International Atomic Energy Agency

INDC(CCP)-377
Distr.: L

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

INELASTIC SCATTERING OF NEUTRONS BY ZIRCONIUM ISOTOPES WITH EXCITATION OF INDIVIDUAL LEVELS

Ya.M. Kramarovskii, L.A. Pobedonostsev
V.G. Khlopin Radium Institute
St. Petersburg, Russia

(Translated from a Russian original published in
Yadernye Konstanty 1/1992, p. 37-40)

Translated by the IAEA

August 1994

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

Reproduced by the IAEA in Austria
August 1994

INDC(CCP)-377
Distr.: L

94-10591 (C)
Translated from Russian

INELASTIC SCATTERING OF NEUTRONS BY ZIRCONIUM ISOTOPES WITH EXCITATION OF INDIVIDUAL LEVELS

Ya.M. Kramarovskii, L.A. Pobedonostsev
V.G. Khlopin Radium Institute
St. Petersburg

ABSTRACT

Inelastic scattering of neutrons with excitation of individual levels of ^{90}Zr, ^{91}Zr and ^{94}Zr was investigated by the associated gamma radiation method. The neutron energy range was from the excitation threshold to E_n = 2400 keV. The results are presented in the form of tables and graphs.

From the very beginning investigations of neutron inelastic scattering have mainly been concerned with nuclei of constructional materials as well as fissile nuclei, and extensive data have now been accumulated in this area. At the moment there is a pressing need to investigate the reactions (n,n') on nuclei situated in the region of the peaks of mass distribution of fission fragments. This is because, the greater the burnup of nuclear fuel, the greater the accumulation of fission products will affect the future operation of the reactor. At the present time there seems to be no viable alternative to nuclear power. One way of improving the latter is to increase the burnup of nuclear fuel. The inelastic scattering of neutrons is characterized by relatively large cross-sections, and it obviously plays an important part in the distortion of the primary neutron spectrum.

Apart from the above reasons, zirconium and alloys based on it play a special role in nuclear power engineering because they are the most widely used materials for fuel cans.

The reaction (n,n') for zirconium was investigated in Refs [1, 2] but the results for inelastic scattering of neutrons with excitation of specific levels refer only to the basic isotope ^{90}Zr.

We made an attempt to investigate inelastic scattering of neutrons with excitation of specific levels for other zirconium isotopes, using a sample with the natural isotopic content. Such an approach did not initially seem too promising, since the percentage content of ^{91}Zr, ^{92}Zr and ^{94}Zr in the natural mixture is small, and in work of this kind it is necessary to use a sample of relatively small size and weight. We used a sample of natural zirconium in the form of a cylinder 1.55 cm in diameter, 2.8 cm high and weighing 33.95 g, situated 10 cm from the target. The neutron source was the reaction T(p,n), and standard titanium-tritium targets with a thickness of (0.2-0.3) mg/cm^2 were used. Protons were produced by a EhG-5 accelerator. The associated gamma radiation method was employed [3]. This method is based on the radiation of a system of gamma levels of the investigated nucleus, as shown in Fig. 1. Figure 2 and Table 1 show the data for the 2186 keV level of ^{90}Zr which practically coincide with earlier results [1, 2].

The interpretation of the experimental results for the other zirconium isotopes is beset with difficulty.

Thus, the first excited state of ^{91}Zr decays with emission of a gamma ray with energy 1204.8 keV, but in the background spectra there is a gamma peak with E_γ = 1204.38 keV from the reaction $^{74}Ge(n,\gamma)$ in the material of the detector. These peaks in the experiment are unresolvable so it is difficult to obtain data on neutron inelastic scattering for ^{91}Zr with excitation of this level. The data for the ^{91}Zr levels with excitation energy 1466.2 and 1882.2 keV are given in Fig. 3 and Table 2.

A similar difficulty is encountered with ^{92}Zr; on transition from the third to the first energy level, the corresponding gamma energy is E_γ = 561.4 keV but in the background spectrum there is a gamma peak with E_γ = 562.9 keV from the reaction $^{76}Ge(n,\gamma)$. In addition, the branching coefficient is unknown for de-excitation of the fourth excited state.

Therefore we are not giving data for ^{92}Zr. However, it should be taken into account that the excitation function of the gamma peak with E_γ = 934.5 keV from the de-excitation of the first excited state of ^{92}Zr almost completely coincides with that from de-excitation of the first excited state of ^{94}Zr with E_γ = 918.79 keV. The system of levels of ^{92}Zr and ^{94}Zr are identical, so there should not be significant differences in the neutron inelastic scattering cross-sections for these nuclei. There is no problem in processing the spectra from ^{94}Zr, and the data for this nucleus are given in Fig. 4 and Table 3. The percentage content of ^{96}Zr in the natural mixture is small (2.8%) and we do not see any gamma transitions from this nucleus in our spectra.

The neutron flux to the sample was determined with the aid of a miniature ionization chamber with known quantity of ^{235}U by recording the fission fragments; the chamber was attached directly to the sample. Corrections have been made to the results for finite geometry.

REFERENCES

[1] GLICKSTEIN, S.S., TESSLER, G., GOLDSMITH, M., Phys. Rev. C. 4 No. 5 (1971) 1886.

[2] NEMILOV, Yu.A., POBEDONOSTSEV, L.A., KRAMAROVSKII, Ya.M., Voprocy atomnoi nauki i tekhniki, Ser. Yadernye konstanty, 1 (1990) 3.

[3] NEMILOV, Yu.A., POBEDONOSTSEV, L.A., KRAMAROVSKII, Ya.M., Neitronnaya fizika (1988) Pt. 3, 226.

Table 1

Neutron inelastic scattering cross-sections for ^{90}Zr with excitation of the 2186 keV level

E_n, keV	Cross-sections, mb
2380	285±20
2350	170±15
2320	135±10
2290	85±7
2260	60±7
2230	40±7

Table 2

Neutron inelastic scattering cross-sections for ^{91}Zr with excitation of the 1466.2 and 1882.2 keV levels

E_n, keV	Cross-sections, mb	
	1466.2 keV level	1882.2 keV level
2380	360±25	180±13
2350	375±25	180±13
2320	350±25	190±14
2290	450±40	230±16
2260	500±35	250±18
2330	570±40	290±20
2200	560±40	320±22
2170	500±35	260±20
2140	490±30	200±14
2110	550±40	110±8
2080	480±30	
2050	530±40	
2010	650±50	
1960	425±30	
1920	470±30	
1870	480±30	
1810	400±25	
1760	510±40	
1720	350±30	
1660	350±30	
1610	250±25	
1560	150±20	

Table 3

Neutron inelastic scattering cross-sections for ^{94}Zr with excitation of the 918, 1300, 1469 and 1671 keV levels

E_n, keV	Cross-sections, mb			
	918.8 keV level	1300 keV level	1469.8 keV level	1671.5 keV level
2380	750±50	140±12	180±10	320±20
2350	790±50	150±13	165±9	330±20
2320	880±60	150±13	100±8	370±30
2290	980±60	180±15	108±8	360±30
2260	800±50	170±13	147±11	330±20
2230	800±50	140±12	115±9	310±20
2200	770±55	160±14	97±8	330±20
2170	860±60	140±12	135±10	320±25
2140	860±60	150±13	135±10	350±30
2110	850±60	155±13	150±12	350±30
2080	660±50	120±12	145±12	320±15
2050	660±50	140±12	92±8	260±20
2010	490±60	180±15	105±9	190±20
1960	730±50	155±13	100±8	160±12
1920	660±50	160±14	120±3	80±6
1870	730±50	180±16	90±8	
1810	714±50	200±17	140±12	
1760	720±50	230±17	120±9	
1720	760±60	260±19	60±7	
1680	690±50	227±17	70±6	
1610	760±60	215±17	30±5	
1560	810±60	160±14		
1510	760±60	170±15		
1460	620±50	130±13		
1410	630±50	35±7		
1360	410±30	50±5		
1310	**410±30**			
1260	**380±30**			
1200	**230±20**			
1150	**200±20**			
1110	**110±10**			

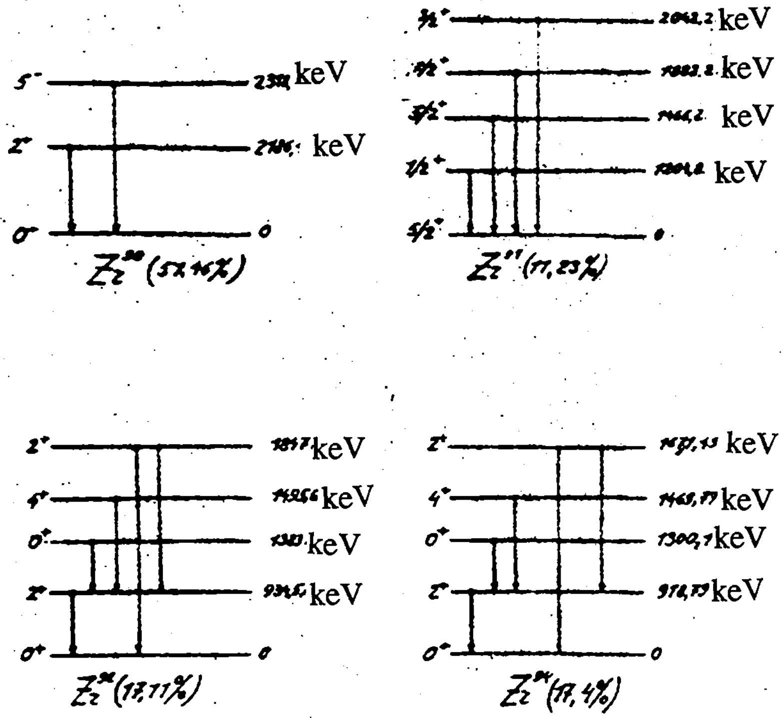

Fig. 1. Systems of low-lying levels for zirconium isotopes

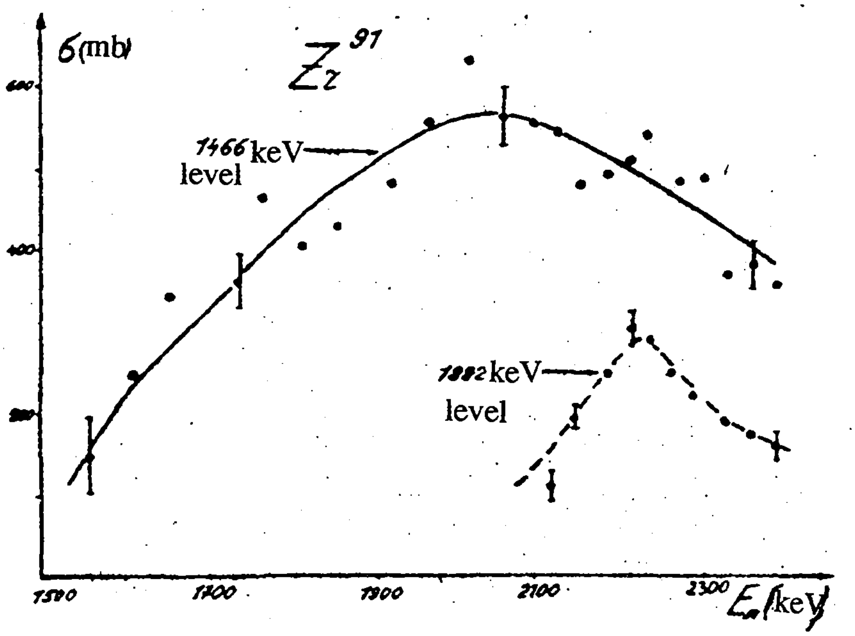

Fig. 2. Neutron inelastic scattering excitation function for the 2186 keV level for ^{90}Zr.

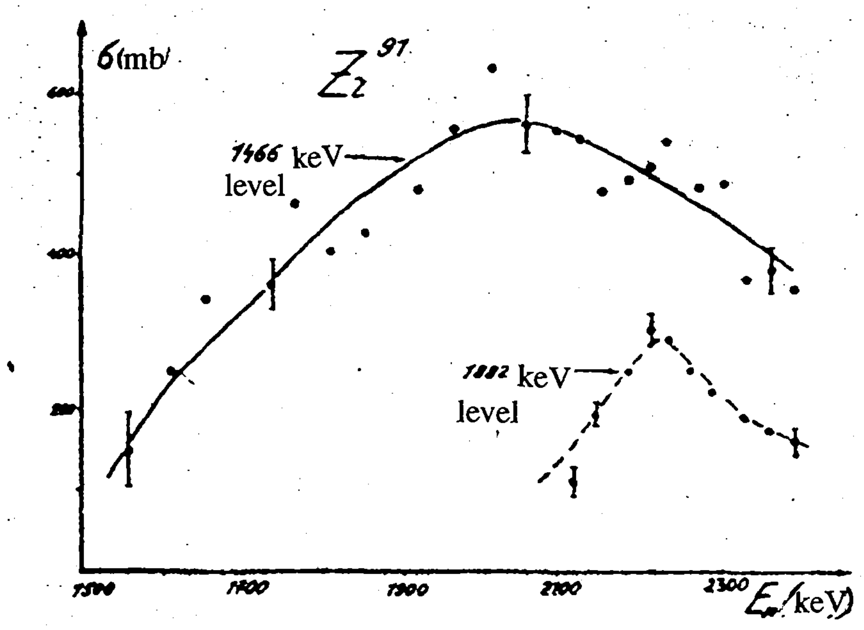

Fig. 3. Neutron inelastic scattering excitation functions for the 1466 and 1882.2 keV levels for ^{91}Zr.

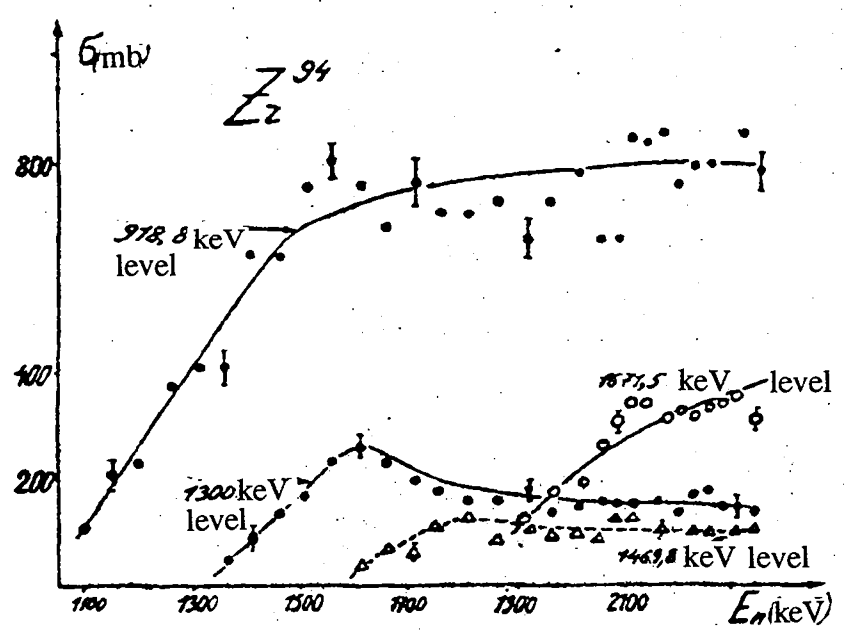

Fig. 4. Neutron inelastic scattering excitation functions for the 918, 1300, 1469 and 1671 keV levels for ^{94}Zr.