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COORDENADORIA DE PROTEÇÃO RADIOLÓGICA E DOSIMETRIA
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INSTITUTO DE ENERGIA ATÔMICA
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IONIC THERMOCURRENT AND OPTICAL–ABSORPTION MEASUREMENTS IN KCl:Sr UNDER REACTOR IRRADIATION (*) (**) (***) (****).

G. M. Sordi and S. Watanabe

SUMMARY

We have studied radiation damage in KCl crystals doped with Sr^{++} using thermoionic current techniques (ITC) and optical absorption measurements. Analysing the radiation damage due to three different gamma ray exposures, we confirmed the results obtained by other authors, namely the gamma irradiation creates *F* type or *V* type colour centre and destroys a fraction of impurity vacancy dipoles. Fast neutron irradiation added to the gamma irradiation increases the efficiency of destruction of dipoles. The fast neutrons also provoke the appearance of a second ITC peak at temperatures near 123°K which is unstable and disappears in a few days. On the other hand thermal neutrons bombarding the samples together with fast neutrons and gamma rays leave unchanged the impurity vacancy dipole concentration obtained after the gamma plus fast neutron irradiation. With thermal neutrons there is a high background current, and the peak resolution is only possible when thermally and electrostatically polarizable electrical carriers have largely disappeared. For this reason it is impossible to compare the 123°K peak obtained with and without thermal neutrons.

1 · INTRODUCTION

The behavior of I V (impurity vacancy) complexes in KCl doped with Sr, Ca and Ba was extensively studied by several authors. See, for instance, the review paper by BARR and LIDIARD[1].

The vacancy in these cases is either in a nearest position (on the positive ion sublattice) or in a next-nearest neighbour position with respect to the impurity and the magnitude of the resulting dipole moment is approximately given by the electronic charge times the geometrical distance between impurity and vacancy.

In the present paper we investigate the behaviour of these dipoles in Sr-doped KCl under high irradiation flux at room temperature at a nuclear facility.

The radiation field in a nuclear-reactor facility is, in general, a mixture of strong gamma radiations, thermal and fast neutrons. Since one can measure the effect of pure gamma rays and, also, since one can absorb totally thermal neutrons, it is possible to study the effect of each radiation separately, under the assumption that their effects are additive.

The relaxation time of dipole at temperature T is given by

$$\tau = \tau_0 \exp[E/kT], \tag{1.1}$$

where E is the activation energy for dipole reorientation, τ_0 the relaxation time constant and k the Boltzmann constant.

The study of the dipolar relaxation can be carried out by measuring the thermally activated release of stored ionic polarization (ionic thermoconductivity or ITC[4,5]).

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(****) Separata do *Il Nuovo Cimento*, Milano, 25 B(1) 145 58.

The density of the depolarization current detected during the heating process of the crystals is given by

$$(1.2)\qquad i(T) = N_{dip}\frac{\mu^2 \alpha E_p}{kT_p}\left[\tau_0 \exp\left[E/kT\right]\right]^{-1} \exp\left[-\int_{T_0}^{T}\left\{b\tau_0 \exp\left[E/kT'\right]\right\}^{-1} dT'\right],$$

where N_{dip} is the concentration of dipoles, T_p the polarization temperature, T_0 the temperature at which one starts to record the depolarization current, μ the dipole moment, α a geometrical factor that for cubic crystals, as in our case, is equal to $\frac{1}{3}$, E_p the applied electric field and b the heating rate dT/dt, generally constant

On the other hand one has

$$(1.3)\qquad \ln\frac{\int_T^{\infty} i(T')dT'}{i(T)} = \ln\tau(T) = \ln\tau_0 + E/kT$$

and

$$(1.4)\qquad N_{dip} = \frac{3kT_0P_0}{\alpha\mu^2 E_p},$$

where P_0 is the polarization frozen in the sample

BELTRAMI *et al* [2] were the first to use the ITC technique to study the X ray radiation effect on KCl:Sr^{++} crystals An exposure to 60 000 R caused a decrease of 15% in the ITC peak; LAJ *et al* [9] also observed a decrease in the ITC peak of LiF:Mg^{++} due to an exposure of 10^6 R from a ^{60}Co source; CRAWFORD[14] found ITC peaks in pure KCl irradiated with an electron beam

Neutron bombardment effects on solids was widely studied in the past, since they are of direct interest in reactor technology[3] Several authors have studied the reactor radiation effect on pure crystals by optical measurements[6 12] and have concluded that the nature of the created colour centres is the same as that produced by gamma radiation Measurements on the change of ionic conductivity have also been performed[3]

The purpose of this paper is to study the effect of the neutron irradiation on the concentration of I V dipoles in Sr doped KCl single crystals and to investigate if new relaxations appear due to neutron radiation damage The creation of colour centres is also studied in order to understand the mechanism of damage Since in our case the neutron flux is accompanied by gamma rays, it is necessary to examine also the effect of pure gamma irradiation for comparison

2 · EXPERIMENTAL PROCEDURE

A Keithley 610 C electrometer was used to measure the thermocurrent and a Keithley 245 power supply was used for the polarization of the sample The heating rate during the depolarization of the sample was chosen to be 0 1 K/s to avoid a significant temperature gradient inside the crystal The pressure inside the Dewar was kept between 10^{-4} and 10^{-6} mm Hg during the measurements One of the electrodes was connected to the body of the system and the other was placed between the crystal to be measured and an undoped crystal (see Fig 1) Wrapping both electrodes there was an In foil to improve the thermal contact The undoped crystal was used to avoid the In foil to short circuit the faces of the doped crystal. We could use it because we verified that the undoped crystal does not present ITC peaks and presents the same background current as the doped one The temperature of the crystal was monitored with a copper constantan thermocouple fixed to the upper electrode (Fig 1)

The optical absorption measurements at room temperature were carried out with a Zeiss DMR2/WZ spectrophotometer The resolution, which is a function of the wave number, is better than

100 cm^{-1} at F and Z_1 bands Z_1 centres were produced by illuminating the crystals during one hour, at room temperature, with F light at 556 nm The band width used was 19 2 nm For this illumination we used a Xe light source and a Bausch and Lomb grid monochromator The total light dose was 2 15 J/cm^2

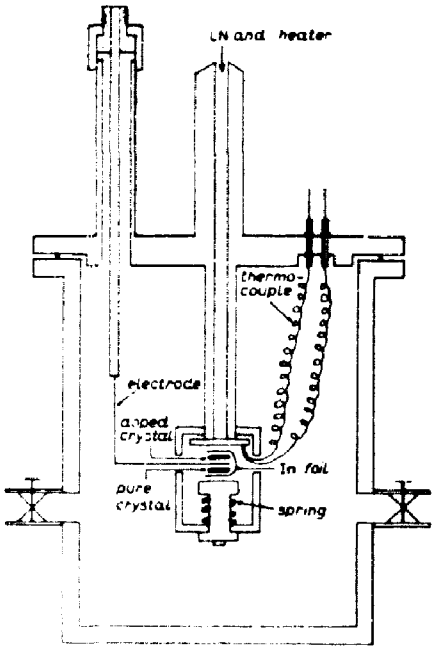

Figure 1 — Schematic representation of the Dewar for ITC measurements

The neutrons and gamma rays used for crystal irradiations were produced by the nuclear reactor IEAR 1 of the Atomic Energy Institute This is a swimming pool type reactor, operating at 2 MW power Gamma-rays, emitted by fission products after the reactor is turned off, were used to observe the pure gamma effect In order to study the effect of gamma plus fast neutron irradiation, the sample was wrapped in Cd foil 0 6 mm thick, to eliminate thermal neutrons The samples were maintained at room temperature during the reactor irradiation inside the pool

The computation of dipole concentration N_{dip}, activation energy E, relaxation parameter τ_0 and theoretical fit of the experimental curves were performed by means of eqs (1 3) and (1 4) at the IBM 1620, Mark II Computer of the Atomic Energy Institute of São Paulo

The KCl crystal used in the present work contained Sr as impurity and its concentration was 10^{-1} in molar fraction They were grown at the Department of Physics, Crystal Growth Laboratory, University of Utah.

A typical size of the crystals used was 0 5 to 1 cm^2 area and 0 5 to 1 mm thickness The faces were covered with a thin film of silver to secure good thermal and electrical contacts Initially the crystals were annealed at 600°C for 30 min and quenched to dissolve the precipitates and the aggregates that grew during the crystal aging at room temperature As the precipitation of I-V dipoles out of the solid solution is relatively slow at room temperature and as the time of each experiment was not very long, we did not see

any change in the I V dipole concentrations in the several measurements done in the same conditions after annealing

The samples were always polarized at 226°K, very close to the ITC peak due to I V dipoles, which occurs in KCl Sr at 225°K The electric fields used had an intensity of 400 V/mm

3 SUMMARY OF THE RESULTS DUE TO GAMMA IRRADIATION

The samples used to study the effect of gamma irradiation on ITC and optical absorption measurements were subjected to the following sequence: a) heat treatment at 600°C for 30 min, b) gamma exposure at room temperature, c) exposure to *F* light and d) heat treatment at 600°C for 30 min Between each step ITC and optical absorption measurements were made

The samples were divided into 4 groups One of the groups was aged between steps b) and c) for 135 days and the remaining ones only for 8 days The aging was carried out in the dark at room temperature

Each group consisting of 2 or 3 samples was exposed to $2 \cdot 10^5$ R, $0\,9\ 10^7$ R or $1\ 1\ 10^6$ R

The results obtained agree with those obtained by other authors, namely the gamma irradiation creates *F* type and *V* type colour centres[12] and destroys a fraction of I-V dipoles[9] For the samples submitted to an exposure of $2 \cdot 10^5$ R the decrease in the I-V dipole concentration was $6\ 0\ 10^{1\ 7}$ cm^{-3} and the creation of *F* centre concentration was $1\ 0 \cdot 10^{1\ 7}$ cm^{-3} We also found that the resulting *F* centre concentration was saturated at approximately 10^7 R

The decrease in the number of I-V dipoles largely exceeds the number of colour centres created by irradiation This might be due to an enhancement of the precipitation of the I V dipoles to form larger aggregates, or to the interaction of the dipoles with free carriers We noticed also that during the aging for 135 days after the gamma irradiation the dipole concentration decreases

4 - FAST NEUTRON PLUS GAMMA IRRADIATION.

Unused samples were subjected to the following treatments:

a) initial heat treatment (30 min at 600°C),

b) simultaneous gamma ray and fast neutron irradiation at room temperature,

c) heat treatment at 600°C for 30 min

Between each step ITC and optical absorption measurements were made

The samples were exposed simultaneously to a fast neutron beam with a flux of $(7\ 3 \pm 0\ 7)\ 10^{1\ 1}$ cm^{-2} and to $2\ 10^5$ R gamma rays with an exposure rate 14 times larger than in the preceding case (pure gamma irradiation) The fast neutron effect was obtained by subtracting the gamma ray effect described in the preceding Section

Two crystals were studied with five ITC measurements each before irradiation, ten after irradiation and five after final annealing

4 1 ITC *measurements*

In table I the I V dipole concentrations obtained from the ITC measurements in each step of the experiment are given

Table I

I-V dipole concentration.

Before irradiation (cm^{-3})	After irradiation (cm^{-3})	Gamma ray destruction (cm^{-3})	Fast-neutron destruction (cm^{-3})	After final annealing (cm^{-3})
$15\,2\,10^{17}$	$3\,5\,10^{17}$	$6\,0\,10^{17}$	$5\,7\,10^{17}$	$13\,0\,10^{17}$

30 hours after gamma and neutron irradiation, during which the samples were kept at room temperature in the dark, the ITC measurements gave a large electric current in the region out of the peak, $4 \cdot 10^{-14}$ A instead of 10^{-14} A (Fig. 2). An ITC measured without the electric field showed a current of $1\,1 \cdot 10^{-14}$ A, which increased to $1.8 \cdot 10^{-14}$ A in the ITC peak region.

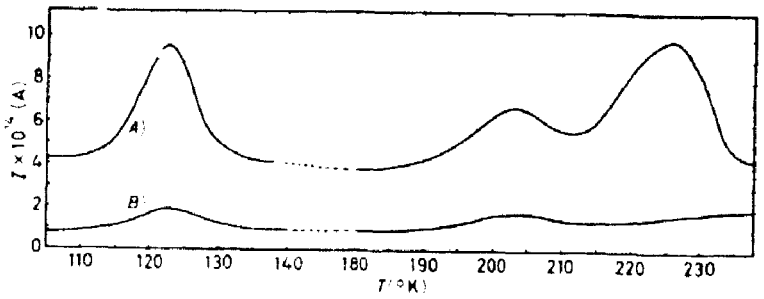

Figure 2 — Ionic thermocurrents of KCl:Sr^{++}:
A) ITC done 30 hours after gamma plus fast neutron irradiation (with applied field),
B) ITC simulation done 2 hours after ITC of curve A) (without applied field).

The high value of current outside the peak region is probably due to charge carrier relaxation over a few lattice parameters and it is reasonable to suppose that these carriers are in part interstitial ions, since, as we will show below, the estimated interstitial concentration is large, $2\,3\,10^{19}$ cm^{-3}. This fact is also supported by other authors, see for instance ref. (14). Another possible contribution to the carriers is the beta emission due to the small activity presented by the samples. As the high current can be seen only during the ITC measurements and not during the ITC simulation the contribution due to the beta emission is so small that can be collected by the electrodes only when we apply the electric field. During the polarization of the sample part of the interstitial ions relaxes under the electric field, over a few lattice parameters, preferably in the anode direction, establishing during the temperature decrease a gradient in the interstitial concentration. The reverse diffusion process during the subsequent heating gives rise to a displacement current that is detected by ITC measurements.

The 203°K ITC peak is due to thermal neutrons not absorbed by the cadmium foil or to the fast neutrons that were thermalized and entered into the crystal. This point will be discussed again in the next Section.

We found a second ITC band, with a peak at about 123°K. This peak is unstable: it increases a little in the first 31 hours after irradiation, decreases afterwards and disappears completely 75 hours after irradiation.

The slope of the curve, between LNT and peak temperature, changes as the height of the peak

decreases, hence no single activation energy can be given The band is probably an envelope of many simpler bands It is possible that this band is due to the small beta activity of our samples STOTT *et al* [14] have found a peak at 125°K for a KCl pure crystal exposed to 1 5 MeV electrons They attributed this band to the escape of electrons from shallow traps We will return to this argument in the next Section

4.2. *Optical absorption measurements*

In Table II, *F* and *M* centre concentrations due to fast neutrons plus gamma-rays, gamma rays only and fast neutrons only are given

Table II

Colour centre concentration.

F centres			*M* centres		
fast n plus gamma irradiation (cm^{-3})	gamma irradiation (cm^{-3})	fast n irradiation (cm^{-3})	fast n plus gamma irradiation (cm^{-3})	gamma irradiation (cm^{-3})	fast n irradiation (cm^{-3})
$4\,2\,10^{17}$	$>1\,0\,10^{17}$	$<3\,2\,10^{17}$	$0\,55\,10^{17}$	$0\,09\,10^{17}$	$0\,46\,10^{17}$

From this Table we see that fast neutron plus gamma irradiation increases the saturation value of *F* and *M* centre concentrations confirming the results of other authors[10] that this depends on the exposure rate In the present case the difference between pure gamma and fast neutron plus gamma irradiation is that in the second case the exposure (*) rate is 14 times larger than in the first one besides the fact that we added the neutron beam The exposure rate is larger because to obtain $2 \cdot 10^{8}$ R with the reactor on we irradiated the sample for 3 hours, while with the reactor off we irradiated it for 42 hours

We are again is a saturation zone The production of defects by fast neutrons is a two-step process The first step consists of ejection of an atom from its normal lattice position by elastic collision with a neutron The effect of the inelastic collision in KCl:Sr^{++} is negligible for fast neutrons from the reactor

The second step is to produce displacements of atoms by the recoiling atom as this moves throughout the crystal

Following the theoretical treatment given by KINCHIN and PEASE[8] to compute displacement due to collision, we found that $4\ 10^{18}$ chlorine ions per cm^3 were displaced to interstitial positions by fast-neutron incidence To this number we should also add interstitial ions due to replacement collisions[7], such that we obtain $2\,3 \cdot 10^{19}$ interstitial ions/cm^3 A similar calculation gives for Sr^{++} ions a concentration of $9\ 10^{15}$ cm^{-3}, a number that is small compared to that of Cl interstitial Assuming that each interstitials ion corresponds to one vacancy responsible for one colour centre we should have found $2\,3\ 10^{19}$ *F*-centres, but we found only $4\,2 \cdot 10^{17}$ This means that the neutron flux we used saturated the *F* centre concentration This is reasonable since the pure gamma irradiation already saturates *F* centre concentration

(*) By definition of the International Commission on Radiological Units and Measurements exposure refers only to X and gamma rays (see I C R U report N° 11, september 8, 1968)

5- THERMAL-NEUTRON IRRADIATION

The experiments were done following the sequence of treatments described in the preceding Section The samples were irradiated simultaneously with $(2\,0 \pm 0\,2)\,10^{8}$ R of gamma-rays, with a fast-neutron flux of $(7\,3 \pm 0\,7)\,10^{16}$ cm^{-2} and with a thermal neutron flux of $(2\,6 \pm 0.3)\,10^{17}$ cm^{-2} This means that a thermal-neutron beam was added to the preceding irradiation conditions. The number of crystals and of ITC measurements are the same as in the case of fast neutron plus gamma irradiation

5.1. ITC *measurements*

In Table III the value of the dipole concentration after each step of the experimental sequence is given

Table III

I-V dipole concentration.

Before irradiation (cm^{-3})	After irradiation (cm^{-3})	Thermal-n destruction (cm^{-3})	Fast n destruction (cm^{-3})	After final annealing (cm^{-3})
$15\,1\,10^{17}$	$4\,3\,10^{17}$	$10\,8\,10^{17}$	$11.7\,10^{17}$	$14\,0\,10^{17}$

The measurements were started 48 hours after irradiation because the activity of the sample was very high, about twenty times that obtained with fast neutrons The current was high and the ITC peak could not be distinguished from the background (curve *A*)in Fig 3) Also an ITC measurement without the electric field (ITC simulation) showed a high electric current (curve *B*)in Fig 3) 94 hours after irradiation the I V ITC peak appeared and the ITC simulation gave us the normal current of 10^{-14} A (curves *A*) and *B*) respectively, Fig 4)

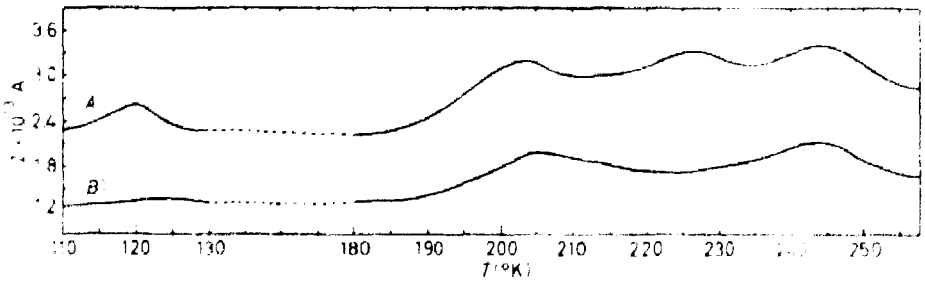

Figure 3 – Inonic thermocurrents of KCl:Sr^{++} :
A) ITC done 48 hours after gamma plus fast and thermal-neutron irradiation,
B) ITC simulation done 5 hours and 30 min after ITC of curve *A*).

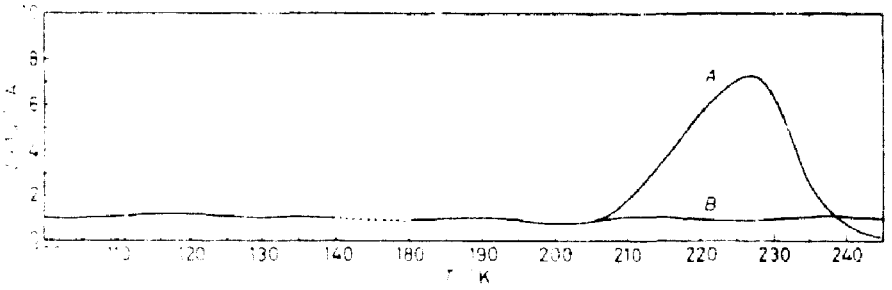

Figure 4 — Ionic thermocurrents of KCl:Sr^{++}
A) ITC done 94 hours after gamma plus fast- and thermal-neutron irradiation.
B) ITC simulation done 1 hour after ITC of curve *A*)

Now we give a summarized description of the behaviour of ITC measurements and ITC simulations between 48 h and 94 h (Fig 3 and 4) after irradiation Without entering into details, for both, measurement and simulation, as the background current decreases in time, it gives peaks more pronounced On the other hand, the peak at 244°K has already disappeared 70 h after irradiation and the peaks at 123 and 203°K 94 h after irradiation The configuration of the 203°K peak, 93 h after irradiation, is the same as that of Fig 2 (fast neutron irradiation) This explains why we attributed this peak to thermal neutrons in the last Section

The 123°K ITC peak grows in the first 80 hours and decreases and disappears in the next 14 hours We cannot compare the height of this peak with that of 123°K peak found in the case of fast-neutron irradiation because of the high background

The possibility that the high abnormal background current found in the ITC measurement is due to space charge present in the neighbourhood of the electrode can be eliminated, since the voltage drop in the crystal measured before and after irradiation is exactly the same as in the circuit presented in Fig 5

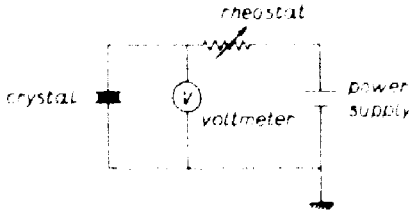

Fig. 5 — Schematic representation of the electric circuit used in the space charge identification

The high current found in the ITC measurements in the first four days after irradiation must be in part due to interstitial ions, moving along several lattice parameters, as already stated in the preceding Section, and in part to the electrons originated in the beta emission and oriented by the field The large current found in the ITC simulation is probably due to the ionization produced by the beta emission of the active material The collected electrons are those travelling in the direction of the electrode and coming from the ionization process

Since the radioactive half life of the activated materials is short, the decay is fast and 94 hours after irradiation the contribution of the electrons originated in the beta emission is negligible

In the third and fourth columns of Table III it may be observed that the change in 1 V dipole

concentration due to irradiation is bigger for fast neutrons plus gammas than for fast neutrons plus gammas and thermal neutrons This variation looks meaningful because it is smaller than the error limits, but we will return to this point later

5.2 *Optical-absorption measurements*

The *F* and *M* centre concentrations found were, respectively, $2.5\ 10^{17}\ cm^{-3}$ and $0.25 \cdot 10^{17}\ cm^{-3}$ We note that the *F* centre concentration increases in the first four days after irradiation reaching $3.5 \cdot 10^{17}\ cm^{-3}$ The samples were kept in the dark at room temperature during all the time except for few minutes when they were prepared for the measurements

The increase in the *F* centre concentration is explained by the spontaneous colouration effect[15], *i.e.* by the increase in the *F* centre number created by the beta and gamma radiation generated in the sample itself which is radioactive

Since the half life of the actived ions of the host crystal is short its decay is fast and the colouration fades significantly in a few days

If we compare these results with those for fast neutron plus gamma irradiation, it is possible to see that the thermal and fast neutrons plus gamma-rays created $1.7\ 10^{17}\ cm^{-3}$ fewer *F*-centres than the gamma-rays plus fast neutrons only, *i.e.* about 40% less The same phenomenon was observed in the creation of *M* centres, the difference being 50%

Based on this result (inhibition of *F* and *M* centre caused by the presence of thermal neutrons) we may consider that the small variation found in the I-V dipole concentration due to the presence of thermal neutrons is a real effect although its value is less than the error involved

5.3. *Discussion*

Summarizing the results we can say that:

a) the ITC peak can be detected only four days after irradiation due to overlapping of the high background caused by the charge carrier relaxation;

b) the actual experimental conditions, such as the small difference in I-V dipole concentrations of different samples or the problem of electrical contact between electrodes and samples, precluded the detection of the effect due to thermal neutrons on dipole concentrations (the variation of the concentration value is about three times the experimental error), an effect that can really exist;

c) the thermal neutron radiation added to fast neutrons and gamma-rays creates respectively 40% and 50% less concentration of *F* and *M* centres than fast neutrons plus gamma-rays only, that is there is an inhibition in the creation of colour centres when we add thermal neutrons.

These results can be easily explained by the suggestion of PETIAU[13], who assumes that neutrons create vacancy pairs LIMA *et al*[11] showed, by internal friction measurements, that the peak found by PETIAU can be created only by thermal neutrons and not by fast ones It is more easy to create a pair of vacancies where there is an *F* colour centre than where there is not because we have to displace to an interstitial position one electron (from the *F* centre) and a cation, *i.e.* practically the mass of one K atom, less than in the second case when we have to displace the mass of two ions, one Cl and one K Then the creation of vacancy pairs would be responsible for the destruction of colour centres and also for the small increase in the I-V dipole concentration when the sample is irradiated with added thermal neutrons Some divalent impurities belonging to the destroyed dipole can capture the cationic vacancy and regenerate the dipole

6 CONCLUSIONS

The principal conclusions are the following:

1) The gamma radiation has the power to decrease part of the dipole concentration, as was observed by other authors; fast neutrons increase this destruction and thermal neutrons leave it unaltered

2) The thermal neutron irradiation effect on the dipole concentration can be explained by the vacancy pair formation hypothesis of PETIAU

3) The gamma irradiation does not affect the normal phenomenon of I V dipole precipitation aged at room temperature

4) One possibility for explaining the dipole concentration destruction is to assume that gamma and fast neutron irradiation accelerates the crystal aging

5) In the fast neutron plus gamma irradiation and in thermal plus fast neutron and gamma irradiation a second ITC peak appears at 123°K; it is unstable and disappears about 75 h and 30 min after irradiation in the first case and after 94 h in the second This peak is probably due to the electrons produced by the activation of the samples, *i e* electrons that escape from shallow traps as was shown by STOTT *et al* [14]

6) The ITC peak induced by the combined thermal plus fast neutron and gamma irradiation becomes observable only when the large current, detected immediately after irradiation, becomes very small This happens four days after irradiation

7) The large electric current obtained in the first few days after thermal plus fast neutron and gamma irradiation is not due to the space charge present in the neighbourhood of the electrodes

8) Colour centre formation cannot explain the total dipole concentration decrease

9) The saturation of colour centre concentration is a function of the radiation intensity, as observed by other authors

10) The neutron flux used was sufficient to saturate the *F* centre concentration

11) Thermal neutron irradiation inhibits colour centre formation created by gamma plus fast neutron irradiation

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RESUMO

Estudou se o dano da radiação em cristais de KCl dopados com Sr^{++} usando a tecnica de corrente termoionica (ITC) e medidas de absorção optica Analisando o dano da radiação causado por três exposições diferentes de radiação gama confirmou se os resultados obtidos por outros autores isto e a irradiação gama cria centros de cor do tipo F e V e destroi uma fração dos dipolos vacancia impureza Irradiação com neutrons rapidos acrescida de radiação gama aumenta a eficiencia na destruição de dipolos Os neutrons rapidos tambem provocam o aparecimento de um segundo pico em

temperatura próxima a 123°K que e instavel e desaparece em alguns dias Por outro lado bombardeamento das amostras com neutrons termicos mais neutrons rapidos a radiação gama deixa inalterada a concentração de dipolos vacancia impureza obtida apos a irradiação com neutrons rapidos mais radiação gama Com os neutrons termicos existe uma alta corrente de fundo e a resolução do pico e unicamente possivel quando carregadores eletricos termica e eletrostaticamente polarizaveis houverem praticamente desaparecidos Por esta razão e impossivel comparar o pico em 123°K obtido com e sem a presença de neutrons termicos

RÉSUMÉ

C est etudie le dommage de la radiation en cristaux de KCl dopee avec Sr^{++} par moyen des techniques de courrent thermoionique (ITC) et measure de absorption optique L analyse du dommage d irradiation resultant des trois different expositions aux rayonnement gamma a confirme les resultats obtenues par des autres auters cet a dire, l irradiation gamma crie des centres de coleurs du type F e V et detruit une fraction de dipoles lacune impurete Irradiation avec de neutrons rapides plus radiation gamma aigmentent l efficience de destruction des dipoles Les neutrons rapides aussi provoquent l apparition d un second pic a la temperature prochaine de 123°K, qui est instable et disparait en quelques jours D'autre part le bombardement de l echantillon avec des neutrons thermiques plus neutrons rapides et radiation gamma ne change pas la concentration des dipoles lacune impurete obtenues apres l'irradiation gamma plus neutrons rapides Avec neutrons thermiques il y a haut courrent du fond et la resolution du pic est uniquement possible lorsque les conducteurs électriques thermiquement et electrostatiquement polarizables ont disparut en grande partie Pour cette raison il est impossible de comparer le pic en 123°K obtenu avec et sans les neutrons thermiques

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