

超热中子活化分析用于燃煤电厂对环境土壤污染的研究

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关键词: 超热中子 活化分析 电厂 环境 土壤

大燃煤电厂每天由烟囱排出的粉尘(飞灰)有几十吨,通过干沉降与湿沉降,它们最终将落在周围土壤表面上。由于地质构成上的不同,一般土壤中的元素浓度与煤飞灰中的元素浓度是不同的,大量飞灰的下落,以及雨水的冲刷、渗透,可能会改变土壤中原有元素的浓度,从而影响人体健康。这是人们关心的问题。

为了搞清燃煤电厂排出物对周围环境的污染程度,在雨季前、后,我们对山西一电厂(装机容量 550MW)周围深层与表层土壤中的微量元素浓度进行了中子活化分析。由于土壤中 Na 含量高,使用通常的中子活化分析时,Na 形成的活度大,对测量其它中长寿命元素不利。为了降低这种干扰,我们采用非破坏性的超热中子活化分析法,通过对土壤中 22 种微量元素的浓度的分析,判断燃煤电厂排出物对环境土壤的影响程度。

一、原 理

中子活化分析可以是热中子活化和超热中子活化。样品中某个核的反应速率 R 为:

$$R = \phi_t \sigma_t + \phi_e I$$

式中, ϕ_t 为热中子通量; ϕ_e 为超热中子通量; σ_t 为热中子活化截面; I 为共振积分活化截面。

超热中子活化分析在辐照时,样品包在锡盒中,锡吸收了热中子,某个核的反应速率 R_e 为:

$$R_e = \phi_e I$$

核素活化后产生的放射性同位素强度正比于反应速率,若在同一孔道中辐照样品,超热中子活化后产生的某放射性同位素的强度 A_e 与通常的堆中子活化后产生的该放射性同位素的强度 A 之比为:

$$A_e/A = R_e/R = \phi_e I / (\phi_t \sigma_t + \phi_e I)$$

又, ϕ_e/ϕ_t 为反应堆中子谱指标,在确定的堆孔道中(功率一定时),它是常数;设 $\alpha = \phi_e/\phi_t$,某核素的 σ_t 和 I 都是定值;设 $\beta = I/\sigma_t$,则

$$A_e/A = \alpha\beta / (1 + \alpha\beta)$$

我们使用的反应堆孔道 $\alpha = 0.02$ 。对于 Na, $\beta = 0.59$, $A_e/A = 0.012$;而对于 U, $\beta = 102$, $A_e/A = 0.67$ 。由此可见,在超热中子活化分析时,Na 形成的活度相对地降低了,从而对某些其它核素容易进行准确的测定。

本工作使用相对比较法,标准用美国国家标准局的标准参考物质 SRM-1633a。

二、取 样

取样点的选择,在主风向的下风向选择两个点:下风 1 (距电厂 4km)、下风 2 (距电厂 6km);在上风向选一个点:上风 1 (距电厂 2km)。

取样时间分别在5月下旬和9月下旬,该地区6—8月降雨量占全年的65%,因此可以说分别在雨季前、后各取样一次。

取样使用土壤取样器,选择未开垦的土壤层。每点每次取两个样,一个是表层土壤(0—5cm),另一个是深层土壤(15—20cm)。

三、辐照与测量

土壤样品经干燥粉碎后,分别称重150mg左右,包好后放入镅盒,在超热中子通量为 $8 \times 10^{10} \text{n/cm}^2 \cdot \text{s}$ 的辐照孔道中辐照10小时。

测量使用高分辨率的Ge(Li) γ 谱仪,共测量两次,一次在出堆后2天进行,分析的元素是As、Ga、K、La、Na、Sb、Sm和U;另一次在出堆后3周测量,分析的元素为Ba、Ce、Co、Cr、Cs、Eu、Fe、Hf、Rb、Sc、Se、Ta、Th和Zn。

表1 雨季前各点土壤中元素的浓度(ppm)

元 素	上 风 1		下 风 1		下 风 2	
	表 层	深 层	表 层	深 层	表 层	深 层
As	9.8	9.6	9.5	11.2	8.6	9.6
Ba	388	456	474	517	695	643
Ce	173	183	179	187	121	149
Co	12.7	11.1	13.1	16.2	9.8	14.0
Cr	31	37	35	32	27	30
Cs	4.2	6.4	5.9	6.0	4.9	6.0
Eu	0.9	—	—	—	0.8	0.6
Fe (%)	2.85	3.65	2.71	2.53	2.79	2.97
Ga	14	13	11	14	12	11
Hf	8.0	4.8	—	7.7	8.4	6.9
K (%)	1.56	1.68	1.62	1.50	1.84	1.56
La	36	42	33	27	38	41
Na (%)	0.93	1.08	1.02	0.97	1.00	0.95
Rb	84	104	78	85	106	112
Sb	1.1	1.0	1.1	1.1	0.9	1.1
Sc	9.9	10.8	9.5	9.8	9.5	9.1
Se	1.7	3.6	2.5	3.3	2.3	3.1
Sm	4.6	5.9	4.8	3.6	4.8	4.1
Ta	0.7	0.6	0.3	0.5	0.5	0.6
Th	10.9	13.1	11.6	9.5	11.5	9.7
U	2.7	2.5	2.2	2.3	2.4	2.3
Zn	46	50	47	54	47	48

四、结果和讨论

1. 雨季前、后各点土壤表层与深层中元素浓度的分析结果分别列于表1和表2。由表1可见,下风向与上风向地区土壤中元素浓度差别不大。由表2可见,雨季后土壤中的元素浓度多数都比雨季前的元素浓度偏低,地表面的元素浓度情况更为显著,说明了雨水的冲刷作用导致了元素的渗透与流失。

2. 我们将雨季前测定的飞灰中相应元素的浓度和世界土壤中相应元素浓度的平均值进行比较(表3)。由表3可见,土壤中Ba、Cs、Fe、K、Na、Rb和Sb的浓度比飞灰中的浓度高,显然不是来自下落的飞灰。土壤中U、Th的浓度与世界土壤的平均值比较看来偏高,我们用土壤中U、Th和天然钾中的 ^{40}K 的平均浓度计算^[1]得出该地区的陆地 γ 辐射空气吸收剂量率为 $6.2 \times 10^{-8} \text{Gy/h}$ 。文献[2]中介绍该地区的 γ 辐射空气吸收剂量率为 $(3.4-7.8) \times$

表2 雨季后各点土壤中元素的浓度(ppm)

元 素	上 风 1		下 风 1		下 风 2	
	表 层	深 层	表 层	深 层	表 层	深 层
As	11.5	12.5	10.3	9.6	6.3	6.8
Ba	249	303	373	310	371	386
Ce	82	87	69	38	94	60
Co	12.9	11.5	10.5	7.6	10.7	6.3
Cr	48	56	40	67	43	24
Cs	5.7	6.1	5.0	4.1	3.7	3.0
Eu	0.3	1.1		1.0	0.8	1.5
Fe (%)	2.20	2.50	1.94	1.86	2.08	1.60
Ga	13	16	12	15	13	13
Hf	4.7	4.0	5.7	6.9	7.2	9.4
K (%)	1.90	2.13	1.62	1.61	1.77	1.61
La	32	36	28	29	36	31
Na (%)	0.90	0.98	0.89	0.88	1.05	0.97
Rb	88	99	80	82	91	69
Sb	1.3	1.2	1.3	1.1	0.7	0.7
Sc	10.1	11.4	8.5	9.3	8.9	8.1
Se	1.9	1.6	1.3	1.9	3.0	1.9
Sm	4.1	4.6	3.8	3.7	4.3	3.9
Ta	0.8	0.9	0.5	1.1	0.4	0.7
Th	9.9	11.5	10.1	9.1	9.7	9.0
U	1.8	2.4	1.8	1.9	1.7	1.8
Zn	53	50	46	47	44	44

10⁻⁶Gy/h,全省平均为6.9×10⁻⁶Gy/h。因此认为,土壤中U、Th的浓度与周围环境中的浓度是一致的。其他元素的浓度多数都低于或接近于世界土壤中浓度的平均值,属于正常范围。

[表 3 飞灰中的元素浓度和世界土壤中元素浓度的平均值^[5]

元 素	飞 灰 (ppm)	世界土壤平均值 (ppm)	元 素	飞 灰 (ppm)	世界土壤平均值 (ppm)
As	7.8	5	La	101	50
Ba	635	500	Na	800	6300
Ce	196	50	Rb	31	100
Co	10.5	8	Sb	0.9	1
Cr	63	100	Sc	22	7
Cs	2.4	10	Se	14	1
Eu	2.3	1	Sm	14	
Fe	24400	38000	Ta	3.2	22
Ga	57	30	Th	55.8	6
Hf	19	6	U	10.5	1
K	3400	13800	Zn	121	50

3. 综上所述,据我们的初步判断,电厂排放的飞灰目前没有对环境土壤中的元素浓度产生明显影响。当然,要得到确切的结论,应尽多地选择取样点,长期进行采样分析。此外,土壤中元素浓度的改变应考虑到流水冲刷、大气、人类活动及施用化肥与农药等其他因素。

参 考 文 献

[1] UNSCEAR(1982)报告,辐射防护通讯,增刊1,115(1983)。
[2] 山西省卫生防疫站,中华放射医学与防护杂志,增刊,10(1985)。
[3] W. S. Lyon, Trace element measurement at the coal-fired steam plant, CRC Press, U. S. 1977,p. 100.
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简 讯

LNW-50A型中子土壤水分计通过省级技术鉴定

1986年12月,江苏农科院原子能所研制的新型中子水分计LNW-50A在南京通过省级鉴定。

该仪器的探测原理是利用快中子与介质中的原子核发生碰撞,使快中子发生散射,其结果是使快中子丢失掉自己的能量,降低了速度,变成了慢中子和热中子。由于氢原子核与快中子的质量基本相等,并且氢核与快中子相互作用的散射面积较大,因此,当快中子遇到含氢量较大的介质时,中子就较快地被慢化,热中子密度也就较大。然后利用⁶Li(锂)玻璃探测器将慢中子检测出来变为微弱的光信号,再通过电子学元件及线路放大和读数,从而知道介质中的水分含量。其关系在一定的水分范围内呈很好的线性相关。

与会专家认为该仪器在兼顾高灵敏度和高分辨率等主要性能上属国内领先并接近国际先进水平。测量误差:当容积含水量为7—30%时,小于1%;大于30%含水量时,小于2%。

该仪器操作方便、耗电省,整机小于60mA,外形尺寸为420×200×200(mm)(高×宽×长),重量11kg。适合野外现场测量土壤含水量,可供农、林、水、地质、建筑、交通等部门研究水分动态变化规律和指导排水、灌溉等。仪器的射线防护符合国家标准,安全可靠。该仪器已由江苏农科院原子能所组织小批量生产。

(江苏农科院原子能所 高国治 林家斌)

neutron activation analysis. The various interferences of nuclides were considered. Corrected factors of the geometry in different positions have been determined. Using the geological standard sample MGM and radiochemical separation neutron activation method as reference, the reliability of this method is proved. Gold content in samples is 0.4—0.009 g/t, silver content is 9—0.3 g/t. Standard deviation is less than 3.5%, the precision of the measurement is 4.8—11.6%.

Keywords: instrument neutron activation analysis geological standard sample

A new expression for neutron activation R (R)-matrix elements

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In the present paper, a new expression for neutron activation R -matrix elements was given. Use $^{175}\text{Yb}(i \text{ or } j) \text{—} ^{169}\text{Yb}(j \text{ or } i)$, $^{153}\text{Gd}(i \text{ or } j) \text{—} ^{159}\text{Gd}(j \text{ or } i)$, $^{103}\text{Ru}(i \text{ or } j) \text{—} ^{97}\text{Ru}(j \text{ or } i)$, or $^{95}\text{Zr}(i \text{ or } j) \text{—} ^{97}\text{Zr}(j \text{ or } i)$ as neutron energy spectrum monitor, j as standard, and R_{ij} as neutron spectrum indicator. Define relative deviation from thermalization: $x = (R_{ij} - 1)/(Q_{0i} - Q_{0j}) \ll 1$, where Q_{0i} and Q_{0j} are the ratios of infinitely dilute resonance integral and thermal neutron capture cross section of i and j respectively. Then, $R_{ij} = 1 + a_i^j x$, $R_{kj} = 1 + \sum_{m=1}^{\infty} a_m^k x^m$, where k represents nuclides other than i and j . R_{kj} series converge rapidly for all k . The accuracy of R_{ij} will not be affected by the errors of Q_{0i} , Q_{0j} and Q_{0k} . The a_m^k 's is determined by experiments with high precision. We use simultaneously four kinds of neutron energy spectrum monitors (also used as standards), use experimental R_{ij} to determine x , and use x and a_m^k 's to calculate R_{kj} , R_{kj} , and B_0^k . Then, very reliable results are obtained. This is the mono-standard or small-number-standards method in the neutron activation analysis.

Keywords: neutron activation R -matrix elements neutron energy spectrum monitor neutron energy spectrum indicator
relative deviation from thermalization mono-standard method
small-number-standards method

Study of the surrounding soil pollution from coal-fired power plant by epithermal neutron activation analysis

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The concentrations of 22 elements in the surrounding soil of coal-fired plant were determined by epithermal neutron activation analysis.

Variations of the element concentration of the surface and depth of soil both before and after rainy season were studied for evaluating the effect of fly ash produced by coal-

fired power plant on the surrounding soil.

Keywords: epithermal neutron activation analysis coal-fired
power plant environment soil

The distribution and background values of trace elements in Jingpo lake water

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The NAA was applied to the multielemental analysis of the lake water taken from the upper, middle and lower reaches of the Jingpo lake. The distribution and the background values of 23 elements(As, Zn, Cr, Fe, Co, Sr, Ba, Rb, Cs, U, Th, Sb, Sc, Se, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu and Au) in lake water were studied. The element contents of various sampling sites indicated that along the horizontal direction the element contents had no significant variation, but in the vertical direction, the content of Fe is increased with increasing depth. The analytical results were compared with the mean values of element contents given in the reference. It is shown that the water in Jingpo lake is out of artificial pollution, but the element contents were strongly influenced by the surrounding natural environment. Therefore the element contents should represent the natural background values of trace elements.

Keywords: neutron activation analysis lake water trace element

^{113m}In isotope used as tracer in the study of underground water flow

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^{113m}In produced by ^{113}Sn - ^{113m}In producer as a tracer has been applied in the study of the movement of underground water flow. TLD made up of $\text{CaSO}_4(\text{Tm})$ in glass tubes has been chosen as nuclear detector to determine the direction of the underground water flow in a borehole. The result shows that ^{113m}In as a tracer to determine the direction of underground water flow is suitable in some special sites such as the rock stratum.

Keywords: direction of underground water flow single borehole tracer
TLD ionization chamber ^{113m}In

Determination of impurities in $^{201}\text{TlCl}$ injection and $^{203}\text{PbCl}$ aqueous solution by ICP-AES

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$^{201}\text{TlCl}$ is an useful radiopharmaceutical. It is widely used to diagnose myocardial disease.