~~UTILIZING MICROSHIELD 3~~

MITNE - 126

~~A U.S. NAVY NUCLEAR SUBMARINE~~

MITNE-126

FINAL REPORT

U.S. BUREAU OF MINES CONTRACT NUMBER H0180895

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TABLE OF CONTENTS

I. INTRODUCTION

The principal objective to this research contract was to determine the prominent gamma rays produced by neutron inelastic scattering in some 20 low Z elements. In addition to completing this major objective, several other smaller tasks were accomplished: these included the listing of the energy and intensity of the known neutron capture gamma rays of 75 elements in order of increasing energy. The determination of the energy and intensity of these capture gamma rays had previously been done at M.I.T. under Air Force contract number AF19(628)5551. The USBM contract paid for the computer time required for the new listing and the cost of publishing the listing produced in this effort.

The second associated task was a comparative study of the gamma-ray spectra produced in coal and iron ore sinter both by a PuBe and a Cf^{252} neutron source. This work was recently completed and a technical report of these measurements accompanies this final report.

Finally this contract supported in a minor way the final compilation and publication of a study of prompt capture gamma-ray analysis which was part of the Ph.D. work of John Hamawi.

II. DETERMINATION OF THE ENERGIES OF THE GAMMA RAYS PRODUCED BY NEUTRON INELASTIC SCATTERING

The energy and intensity of the principal gamma rays produced by neutron inelastic scattering were determined using a 5 Ci PuBe neutron source and a high resolution 30 cm^3 Ge(Li) gamma-ray spectrometer. The elements studied were Li, C, N, O, Mg, Al, Na, Si, S, Cl, K, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, and Pb.

A computer program was developed that calculated the production cross section for each of the gamma rays from the known neutron source strength, the irradiation geometry, the gamma-ray detector efficiency, and the measured counting rate in the detector.

The initial measurements of this study were done by D. Simonson. The results of this early study were used to set up a more detailed and exact set of measurements carried out by B. Hui. A technical report, MITNE-112, of these results by. B. Hui and N.C. Rasmussen was submitted to the U.S. Bureau of Mines. This report includes exact details of the measurement and calculational techniques used. In addition, spectral plots of the various runs were included. The major results of these runs were summarized in Table 4.3 of that report and are reproduced below.

Table 4.3**

Energy and Production Cross-section of Each Element

Element	Energy Kev (±5Kev)	Intensity (counts / min x gm)	Error	σ ± 50% barn
Lithium	479	0.459	3%	0.68
Carbon	{4446 3935(SE) 3422(DE)	0.003	10%	0.02
Nitrogen	2317	0.2205	2%	3.33
Oxygen	*			
Magnesium	1369	0.029	3%	0.477
Aluminum	843	0.018	1%	0.17
	1014	0.024	2%	0.35
	1369	0.007	10%	0.01
	1722	0.003	6%	0.06
	1984	0.003	5%	0.09
	2212	0.005	2%	0.15
	{2988 1963(DE)	0.0006	18%	0.01
Sodium	438	0.100	2%	0.54
	619	0.0188	5%	0.12
	1530(DE)	0.0017	32%	0.02
	2276	0.0003	38%	0.01
	{2404 1383(DE)	0.0016	35%	0.03
	{2663 1637(DE)	0.0053	15%	0.08
Silicon	1270	0.0001	20%	0.001
	1779	0.0096	6%	0.26
Sulphur	2225	0.0042	5%	0.14
Chlorine	1217	0.0019	15%	0.04
	1762	0.0020	11%	0.07

* The weight of oxygen in the sample cannot be determined accurately

DE, SE means Double or Single Escape, see page 51

** From MITNE-112

Table 4.3 (contd.)

Element	Energy Kev (±5Kev)	Intensity (counts / min x gm)	Error	σ ± 50% barn
Potassium	2514	0.0008	20%	0.03
	{2760 1732(DE)	0.0292	3%	1.03
	{3593 2575(DE)	0.0018	30%	0.06
Titanium	889	0.0151	4%	0.25
	984	0.0712	2%	1.80
	1313	0.0089	4%	0.28
	1347	0.0009	24%	0.02
	1438	0.0015	10%	0.22
Vanadium	608	0.009	5%	0.49
	928	0.0066	28%	0.16
	1609	0.0091	4%	0.35
	1813	0.001	6%	0.04
Chromium	749	0.005	30%	0.09
	935	0.009	11%	0.21
	1434	0.030	2%	1.21
	1528	0.003	15%	0.12
Manganese	858	0.0133	8%	0.12
	1166	0.0011	46%	0.01
	1253(DE)	0.0006	19%	0.01
	1521	0.005	2%	0.11
	1880	0.002	3%	0.04
Iron	847	0.06	1%	1.20
	1237	0.008	2%	0.24
	1408	0.001	3%	0.16
	1810	0.003	3%	0.16
Cobalt	260	0.0734	3%	0.325
	381	0.005	8%	0.05
	555	0.0027	10%	0.02
	1099	0.005	4%	0.16
	1191	0.0148	3%	0.51
	1293	0.0032	4%	0.12
	1483	0.0031	4%	0.14
	1745	0.0013	6%	0.06

Table 4.3 (Contd.)

Element	Energy Kev (±5Kev)	Intensity (counts / min x gm)	Error	σ ±50% barn
Nickle	1011	0.0019	8%	0.06
	1332	0.0117	3%	0.43
	1457	0.0157	2%	0.12
Copper	361	0.0041	5%	0.03
	670	0.0037	4%	0.05
	967	0.0032	8%	0.10
	1122	0.0072	5%	0.25
	1333	0.0047	10%	0.20
	1442	0.001	25%	0.003
	1487	0.004	53%	0.02
	1876	0.0002	17%	0.01
Lead	568	0.0017	20%	0.07
	583	0.0029	20%	0.13
	803	0.0038	10%	0.31
	898	0.0004	7%	0.03
	1063	0.0004	9%	0.05
	1366	0.0001	30%	0.01
	1822	0.0001	40%	0.02
	{2614 / 1592 (DE)}	0.0041	15%	0.91

III. CAPTURE GAMMA-RAY ENERGIES AND INTENSITIES LISTED IN ORDER OF ENERGY

The terminal effort on US Air Force contract number AF19(628)5551 was a determination of the energy and intensity of the capture gamma rays of 75 elements. This work was carried out using the M.I.T. Triple Coincidence Spectrometer and represented the most comprehensive study of its kind ever compiled. This compilation included more than 10,000 gamma-ray lines.

In prompt capture gamma-ray analysis one often finds a line in the spectrum the source of which is unknown. In order to identify such a line it is necessary to know what element or elements contain a line of this energy within experimental error. To look up such a line becomes almost an impossible task unless the lines are listed in terms of increasing energy. No such listing existed, so the results of the USAF research contract were put into the computer memory and a program written to re-order them by increasing energy. At the same time the line intensities were recalculated in units of number of gammas/gm/unit neutron flux. This latter intensity definition is much more useful in capture gamma -ray analysis work. The results of this work were issued as technical report number MITNE-105 by J. Hamawi and N.C. Rasmussen, copies of which were sent to the U.S. Bureau of Mines.

IV. COAL AND IRON ORE SINTER MEASUREMENTS USING A Cf^{252} SOURCE

In this investigation the capture gamma ray spectra from four types of coal and from iron ore sinter, produced by a Cf^{252} neutron source were measured with the Ge(Li) gamma-ray spectrometer. The details of these measurements are reported in technical report MITNE-125 and the results are summarized below.

4.1 Coal Measurements

In these measurements the neutron source was placed in the center of a 55 gal drum of coal and the gamma ray detector was placed outside the drum. The gamma-ray spectra from four different coal samples furnished by the U.S. Bureau of Mines were recorded. For comparative purposes the Arkwright sample was used as a standard and the sulfur, hydrogen, and carbon content of the other three samples determined relative to the Arkwright standard. The results of these measurements were summarized in Table 3.1 of MITNE-125 and are reproduced below.

The results of these high energy resolution runs confirmed that there is relatively little interference from other components in the coal in the energy range of the prominent peaks of H, C, and S. This verifies the results of Stewart of the U.S. Bureau of Mines that sulfur can be quite adequately measured by the use of NaI detectors.

A comparison of the runs on Arkwright coal with a PuBe and a Cf^{252} source (Figures A.4 and A.5 of MITNE-125) show that the S peak height relative to background is 1.25:1 with the Cf^{252} source,

COAL TYPE	SULFUR WEIGHT %		HYDROGEN WEIGHT %		CARBON WEIGHT %	
	THIS WORK	CHEMICAL ANALYSIS	THIS WORK	CHEMICAL ANALYSIS	THIS WORK	CHEMICAL ANALYSIS
LIGNITE	0.4	0.4	7.8	6.8	46	42
ARKWRIGHT *	3.1	3.1	5.3	5.3	64.5	64.5
LOW ASH	1.1	1.1	6.4	5.5	82	80
ROBENA	1.8	1.8	5.9	5.4	74	76

* STANDARD

TABLE 3.1* ELEMENTAL CONCENTRATIONS IN COAL SAMPLES

*From MITNE-125

and is 0.75:1 for the PuBe source. This indicates that the accuracy for the S determination will be somewhat better if the Cf^{252} is used. Of course the strong carbon line at 4445 keV due mostly to the PuBe source is greatly reduced when Cf^{252} is used.

4.2 Iron Ore Sinter

Measurements similar to the ones made above on coal were also carried out on some iron ore sinter. In such measurements it would be particularly valuable if the silicon content of the ore could be determined. The results of these measurements showed that the only prominent lines in the spectra were from the iron. A small inelastic line from oxygen was visible and a weak hydrogen line could also be seen. These rather poor results are due partly to the fact that the sinter contains only very small amounts of light elements that can slow down the neutrons. This results in a rather low neutron capture probability in the sample.

To overcome the above difficulty one of the sinter samples was saturated with water. This is not a completely impractical measurement since in some steps of at least some commercial processes the ore is pumped as a water slurry. As would be expected this considerably improved the peak to background ratio in the spectrum. Of course the spectrum is still dominated by the iron peaks but a few weak peaks of silicon could be identified. Unfortunately a number of the silicon peaks fall very close to prominent iron peaks and the few that don't appear to be too weak to offer any real possibility of using them for quick accurate analysis.

V. THESES AND PUBLICATIONS

5.1 Theses

This research contract supported in whole or in part the following thesis research.

1. Prompt Gamma Ray Spectra Produced by Neutrons from a Plutonium-Beryllium Source. David P. Simonson, S.M. Thesis, August 1968.
2. Study of Gamma Rays from Neutron Inelastic Scattering. Bertram H. Hui, S.M. Thesis, September 1969.
3. Investigation of Elemental Analysis Using Neutron-Capture Gamma-Ray Spectra. John N. Hamawi, Ph.D. Thesis, September 1969.
4. Prompt Activation Analysis of Coal and Iron Ore Robert W. Schaefer Jr., S.M. Thesis, August 1970.

5.2 Publications

1. Neutron Capture Gamma Rays of 75 Elements Listed In Terms of Increasing Gamma-Ray Energy, by J.N. Hamawi and N.C. Rasmussen. October 1969. MITNE-105
2. Study of Gamma Rays from Neutron Inelastic Scattering by B.H. Hui and N.C. Rasmussen, February 1970. MITNE-112.
3. Investigation of Elemental Analysis Using Neutron-Capture Gamma Ray Spectra. J.N. Hamawi and N.C. Rasmussen. September 1969. MITNE-107
4. Prompt Activation Analysis of Coal and Iron Ore by R. W. Schaefer Jr. and N.C. Rasmussen, August 1970. MITNE-125

5. "The Potential of Prompt Activation Analysis in Industrial Processing" by Norman C. Rasmussen. Analysis Instrumentation, Volume 7, 1969. Presented at the 15th AID Symposium, New Orleans, La., May 1969.

6. "Integral Gamma-Ray Production Cross Section Measurements with a Pu-Be Neutron Source" by V.C. Rogers, D.C. Hedengren, M.W. Perkins, N.C. Rasmussen and B.H. Hui. Trans. American Nuclear Society, Volume 13, Number 2, November 1970 (p. 864).

VI. PATENTS

The principal investigator feels that no patentable discoveries have resulted from this work.