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TRACE ELEMENT ANALYSIS OF COAL BY NEUTRON ACTIVATION

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ABSTRACT

The irradiation, counting, and data reduction scheme is described for an analysis capability of 1000 samples per year. Up to 56 elements are reported on each sample. The precision and accuracy of the method are shown for 25 elements designated as "hazardous" by the Environmental Protection Agency (EPA). The interference corrections for selenium and ytterbium on mercury and ytterbium on selenium are described. The effect of bromine and antimony on the determination of arsenic is also mentioned. The use of factorial design techniques to evaluate interferences in the determination of mercury, selenium, and arsenic is shown. Some typical trace element results for coal, fly ash, and bottom ash are given.

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INTRODUCTION

This report presents the technology methods used at the NASA Plum Brook reactor (PBR) to analyze coal by neutron activation analysis. The work was performed for the Environmental Protection Agency (EPA) Division of Air Surveillance at Research Triangle Park, North Carolina, by the NASA Plum Brook reactor at Sandusky, Ohio, under an interagency agreement. Unfortunately, the work was terminated in January 1973 when the Plum Brook reactor was closed.

The general scheme of analysis - sample preparation, irradiation, and sample counting - is described. The discussion of data reduction includes the computerized method, interference corrections, and the precision and accuracy of the method. Some typical trace element results are given for coal, fly ash, and bottom ash. The manpower requirement for the analysis of 1000 samples per year is stated.

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THE ANALYSIS SCHEME

Figure 1 shows the overall analysis scheme used at PBRF to analyze coal and fly ash samples by neutron activation analysis (NAA). (These same techniques and methods, with only slight modification, were used for the NAA of kerosene, jet fuel, gasoline, fuel oil, residual oil, ore, air particulates on filters, bottom ash, sand, clam tissue, corn, cement, limestone, stack scrubber water, crab shells, and river water.)

The basic procedure used two aliquots of the sample. One aliquot was encapsulated in a polyethylene vial, the other in a synthetic quartz (Suprasil) vial. The polyethylene vial, containing 50 to 100 milligrams of coal (10 mg or less of fly ash), was irradiated for 5 minutes in a thermal neutron flux of 1.5×10^{14} n/cm^2/sec. Then the irradiated sample was counted at decay times of ~5 minutes, ~30 minutes, and 24 hours. The quartz vial was irradiated for 12 hours in the same flux and counted at about 3 weeks decay.

Samples were counted on a 4096 channel gamma ray spectrometer using a Ge (Li) detector with a crystal diameter of 35 mm and length of 27 mm. Acceptable counting distances ranged from 3 to 40 cm, with detector dead time restricted to <20% whenever possible. The detector resolution was 3 keV with linearity adjusted to 1 keV/channel and maintained at ±1 channel or less.

DATA REDUCTION

Altogether there were two irradiations associated with each pollution sample, and four counts - 5 minutes, 30 minutes, 24 hours, and 3 weeks decay. Each count of each aliquot produced a paper tape. Each tape, along with information regarding decay time, count time, flux level, sample weight, counting distance, and other parameters was processed through the data reduction code "SPECTRA."[1] Computing time on an IBM 360 Mod 67 was under 1 minute for all four tapes associated with one sample. Data were reported to EPA as parts per million of each trace element in the sample.

INTERFERENCE CORRECTIONS

EPA designates the elements Hg, Se, As, as "very hazardous." As a result, we devoted much attention to the accurate determination of these four elements by NAA. We found that, in coal, both selenium and ytterbium interfered with the detection of mercury; ytterbium interfered with selenium; and bromine and antimony interfered with arsenic.

The appendix to this paper describes how factorial experiment design techniques were used to derive empirical correction factors needed for the accurate determination of Hg, Se, and As.

PRECISION AND ACCURACY

Table 1 shows the standard deviation and the range of counting precision associated with the determination of trace elements in coal. The standard deviation is based on five aliquots.

Table 2 provides information on the accuracy of the NAA methods. Results of NAA of NBS standard reference materials (trace elements in a glass matrix) are compared with certified and interim NBS values. Other elements reported to EPA were frequently checked with homemade standards and with standards submitted by EPA.

TYPICAL TRACE ELEMENT RESULTS

Tables 3.1 to 3.4 show the form of computer outputs typically obtained, one for each of the four spectra associated with one sample. The data include the PBR sample number, the EPA identification number, and the input data required for the computerized data reduction. The third column shows the 56 elements that were routinely reported. Column four gives the results in ppm, and column 5 gives the standard deviation at 1σ in ppm.

Typical results are tabulated in table 4 for seven coal samples, bottom ash, and fly ash. The results are given in ppm. The elements are listed along with the isotopes actually detected. Examination of the data shows that calcium, cerium, iron, aluminum, barium, potassium, manganese, sodium, rubidium, tin, titanium, thorium, uranium, vanadium, and zirconium are concentrated in fly ash. An additional comment regarding uranium and thorium: these elements are naturally radioactive and are α-emitters. For each ton of coal burned, the potential hazard exists of emitting 0.3 curies of α-activity, based on 1 ppm of uranium in coal.

No element in table 4 shows a higher concentration in the bottom ash than in the fly ash.

THE ANALYSIS CAPABILITY

The analysis capability developed at the Plum Brook reactor was geared to analyze 1000 samples per year as a part time effort. The program was also geared to developing the technology to handle and irradiate a large variety of pollution related samples with a minimum of manpower. During a typical work week, 24 samples were irradiated, counted, and reported. Total manpower expended averaged 3.0 to 3.5 hours per sample. Computer running time amounted to approximately 1 minute per sample with 56 elements reported.

CONCLUDING REMARKS

The trace element analysis of coal using NAA has been shown to be an accurate, reliable, and instrumental method of analysis. The associated technology was also developed to permit the analysis of up to 56 trace elements in each of 1000 samples

per year as a part-time effort. Computerized data reduction reduced the total manpower required to 3.0 to 3.5 hours per sample.

APPENDIX - INTERFERENCE CORRECTIONS FOR MERCURY, SELENIUM, AND ARSENIC

by Anne Bodnar

The elements Hg, Se, As, and Cd are designated as "very hazardous" by EPA. This appendix describes the method used to derive the complex correction factors required to achieve an accurate determination of Hg, Se, and As by NAA. Cadmium did not require any special interference corrections.

We detected an accuracy problem with the determination of Hg in coal. A count at 5 to 6 weeks decay time produced a Hg result ranging from 2 to 10 times smaller than the value obtained at 3 weeks decay. A correction for Se interference on Hg was being made, but, because of the similarity in the half-lives of Hg^{203} and Se^{75}, the low Hg results at 6 weeks decay could not be explained.

A search of the Nuclear Data Tables[2] produced another interference: 4.2-day Yb^{175}. Not only did the 282-keV peak of Yb^{175} interfere with Hg^{203}, but also the 400.7-keV peak of Se^{75} interfered with the 396-keV peak area of Yb^{175}, which was used for the Yb correction on Hg^{203}. In addition, another Yb isotope, 32-day Yb^{169} interfered with the 264-keV peak area of Se^{75}, which is used in the correction on Hg^{203} (peak area at 279 keV). These discrepancies were not eliminated by using theoretical corrections.

Finally, the problem was resolved by irradiating standards and mixtures of standards in a factorial experiment. The experiment design was a full factorial experiment with three variables (Hg, Se, Yb) at two levels, with replication, and with a center point added to test higher order effects. The high level was selected as 100 micrograms (μg), the low level as 10 μg. Table A-1 shows the treatments that were used.

Regression analysis on the data was used to estimate the coefficients in a predictive model equation. The dependent variable was chosen as the difference between the computer calculated value for Hg (or Se or Yb) and the true value. Independent variables were the other two elements plus plausible interactions (e.g., the interaction of Se-Yb on Hg). The coefficients derived for the predictive equations served as the basis for the empirical correction of Yb on Se and vice versa, and Yb-Se on Hg. Table A-2 compares the theoretical correction factors with the final form of the corrections based on the empirical data. A special subroutine was added to the SPECTRA computer program. The program was then tested by irradiating and analyzing other known samples. The calculated values agreed with the known sample contents. The method now allows us to determine Se and Hg in the presence of interferences which may be ten times greater in quantity.

This same technique has been used to determine arsenic in the presence of bromine and antimony.

REFERENCES

1. G. A. Borchardt, G. E. Hoagland, and R. A. Schmitt, J. Radioanalyt. Chem., 6, 241 (1970).

2. Anon., "Nuclear Data Tables," Academic Press, New York, N.Y.

TABLE A-1

Treatment	Se	Hg	Yb
1	-1	-1	-1
2	+1	-1	-1
3	-1	+1	-1
4	-1	-1	+1
5	+1	+1	-1
6	-1	+1	+1
7	+1	+1	+1
8	+1	-1	+1
Replicates			
4	-1	-1	+1
7	+1	+1	+1
8	+1	-1	+1
Center point	CP	CP	CP

(-1) indicates low level, 10 μg

(+1) indicates high level, 100 μg

CP indicates $\left(\frac{\text{High level + low level}}{2}\right)$

TABLE A-2

1. Theoretical corrections for Se and Yb interferences on Hg

1. $A_c = A_u - 0.0369\ X$

2. $B_c = B_u - 0.118\ A_c$

3. $D_c = D_u - 0.959\ B_c - 0.387\ A_c$

2. Empirical form of Se and Yb correction factors for interference on Hg

1. $A_c = A_u - 0.0433\ X$

2. $B_c = 0.443(B_u - 0.118\ A_c)$

3. $D_c = D_u - 1.65\ B_c - 0.387\ A_c$

where A_c = selenium 264.6 KeV area corrected for Yb^{169}

A_u = net area of selenium (264.6 KeV), uncorrected

X = net area of Yb^{169} at 177.2 KeV

B_c = ytterbium 396.1 KeV area corrected for selenium (264.6 KeV)

B_u = net area of ytterbium (396.1 KeV) uncorrected

D_c = mercury 279.1 KeV area corrected for selenium and ytterbium

D_u = net area of mercury (279.1 KeV) uncorrected

TABLE 1. - PRECISION OF EPA ROUND ROBIN COAL SAMPLE

Element	ppm	% std dev (1σ)	Range of counting precision at 1 std dev, %
Ti	1 312	12	10-20
V	36	11	5-10
Al	15 700	9	0.6-1
S	<30 500	50	------
U	0.98	8	8-12
Ba	340	12	5-8
Sr	93	10	8-11
I	2.8	14	12-30
Mn	38	7	0.5
Mg	890	28	12-33
Na	370	9	2-3
Cl	750	10	2
Ca	4 070	14	8-15
Cu	14	6	3-5
As	5.9	9	10-12
Br	20.	15	9-12
K	3 500.	10	3-4
Cd	<55	23	-----
Ce	17.3	5	1-2
Se	3.8	13	25-33
Hg	0.95	10	7-40
Cr	19	4	3-5
Cs	2.6	3	8-10
Ag	<0.4	25	-----
Zr	<70	55	-----
Zn	7.5	--	33
Fe	7 520	2	1
Co	5.5	15	1-13
Sb	6.4	24	8-15
Ni	<65	31	-----

TABLE 2. - COMPARISON OF NBS STANDARD REFERENCE MATERIALS WITH PBR RESULTS

	NBS 610*/PBR	NBS 612/PBR	NBS 614/PBR	NBS 616/PBR
Antimony	---	---	(1.06)/1.1±.1	0.078±.007/0.12±.02
Cerium	---	(39)/37±2	---	---
Cobalt	(390)/135±14	(35)/31±1	0.73±0.02/0.59±.006	---
Europium	---	(36)/26±1	0.99±.04/1.1±.6	---
Gold	(25)/20±2	(5)/4.7±1	(0.5)/1.0±.8	---
Lanthanum	---	(36)/35±15	0.83±.02/<2	---
Thorium	---	37.6±.09/31.2±1	0.746±.007/0.58±.15	0.025±.004/0.018±.002
Scandium	---	---	0.59±.04/0.68±.23	0.026±.012/0.020±.004
Silver	(254)/180±80	22.0±.8/31±7	0.46±.02/0.57±.07	---

*NBS values in parentheses are interim values for various reasons. Others are certified values.

TABLE 3.1 - TYPICAL INPUT AND OUTPUT DATA

```
 SAMPLE NUMBER   2685
---EPAFA1280


          DECAY TIME            810.    SEC.
          COUNT TIME            200.    SEC.
          SAMPLE MASS      0.4400E-01   GRAMS
          DEAD TIME   32.00   %
          LENGTH OF IRRADIATION TIME          300.0   SEC.
          FLUX LEVEL      0.1720E 15   NT. PER SQ.CM. PER SEC.
          DISTANCE    10.0CM.
          AREA OF FILTER IRRADIATED           0.000   SQ.CM.
          TOTAL AREA OF FILTER          0.000   SQ.CM.
          VOLUME OF AIR FILTERED    0.00000000        CUBIC METERS
          KSUPRA    4
RDG 2685 , ---EPAFA1280 ,  RH          ,      0.58629274E-01 ,  0.68124980E-02
RDG 2685 , ---EPAFA1280 ,  TI          ,      0.32399634E 03 ,  0.43813904E 02
RDG 2685 , ---EPAFA1280 ,  V           ,      0.12669642E 02 ,  0.68239158E 00
RDG 2685 , ---EPAFA1280 ,  AL          ,      0.34132515E 04 ,  0.44224457E 02
RDG 2685 , ---EPAFA1280 ,  S           , E <  0.74391914E 04 ,  0.49796406E 04
```

TABLE 3.2 - TYPICAL INPUT AND OUTPUT DATA

SAMPLE NUMBER 2687
---EPAFA1280

DECAY TIME 2775. SEC.
COUNT TIME 1000. SEC.
SAMPLE MASS 0.4400E-01 GRAMS
DEAD TIME 20.00 %
LENGTH OF IRRADIATION TIME 300.0 SEC.
FLUX LEVEL 0.1720E 15 NT. PER SQ.CM. PER SEC.
DISTANCE 10.0CM.
AREA OF FILTER IRRADIATED 0.000 SQ.CM.
TOTAL AREA OF FILTER 0.000 SQ.CM.
VOLUME OF AIR FILTERED 0.00000000 CUBIC METERS
KSUPRA 4

RDG 2687	---EPAFA1280	U		0.57538927E 00	0.76583624E-01
RDG 2687	---EPAFA1280	DY		0.57757938E 00	0.11211038E-01
RDG 2687	---EPAFA1280	BA		0.58969208E 02	0.60901299E 01
RDG 2687	---EPAFA1280	SR		0.39513138E 02	0.71572199E 01
RDG 2687	---EPAFA1280	I	<	0.25789185E 01	0.50899118E 00
RDG 2687	---EPAFA1280	MN		0.31050940E 01	0.68131626E-01
RDG 2687	---EPAFA1280	NA		0.24354018E 03	0.64180508E 01
RDG 2687	---EPAFA1280	CL		0.11268865E 04	0.20264618E 02
RDG 2687	---EPAFA1280	TE		0.12514082E 02	0.45227633E 01
RDG 2687	---EPAFA1280	GE	<	0.42372360E 02	0.27317642E 02
RDG 2687	---EPAFA1280	IN	<	0.16031872E-01	0.82265325E-02
RDG 2687	---EPAFA1280	MG	<	0.22164131E 04	0.10726028E 04
RDG 2687	---EPAFA1280	CA		0.13337019E 04	0.29988428E 03

TABLE 3.3 - TYPICAL INPUT AND OUTPUT DATA

```
 SAMPLE NUMBER   2694
---EPAFA1280


          DECAY TIME        68600.    SEC.
          COUNT TIME         1000.    SEC.
          SAMPLE MASS      0.4400E-01   GRAMS
          DEAD TIME   10.00   %
          LENGTH OF IRRADIATION TIME          300.0   SEC.
          FLUX LEVEL      0.1720E 15   NT. PER SQ.CM. PER SEC.
          DISTANCE     3.0CM.
          AREA OF FILTER IRRADIATED          0.000   SQ.CM.
          TOTAL AREA OF FILTER          0.000   SQ.CM.
          VOLUME OF AIR FILTERED    0.00000000        CUBIC METERS
          KSUPRA    4
RDG 2694 , ---EPAFA1280 ,  SM          ,      0.69226021E 00 ,  0.36308378E-01
RDG 2694 , ---EPAFA1280 ,  EU          ,      0.16409475E 00 ,  0.23647603E-01
RDG 2694 , ---EPAFA1280 ,  TB          ,      0.12648592E 01 ,  0.19465458E 00
RDG 2694 , ---EPAFA1280 ,  AU          ,  C<  0.21256655E 00 ,  0.39333303E-01
RDG 2694 , ---EPAFA1280 ,  CU          ,      0.72881899E 01 ,  0.35303468E 00
RDG 2694 , ---EPAFA1280 ,  AS          ,      0.18097029E 01 ,  0.51812541E 00
RDG 2694 , ---EPAFA1280 ,  BR          ,      0.34650284E 02 ,  0.18843575E 01
RDG 2694 , ---EPAFA1280 ,  GA          ,      0.17451668E 01 ,  0.61991853E 00
RDG 2694 , ---EPAFA1280 ,  K           ,      0.21976392E 03 ,  0.73871231E 02
RDG 2694 , ---EPAFA1280 ,  LA          ,      0.49075308E 01 ,  0.54219288E 00
RDG 2694 , ---EPAFA1280 ,  PT          ,  E <  0.90368561E 02 ,  0.69488037E 02
RDG 2694 , ---EPAFA1280 ,  W           ,  E <  0.14073496E 01 ,  0.65515435E 00
RDG 2694 , ---EPAFA1280 ,  GD          ,  E <  0.18515747E 02 ,  0.18053726E 02
RDG 2694 , ---EPAFA1280 ,  CD          ,  E <  0.59213211E 02 ,  0.54743378E 02
RDG 2694 , ---EPAFA1280 ,  RE          ,  E <  0.97890139E-01 ,  0.60177512E-01
RDG 2694 , ---EPAFA1280 ,  MO          ,  E <  0.65644312E 03 ,  0.39779175E 03
```

TABLE 3.4 - TYPICAL INPUT AND OUTPUT DATA

SAMPLE NUMBER 2701
---EPAFA1280

DECAY TIME 2160000. SEC.
COUNT TIME 4000. SEC.
SAMPLE MASS 0.4085E 00 GRAMS
DEAD TIME 13.00 %
LENGTH OF IRRADIATION TIME 43200.0 SEC.
FLUX LEVEL 0.1190E 15 NT. PER SQ.CM. PER SEC.
DISTANCE 3.0CM.
AREA OF FILTER IRRADIATED 0.000 SQ.CM.
TOTAL AREA OF FILTER 0.000 SQ.CM.
VOLUME OF AIR FILTERED 0.00000000 CUBIC METERS
KSUBRA 1

RDG 2701	---EPAFA1280	CE		0.72096167E 01	0.10686743E 00
RDG 2701	---EPAFA1280	LU		0.17842478E 00	0.13465714E-01
RDG 2701	---EPAFA1280	SE		0.25705500E 01	0.64358050E 00
RDG 2701	---EPAFA1280	HG	<	0.64538258E 00	0.12052262E 00
RDG 2701	---EPAFA1280	TB		0.12754779E-01	0.62869885E-03
RDG 2701	---EPAFA1280	TH		0.95413691E 00	0.18919755E-01
RDG 2701	---EPAFA1280	CR		0.83224478E 01	0.27451819E 00
RDG 2701	---EPAFA1280	HF		0.30085230E 00	0.18846393E-01
RDG 2701	---EPAFA1280	ND	E <	0.27277546E 01	0.13943005E 01
RDG 2701	---EPAFA1280	ZR		0.38244324E 02	0.14130380E 02
RDG 2701	---EPAFA1280	CS		0.40247416E 00	0.54329596E-01
RDG 2701	---EPAFA1280	SC		0.16070576E 01	0.52692741E-02
RDG 2701	---EPAFA1280	RB		0.32748070E 01	0.60219342E 00
RDG 2701	---EPAFA1280	ZN		-0.36989384E 01	-0.10403924E-01
RDG 2701	---EPAFA1280	TA		0.10774279E 00	0.20200226E-01
RDG 2701	---EPAFA1280	FE		0.26460225E 04	0.22373123E 02
RDG 2701	---EPAFA1280	CO		0.35183659E 01	0.29760309E-01
RDG 2701	---EPAFA1280	SB		0.95392728E 00	0.92135251E-01
RDG 2701	---EPAFA1280	AG	E <	0.13639234E 00	0.96802831E-01
RDG 2701	---EPAFA1280	SN		0.16124039E 02	0.42969913E 01
RDG 2701	---EPAFA1280	NI		0.33774506E 02	0.12184061E 02
RDG 2701	---EPAFA1280	YB		0.76171124E 00	0.13029099E 00

TABLE 4. - ENVIRONMENTAL PROTECTION AGENCY SAMPLES* - COAL, FLY ASH, AND BOTTOM ASH

Element/ isotope	Coal L-14	Coal L-15	Coal L-16	Coal L-17	Coal L-18	Coal L-19	Coal L-20	Bottom ash L-21	Fly ash L-22	Fly ash L-23
Ag^{110M}	<0.9	<0.7	<0.6	<0.6	<0.2	<0.2	<0.3	<0.2	<0.4	<2
Al^{28}	17 200	8 080	13 300	12 100	10 800	6.170	27 600	67 500	89 600	99 700
As^{76}	7.00	<1.2	4.8	<5	2.44	1.6	<6	<5	<7	<6
Au^{198}	0.003	0.10	0.07	0.15	0.06	0.02	<0.4	<0.5	<2	<2
Be^{139}	92	34	48	53	45	29	565	1500	1641	2370
Br^{82}	20	3	22	19	9.0	16	<20	<15	<50	<30
Ca^{49}	7 740	3 640	5640	<5 000	3290	1910	5960	14 300	23 200	26 200
Cd^{115}	<300	<110	<110	<90	<200	<30	<100	<900	<1200	<2000
Ce^{141}	21.1	8.83	16.2	13.0	10.6	8.97	28.0	71.8	104	103
Cl^{38}	2820	1220	2760	1450	1250	2350	189	94	<200	168
$Ni(Co^{58})$	<90	<30	<80	<70	<60	<30	<20	<50	<80	<50
Co^{60}	5.98	3.07	5.22	4.40	3.84	4.02	1.92	4.72	6.6	6.8
Cr^{51}	24.2	18.0	21.4	19.4	19.3	12.2	5.26	14.8	22	21
Cs^{134}	3.32	1.56	2.58	2.35	2.03	1.13	0.92	2.81	4.4	4.1
Cu^{64}	<30	29	<20	<20	<20	<20	<50	37	57	70
Dy^{165}	1.2	0.58	0.76	0.77	0.67	0.42	0.90	2.0	2.8	3.50
Eu^{152ml}	0.56	0.2	0.32	0.31	.30	.18	.36	0.91	1.2	1.5
Fe^{59}	8970	13 700	9500	10 900	11 600	4550	6150	20 000	24 400	23 600
Ga^{72}	7.2	<2	4.0	4.2	5.5	2.9	<6	<2	<30	<30
Ge^{75}	<70	<4	<120	<40	<150	<150	<20	<200	<300	<400
Hf^{181}	1.05	0.50	0.81	0.65	0.60	0.42	2.28	6.50	8.5	8.7
Hg^{203}	<0.7	<0.5	<0.6	1.91	0.16	<0.3	<0.5	<0.7	<0.9	<0.9
Gd^{159}	<70	<60	<40	<30	<40	<20	<80	<120	<140	<400
I^{128}	<0.2	<1	<0.5	1.8	<2	0.65	<2	<1	<2	<20
In^{116mI}	<0.05	<0.03	<0.02	0.073	0.029	<0.01	<0.05	<0.07	<0.02	<0.07

*The EPA could not reveal the source of these samples.

TABLE 4. - Continued. ENVIRONMENTAL PROTECTIVE AGENCY SAMPLES - COAL, FLY ASH, AND BOTTOM ASH

Element/ isotope	Coal L-14	Coal L-15	Coal L-16	Coal L-17	Coal L-18	Coal L-19	Coal L-20	Bottom ash L-21	Fly ash L-22	Fly ash L-23
Ir^{192}	5.3	1.9	2.2	6.7	1.6	1.8	7	11	9.8	13
K^{42}	7130	2464	3932	3748	3420	1690	1810	7170	9064	9800
La^{140}	17.2	5.7	7.2	26	7.3	5.4	20	29	25	57
Lu^{177}	0.58	0.36	0.42	0.32	0.35	0.22	0.51	1.23	1.6	1.8
Mg^{27}	<450	<850	<1200	<4000	585	<600	1320	<11 000	2400	<9000
Mn^{56}	95	53	62	49	38	25	93	300	371	422
Mo^{99}	<600	<700	<260	<350	<300	<200	<3100	<2200	<13 000	<6000
Na^{24}	1250	882	1070	833	757	487	2850	6080	8430	14 000
Nd^{147}	<7	<2	<2	<5	<7	<3	<7	<10	<40	<30
Pt^{197}	<300	<170	<160	<230	<200	<100	<1000	<700	<1400	<3200
Rb^{86}	25.6	12.3	20.7	21.4	16.8	7.98	8.66	15.9	45	41
Re^{188}	<0.3	<0.2	<0.2	<0.3	<0.4	<0.3	<0.5	<2	<1	<0.4
Rh^{104}	<0.03	<0.09	<0.04	<0.2	<0.06	<0.06	<0.07	<0.3	<4	<0.3
S^{37}	*	37 500	<53 000	<7 000	<9000	<30 000	<200 000	168 000	<200 000	<300 000
Sc^{46}	4.56	2.67	3.84	3.42	3.17	2.07	3.02	7.42	11.4	11.7
Sb^{124}	1.39	0.84	1.12	0.93	0.62	0.86	0.80	0.50	2.1	1.8
Se^{75}	4.15	3.12	2.99	3.19	2.86	1.77	3.07	2.10	5.98	5.72
Sm^{153}	2.23	0.82	1.2	1.2	1.1	0.81	1.5	3.5	4.4	4.9
Sr^{87m}	56	<30	36	<20	<40	<20	106	<100	223	<200
Sn^{117m}	76.5	<40	74.2	66	50	34	86	428	555	422
Ta^{182}	0.35	0.12	0.27	0.25	0.18	0.17	0.65	1.66	2.4	2.4
Tb^{160}	0.036	0.018	0.027	0.025	0.022	0.015	0.048	0.12	0.18	0.18
$Th(Pa^{133})$	4.19	2.16	3.23	2.84	2.84	1.73	7.49	19.1	25	25

*Data missing.

TABLE 4. - Concluded. ENVIRONMENTAL PROTECTIVE AGENCY SAMPLES - COAL, FLY ASH, AND BOTTOM ASH

Element/ isotope	Coal L-14	Coal L-15	Coal L-16	Coal L-17	Coal L-18	Coal L-19	Coal L-20	Bottom ash L-21	Fly ash L-22	Fly ash L-23
Ti^{51}	1680	912	608	980	908	529	893	3820	4280	3428
U^{239}	1.5	0.96	0.82	1.14	0.82	0.68	1.3	3.7	4.7	4.9
V^{52}	34	23	26	27	23	15	18	29	65	64
W^{187}	<4	<0.3	<0.4	<2	<2	<2	<20	<15	<20	<30
Yb^{175}	3.68	1.88	4.06	1.83	0.46	0.91	0.84	2.36	3.8	2.9
Zn^{65}	264	<3000	220	148	118	<400	<2000	187	299	341
Zr^{95}	<50	<50	<50	<40	<50	<30	107	261	400	556

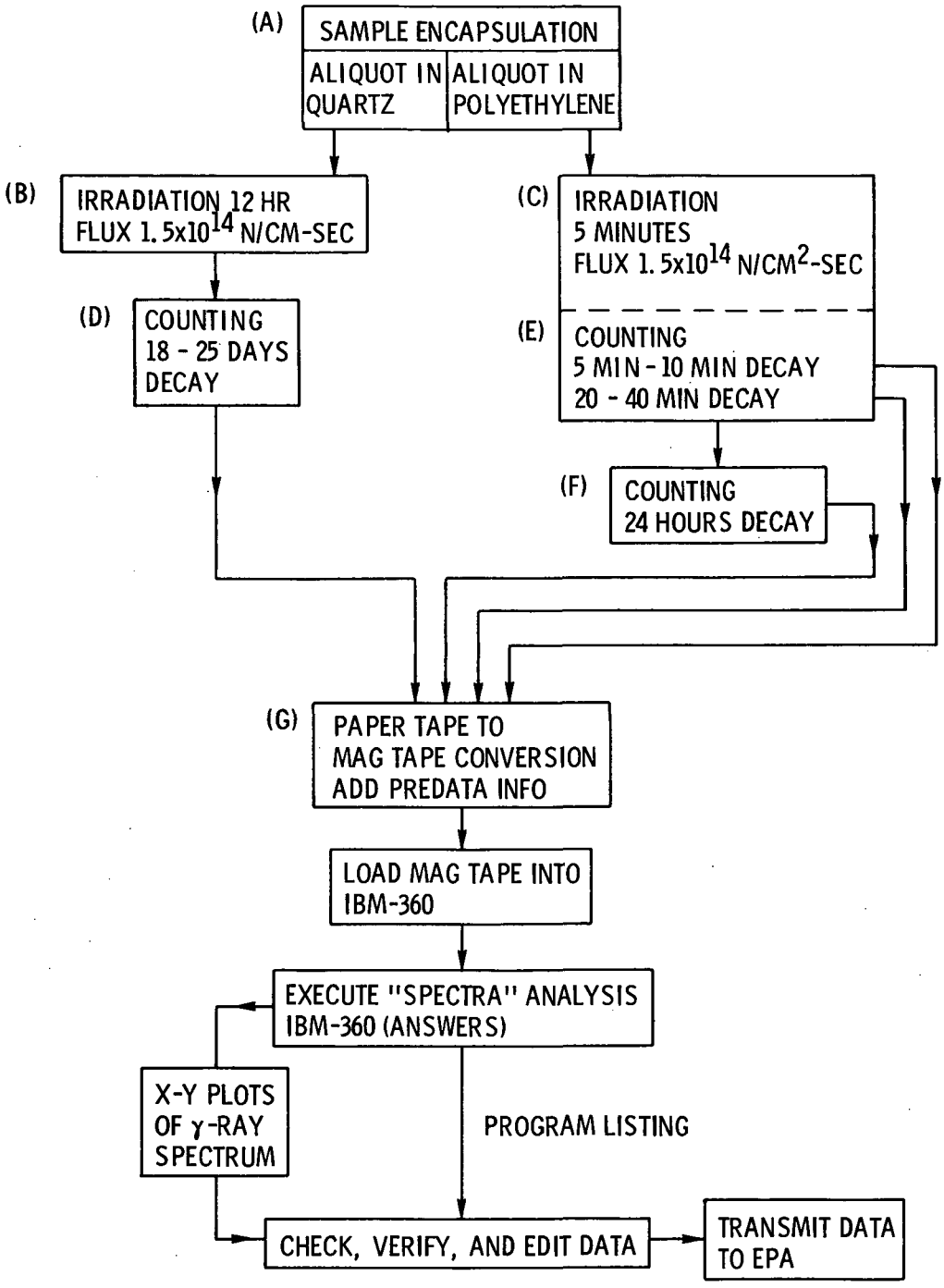

Figure 1. - Flow chart showing scheme for sample irradiation, counting, and data reduction of coal samples.