STUDIES ON DETERMINATION AND STANDARDIZATION OF SOME RADIOACTIVE ISOTOPES

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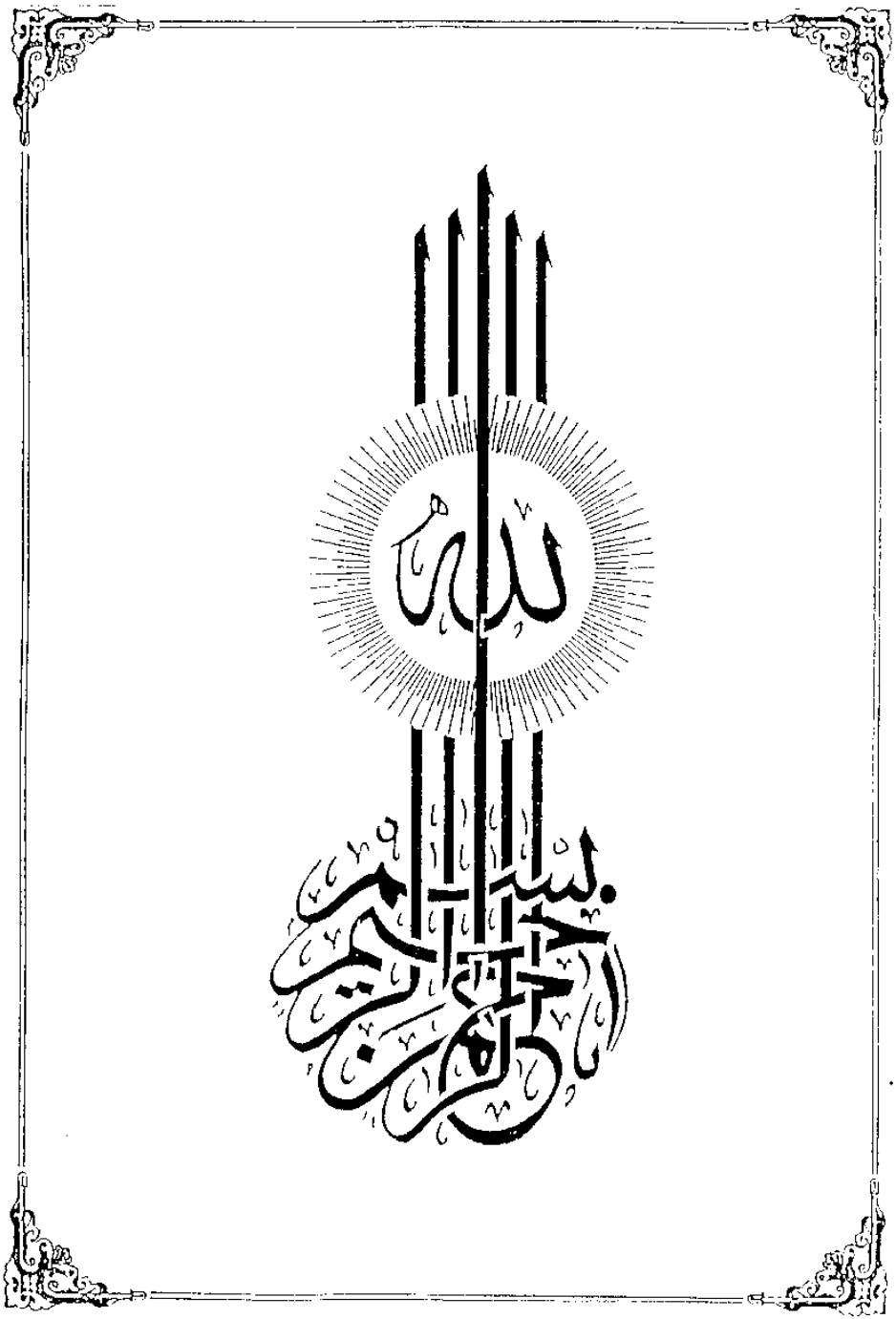

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1. Introduction

This work aims at the accurate determination of the activity of a large ^{60}Co source for the use in different scientific and other purposes. The source was prepared by the irradiation of pure cobalt targets at the Rheinsberg power reactor (WWER-2) in German Democratic Republic and the collection of these irradiated targets was made in the isotope production laboratory at Rossendorf.

1.1 Decay Scheme of ^{60}Co

^{60}Co decays by β-emission to the metastable state ^{60}Ni at 2.5 MeV energy level this metastable state decays to the stable ^{60}Ni through the emission of 2 gamma rays (1.17, 1.33 MeV) in cascade as shown by its decay scheme Fig. 1 [1]. It's β-particles are fairly weak betas of maximum energy 0.310 MeV, which can be fully absorbed through 0.3 mm Al thickness, while the 2 photons are relatively strong gamma rays. The more recent value of ^{60}Co half-life is 5.27 years as given by [2].

Because of its two strong γ-rays, its relatively long half-life (5.27 years) and the possibility of its production in an adequat specific activity, ^{60}Co is attractive as an irradiation source, but of limited interest as an isotopic power source. However, the gamma rays can be absorbed in heavy materials and the resulting heat energy can be used directly for various heating applications.

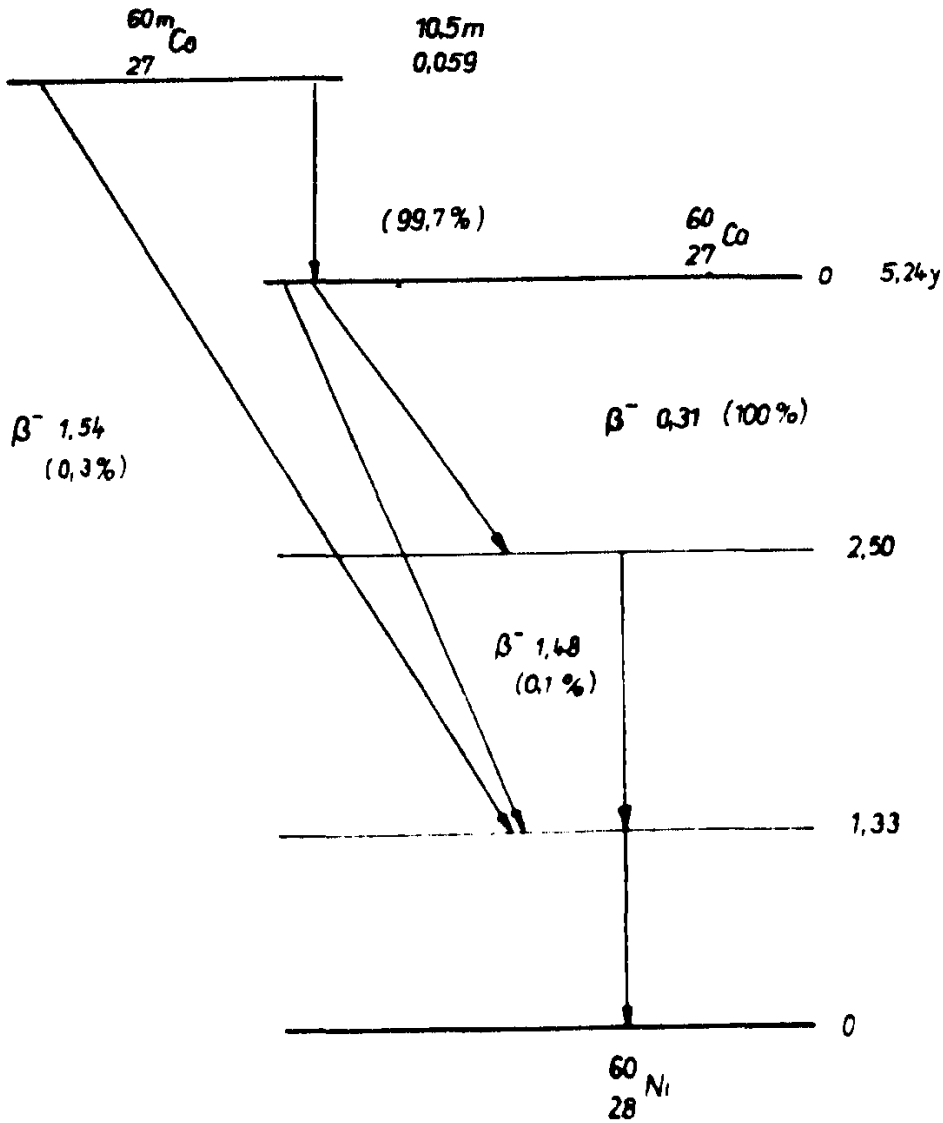

Fig 1 Decay Scheme of ^{60}Co

1.2 ^{60}Co as an Irradiation Source

In the last 20 years large ^{60}Co irradiation sources have gained an increasing international significant value in many industrial, medical, agricultural and scientific research fields.

In industry [3,4] ^{60}Co irradiation sources are used in the different following branches:

- Vulcanization of rubbers and plastics,
- Manufacturing of wood-plastic combinations,
- Applications to textile materials for the modification of its properties,
- Modification of semi-conductor properties,
- Radiation induced syntheses of compounds of biological interest,
- Sterilization in medicine, industry and food reservation,
- Prevention of vegetable germination,
- Polymerization and copolymerization for the production of high molecular compounds,
- Catalization for chemical reactions initiation,
- Hydrogenation of coal and coal products to produce hydrocarbon fuels,
- Pasteurization of vegetables, fruits, fruit juice, meat and fish.

Some of these possible applications are still in the stage of investigations, others like rubber and plastics vulcanization, manufacturing of wood-plastic combinations and modification of textile materials properties are already in the pilot plant pro-

duction in Soviet Union, Great Britain, USA, Japan and Canada.

In medicine [5]: by 1952 it became obvious that the idea of using radioisotopes in teletherapy could be extended in many directions and the production of teletherapy machines has become too widespread.

The rapidly developing realization that shielding is one of the main expenses in the installation of teletherapy machines and the current high price of ^{60}Co forced an investigation into fission-product sources. It was also realized, that the 5.27 years half-life of ^{60}Co is not an ideally long half-life. Cesium-137 was one of the obvious choices for teletherapy with an energy (0.662 MeV) half that of ^{60}Co, the shielding problems were much reduced and with a half-life (37 y) six times that of ^{60}Co the problem of decay was considerably improved. But cobalt-60 is a real clinical advantage due to the following apparent physical advantages:

1. Skin sparing and increased depth dose with ^{60}Co have made radiotherapy more tolerable for the patient.
2. Decreased bone absorption when treating malignant tumours underlying bone due to the increasing depth dose.
3. Radiation sickness is less severe in patients treated with ^{60}Co.
4. Simplified techniques for treatment and dependability as it has been the experience of users of ^{60}Co teletherapy that mechanical breakdown are rare.

^{60}Co sources have also other numerous useful applications in agriculture and scientific researches.

1.3 The Nuclear Processes for ^{60}Co Production

Natural cobalt consists of 100 % ^{59}Co, the target atom for production of ^{60}Co. Irradiation of cobalt with reactor neutrons gives not only ^{60}Co but also ^{59}Fe and ^{56}Mn according to the reactions $^{59}Co(n,p)^{59}Fe$, $^{59}Co(n,\alpha)^{56}Mn$. The second reaction is due to fast neutron irradiation [6]. The cross-sections of these reactions are small compared to that for the reaction $^{59}Co(n,\gamma)^{60}Co$. This means, that cobalt is sensitive in the thermal region and the final product obtained when irradiating a cobalt target in a reactor is mainly ^{60}Co.

The ^{60}Co effective thermal neutron cross-section is the sum of the thermal neutron cross-sections to ^{60}Co + to ^{60m}Co. It is given by [7] as 29 barns calculated at the reactor temperature (300 ^{o}C [572 ^{o}F] a temperature chosen to be representative of most power reactor operations). Because of this fairly high production cross-section ^{60}Co can be produced with adequate specific activity by long irradiations Fig. 2 [7] and little of the product is lost by further neutron capture. The nuclear processes considered for production of ^{60}Co from ^{59}Co are shown in Fig. 3 [7]. Some metastable 10.4 min ^{60m}Co is formed, which is lost by beta decay to ^{60}Ni, neutron capture to form ^{61}Co or isomeric transition to ^{60}Co. The thermal neutron capture cross-section of 10.4 min. ^{60m}Co is 100 barns but in a flux as high as 10^{15} neutrons/cm^2. sec. The transformation rate by neutron capture is only 0.01 % of the beta decay rate. The ratio of isomeric transition to beta decay is

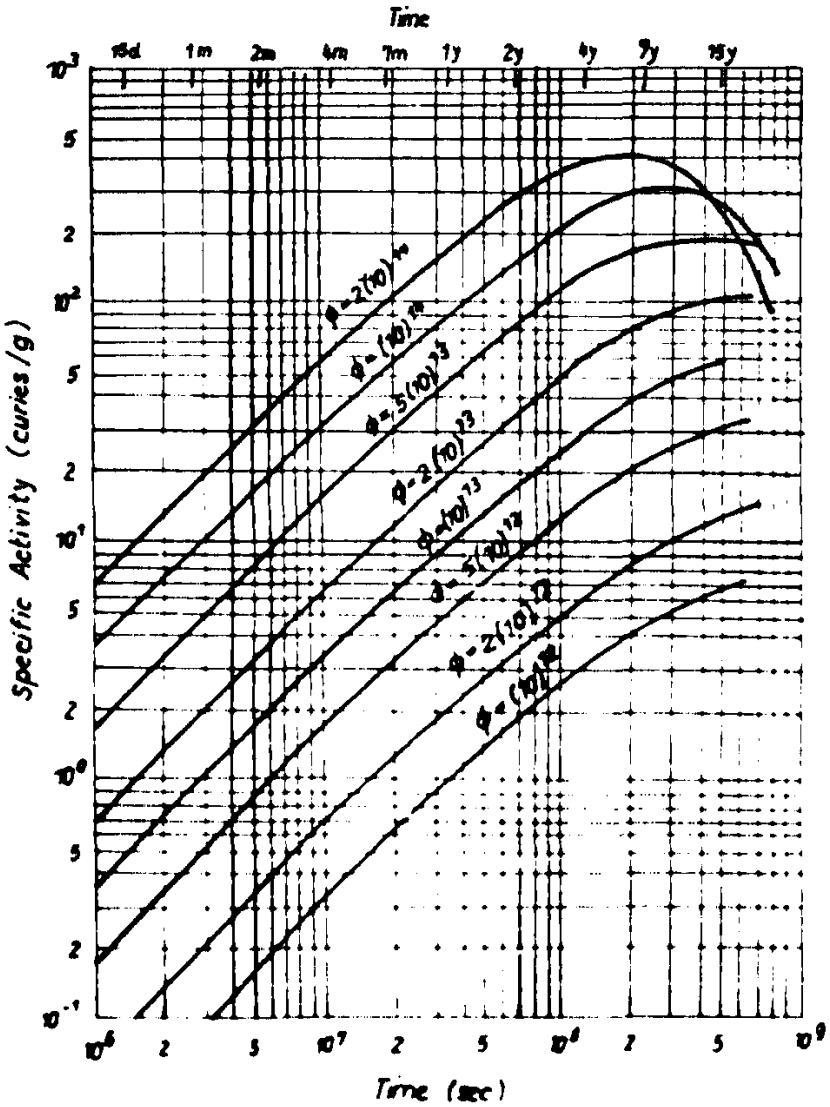

Fig 2 Production of ^{60}Co

> 99:1 [7] therefore, isomeric transition is predominant, and very little error is introduced by neglecting the formation of ^{60m}Co and assuming that all ^{59}Co is converted into ^{60}Co.

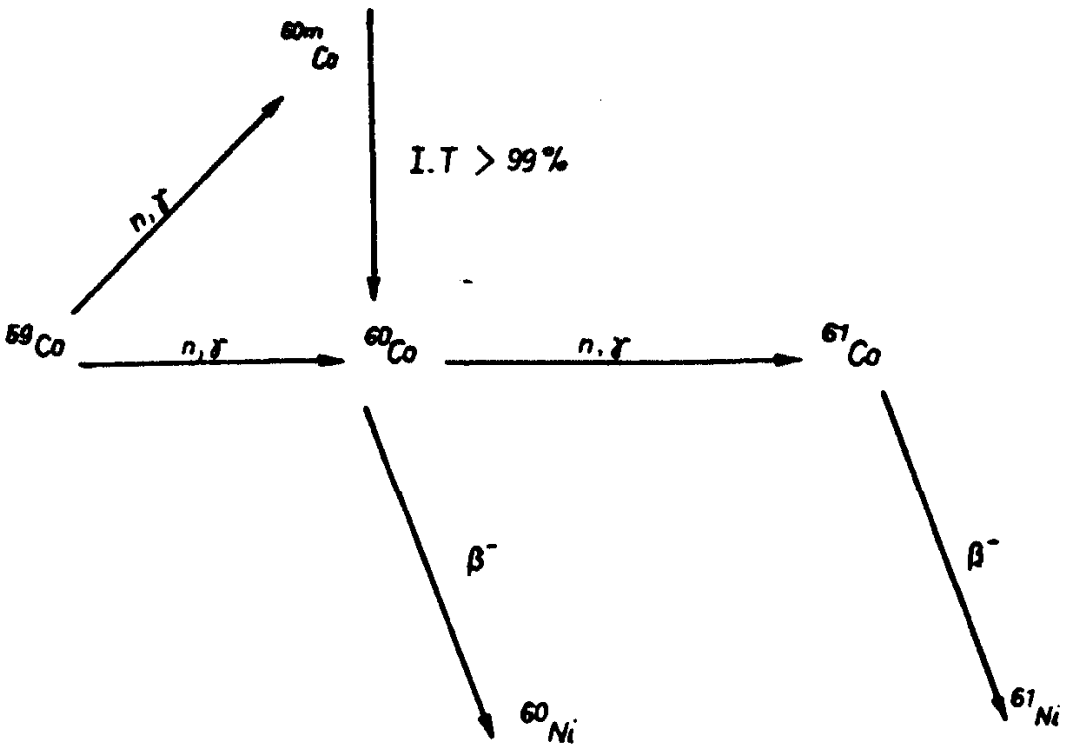

Fig. 3 Production of ^{60}Co from ^{59}Co [7]

1.4 Radioactive Nuclides of Cobalt

By the irradiation of pure inactive cobalt in reactor we obtain ^{60}Co and no other radioactive cobalt isotopes which are shown in table 1.

Table 1

Radioactive Isotopes of Cobalt [8,9]

Nuclide	$T_{1/2}$	Mode of decay	Energy of Radiation (in MeV)	Method of preparation
^{54}Co	0.18 sec	β^+	7.4	$^{54}Fe(p,n)$
^{55}Co	18.2 h	β^+, EC	β^+: 1.5 γ : 0.477, 0.935, 1.41	$^{54}Fe(d,n)$ $^{54}Fe(p,\gamma)$, $^{56}Fe(p,2n)$
^{56}Co	72 d	Ec, β^+	γ : 0.845, 1.26, 1.74 2.01, 2.255, 3.25	$^{56}Fe(d,2n)$, $^{56}Fe(p,n)$ $^{58}Ni(d,\alpha)$, $^{55}Mn(\alpha,3n)$
^{57}Co	270 d	β^+	β^+: 0.26 γ : 0.119, 0.131	$^{56}Fe(d,n)$, $^{56}Fe(p,\gamma)$ $^{55}Mn(\alpha,2n)$, $^{58}Ni(\gamma,p)$
^{58m}Co	9.2 h	IT	γ : 0.025	$^{55}Mn(\alpha,n)$
^{58}Co	72 d	EC, β^+	β^+: 0.47 γ : 0.81, 1.62 0.51 (with β^+)	$^{55}Mn(\alpha,n)$
^{59}Co	Stable			
^{60m}Co	10.1 min	IT, β^+	β^-: 1.56 γ : 0.059	$^{59}Co(n,\gamma)$
^{60}Co	5.3 y	β^-	β^-: 0.306 γ : 1.33, 1.17	$^{59}Co(n,\gamma)$

Table 1 (continued)

Nuclide	$T_{1/2}$	Mode of decay	Energy of Radiation (in MeV)	Method of preparation
^{61}Co	99 min	β^-	β^-: 1.42, 1.00	$^{59}Co(t,p)$ $^{64}Ni(p,\alpha)$ $^{61}Ni(n,p)$, $^{64}Ni(d,\alpha n)$
^{62}Co	13.9 min	β^-,γ	β^-: 2.88 γ : 1.17, 1.47 1.74, 2.03	$^{64}Ni(d,\alpha)$ $^{62}Ni(n,p)$
^{63}Co	52 sec	β^-	β^-: 3.6 max	$^{64}Ni(\gamma,p)$
^{64}Co	5 min			$^{64}Ni(n,p)$

1.5 Production of ^{60}Co in a Power Reactor

In principle, any neutron generated radioisotope can be produced in a power reactor, but actually only a few ones appear to be of interest.

^{60}Co due to its relatively long half-life can be easily produced in a power reactor, while short lived radioisotopes production which requires that targets be inserted and removed from the reactor on a frequent schedule would be impractical for power reactor unless special facilities were designed and built into them. This requires penetrations of the reactor pressure vessel, and it is highly unlikely that income from production of short lived radioisotopes