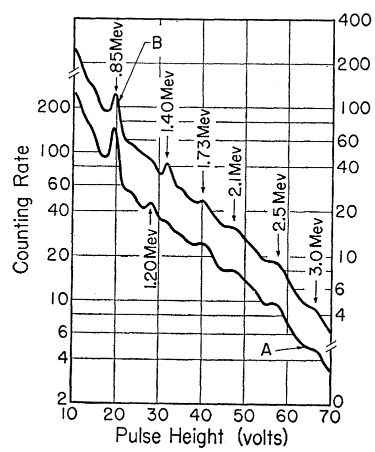

FIG. 2. Pulse-height curves obtained with scintillation spectrometer. (*A*) Normal iron sample; (*B*) enriched iron sample. Neutron energy=4.4±0.1 Mev. Pulse-height analyzer channel width =1.0 volt.

and with the behavior of even-even nuclei in the vicinity of 28 neutrons.[8] The second level in Fe^{54} should be at $\sim 2.2\times 1.4 = 3.1$ Mev,[9] and would be harder to excite than the corresponding level in Fe^{56}. Any gamma rays from this level in Fe^{54} could be masked by the higher-energy radiation from Fe^{56}. The possibility that the 1.40-Mev gamma ray follows a process other than neutron inelastic scattering cannot be ruled out, but this seems unlikely because of the similarity of its yield to that of the 0.85-Mev gamma ray.

TABLE I. Isotopic composition of iron samples.[a]

Isotope	Normal sample (percent)	Enriched sample[b] (percent)
Fe^{54}	5.84	34.47
Fe^{56}	91.68	65.31
Fe^{57}	2.17	0.203
Fe^{58}	0.31	0.016
Other elements present in negligible amounts.		

[a] Reported by Dr. C. P. Keim, Oak Ridge National Laboratory.
[b] Oak Ridge National Laboratory Lot Do 447(a).

[1] G. L. Griffith, Phys. Rev. **98**, 579 (1955).
[2] G. A. Jones and D. H. Wilkinson, Proc. Phys. Soc. (London) **A66**, 1176 (1953); R. M. Sinclair, Phys. Rev. **93**, 1082 (1954).
[3] R. B. Day, Phys. Rev. **89**, 908 (1953); Garrett, Hereford, and Sloope, Phys. Rev. **92**, 1507 (1953); R. M. Kiehn and C. Goodman, Phys. Rev. **95**, 989 (1954).
[4] Woodbury, Tollestrup, and Day, Phys. Rev. **93**, 1311 (1954).
[5] C. M. Davisson and R. D. Evans, Revs. Modern Phys. **24**, 79 (1952).
[6] These values differ slightly from those reported earlier [R. M. Sinclair, Phys. Rev. **98**, 1147 (A)(1955)], but are those presented at the January, 1955, American Physical Society meeting.
[7] Phillips, Gossett, Schiffer, and Windham, Bull. Am. Phys. Soc. **30**, No. 3, 55 (1955).
[8] G. Scharff-Goldhaber, Phys. Rev. **90**, 587 (1953); P. Stähelin and P. Preiswerk, Nuovo cimento **10**, 1219 (1953).
[9] G. Scharff-Goldhaber and J. Weneser, Phys. Rev. **98**, 212 (1955).