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CONDUCTIVITY MEASUREMENTS AS A METHOD FOR DIFFERENTIATION BETWEEN IRRADIATED AND NON IRRADIATED POTATOES

by

Dr. H. SCHERZ
Bundesforschungsanstalt für Lebensmittelfrischhaltung

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Report prepared by
Bundesforschungsanstalt für Lebensmittelfrischhaltung
Institut für Strahlentechnologie, Karlsruhe - Germany

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and unirradiated potatoes as long as the latter remain unsprouted. Tubers treated with the chemical sprout inhibitor CIPC continue to show the initial conductivity decline even after 8 months of storage. When tubers that are unirradiated and not treated with CIPC begin to sprout, the initial conductivity decline is no longer observed.

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ABSTRACT

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KEYWORDS

ELECTRIC CONDUCTIVITY
IRRADIATION
POTATOES
RADIATION DOSES
RADIATION EFFECTS
STORAGE LIVE
DATA
TEMPERATURE
APPLES
BEETS
CARROTS
ONIONS
VEGETABLES
TIME DEPENDENCE
FRUITS
LINEAR ACCELERATORS
ELECTRONS

C o n t e n t

1. Introduction

The alternating current conductivity of the cells is a measure for the permeability of the cell membranes. The fundamental studies of OUSTERHOUT (1) have shown, that the conductivity of the cell membranes increases on cell death. In details PAECH (2) studied the influence of a number of external factors (cold, heat, mechanical injuries) on the cell conductivity of several fruits and vegetables. In most cases, an increase of the conductivity has been observed. Only treatment with some narcotics causes a decrease of the cell conductivity. The influence of irradiation on the conductivity of Nitella cells was studied by HANSEN (3) and he found also an increase of the conductivity. For irradiated fruits and vegetables no literature was found.

In the present investigation, an attempt was made to use the measurements of alternating current conductivity for differentation between irradiated and nonirradiated food. The approach can be useful only for materials consisting of living cells, which are not much altered by chemical or physical influences during the trade. Some fruits and vegetables appeared to be suitable materials. Especially potatoes are of great practical interest, since irradiation of them is an effective means for inhibition of sprouting.

2. Materials and Methods

The products for the present study were potatoes, apples, carrots, white beets, asparagus, swedish turnips and onions.

The following potato varieties were used: Bintje, Maritta, Grata, Saskia, Sirtima, Erstling, Agora, Ostara, Sieglinde, and Pfälzer Frühkartoffel.

The samples were irradiated in a linear accelerator with 10 MeV electrons. After irradiation, the materials were transferred to controlled temperature storage rooms. Prior to the measurements they were adjusted to room temperature of 20° C. The electric conductivity was measured at 50 cycles with an alternating current bridge+) equipped with a puncture electrode consisting of steel tips (Fig. 1). The electrodes were calibrated using solutions of 0.1 and 0.01 N KCl. The obtained values were expressed as specific conductivity (Ohm^{-1} cm^{-1}).

+) Wissenschaftlich-Technische Werkstätten GmbH, Weilheim

The conductivity was measured immediatly after puncture of the electrodes into the material. For some materials, it was found that the conductivity decreases immediatly after puncturing. The change of the conductivity with the time was followed, using a stop watch. The temperature dependence of the conductivity and of the conductivity decrease with the time was measured immediatly after the removal of the material from the controlled temperature cells, in which they had been stored at various temperatures.

3. Results

a) Potatoes

In potatoes, irradiation causes a decrease of the conductivity measured immediatly after puncturing. Fig. 2 (variety Bintje) shows, that the effect is not linear with the dose applied. At low doses (till 20 krad) a high decrease occurred, and hereafter the values remained constant. This effect was observed for all varieties which we have studied. The results of eight of them are presented in table 1. Mean values and standard deviations were calculated from fifteen measurements each.

In further experiments the influence of external factors was studied. Table 2 shows the dependence of the conductivity on dose for a storage period up to 30 days after irradiation. In table 3 the conductivity of potatoes, which were irradiated with 10 krads, is compared with that of unirradiated ones and with potatoes, which were treated with a chemical sprouting inhibitor (CIPC = Chlorisopropylphenylcarbamate). Raising of the temperature causes an increase of the conductivity for irradiated and unirradiated material (table 4).

Table 1

Dependence of conductivity on irradiation dose for eight varieties. The values were obtained immediatly after puncture; measured at 20° C. Storage temperature: 15°C

$\Lambda \cdot 10^{-4}$ Ohm^{-1}cm^{-1}

Variety	0 krad	10 krad	20 krad	50 krad	100 krad
Saskia	2.60±0.16	2.24±0.17	2.19±0.07	1.11±0.03	1.00±0.10
Agora	3.46±0.41	3.24±0.29	2.95±0.23	2.90±0.23	2.72±0.30
Ostara	4.28±0.28	4.03±0.32	3.78±0.42	2.70±0.52	2.22±0.37
Erstling	3.70±0.22	3.38±0.29	3.24±0.20	2.14±0.57	2.04±0.54
Sirtima	4.35±0.33	3.20±0.47	3.12±0.25	2.04±0.38	2.04±0.38
Bintje	4.20±0.19	1.75±0.19	1.18±0.15	1.15±0.14	1.07±0.28
Maritta+	3.78±0.20	-	2.63±0.15	-	-
Grata+	3.20±0.10	-	1.60±0.15	-	-

+Determination 2 months after irradiation

Table 2

Dependence of conductivity (immediatly after puncture) on irradiation dose, up to a storage period of 30 days; measured at 20° C; variety: Saskia; storage temperature: 15° C.

$\Lambda \cdot 10^{-4}$ Ohm^{-1}cm^{-1}

Time	0 krad	10 krad	20 krad	50 krad	100 krad
6 h	2.68±0.16	1.75±0.16	1.75±0.16	1.30±0.17	1.32±0.15
1 day	2.71±0.10	1.92±0.13	1.90±0.16	1.30±0.19	1.00±0.30
2 days	2.80±0.13	1.99±0.03	1.77±0.18	1.38±0.10	1.30±0.12
3 days	2.60±0.16	2.24±0.17	2.19±0.07	1.11±0.03	1.00±0.10
8 days	2.30±0.16	2.20±0.11	2.00±0.10	1.60±0.23	1.35±0.18
14 days	2.68±0.10	2.36±0.10	2.13±0.15	1.75±0.19	1.30±0.17
30 days	2.83±0.10	2.20±0.50	1.75±0.50	1.50±0.15	1.68±0.40

Table 3

Dependence of conductivity (immediately after puncture) on storage time for potatoes irradiated with 10 krad or treated with CIPC; measured at 20° C; storage temperature 10° C.

$\Lambda \cdot 10^{-4}\ Ohm^{-1}\ cm^{-1}$

	1st month	2nd month	4th month	6th month	8th month
Bintje					
unirrad.	4.85±0.26	4.32±0.28	4.81±0.35	3.78±0.69	-+)
10 krad	4.10±0.20	3.64±0.40	4.40±0.32	3.70±0.37	2.76±0.41
CIPC treated	5.10±0.24	4.40±0.29	5.40±0.31	4.70±0.52	3.30±0.58
Maritta					
unirrad.	3.78±0.27	4.90±0.36	4.65±0.28	3.52±0.67	-+)
10 krad	3.54±0.44	-	4.34±0.50	3.50±0.55	2.91±0.22
CIPC treated	4.91±0.25	4.96±0.18	4.95±0.24	4.10±0.35	3.61±0.32
Sieglinde					
unirrad.	4.55±0.26	4.55±0.24	3.94±0.42	5.82±0.54	-+)
10 krad	4.30±0.37	3.88±0.47	4.44±0.36	3.44±0.13	3.12±0.34
CIPC treated	5.05±0.45	4.43±0.12	4.44±0.30	4.14±0.4	3.06±0.55

+) potatoes totally sprouted

Table 4

Dependence of conductivity (immediately after puncture) on temperature during measurements; potato variety: Erstling and Sirtima

$\Lambda \cdot 10^{-4}\ Ohm^{-1}\ cm^{-1}$

Sample	0°C	20°C	35°C	45°C
Erstling				
unirradiated	2.94±0.46	3.70±0.22	4.27±0.39	4.12±0.38
20 krad	2.48±0.22	3.24±0.20	3.78±0.43	4.02±0.46
Sirtima				
unirradiated	2.86±0.13	4.35±0.33	4.30±0.58	4.60±0.57
20 krad	2.60±0.09	3.12±0.25	3.58±0.30	3.70±0.26

The measurement of the conductivity must be carried out immediately after puncturing. Otherwise in the case of unirradiated potatoes, the conductivity decreases within the first three minutes reaching values close to those of the irradiated potatoes. This conductivity decrease is diminished by irradiation and figure 3 illustrates the effect with the variety "Agora".

The conductivity values were measured immediately after puncturing (the time difference between puncture and registration was approximatly 2 - 4 seconds), and after 30, 60, 120 and 180 seconds. The electrodes were left in the material throughout this time.

It appeared that this decrease of the decline of conductivity as a result of irradiation might be a better method to distinguish between irradiated and unirradiated potatoes than the measurement of conductivity immediately after puncturing.

Figure 4 shows the effect for the variety "Sirtima".

In table 5, the conductivity differences between Λ_t (0, 30, 60, 120 sec) and Λ_t (180 sec) are given for the four varieties Sirtima, Ostara, Agora and Erstling. The storage time after irradiation was eight days, the mean values and standard deviations were calculated from 15 measurements each. The effect of irradiation on the initial conductivity decline is clearly observed in all four varieties.

Table 6 shows the dependence of the conductivity decline on the storage time and table 7 its dependence on the temperature during the measurement.

Table 5

Dependence of the conductivity decline (differences $\Lambda_t - \Lambda_{t(180)}$) on the radiation dose for four potato varieties; measured at 20° C; potato variety: SIRTIMA, OSTARA, AGORA, ERSTLING; storage temperature: 10° C; storage time after irradiation: 8 - 10 days.

$\Lambda_t - \Lambda_{t(180)} \cdot 10^{-4}$ $Ohm^{-1}cm^{-1}$

	0 sec	30 sec	60 sec	120 sec
SIRTIMA				
0 krad	0.80±0.13	0.33±0.08	0.21±0.07	0.08±0.05
10 "	0.29±0.10	0.14±0.08	0.08±0.08	0.03±0.03
20 "	0.15±0.08	0.11±0.06	0.07±0.05	0.05±0.03
50 "	0.09±0.08	0.04±0.05	0.03±0.03	-
100 "	0.03±0.10	0.04±0.06	-	-
OSTARA				
0 krad	0.96±0.26	0.47±0.12	0.23±0.08	0.045±0.04
10 "	0.51±0.18	0.18±0.07	0.15±0.09	0.03±0.03
20 "	0.43±0.21	0.24±0.13	0.11±0.10	0.06±0.05
50 "	0.30±0.13	0.23±0.12	0.12±0.12	0.08±0.05
100 "	0.03±0.13	0.04±0.09	0.04±0.03	-
AGORA				
0 krad	0.71±0.20	0.44±0.10	0.29±0.08	0.15±0.08
10 "	0.45±0.09	0.23±0.05	0.15±0.06	0.05±0.04
20 "	0.36±0.14	0.14±0.08	0.10±0.06	0.07±0.06
50 "	0.11±0.09	0.09±0.06	0.08±0.05	0.04±0.03
100 "	0.07±0.05	0.02±0.07	0.03±0.06	-
ERSTLING				
0 krad	0.72±0.21	0.33±0.12	0.22±0.09	0.11±0.07
10 "	0.41±0.10	0.23±0.15	0.15±0.07	0.06±0.04
20 "	0.33±0.14	0.16±0.08	0.11±0.06	0.07±0.05
50 "	0.11±0.05	0.05 ±0.09	0.02±0.08	-
100 "	0.08±0.14	0.02±0.08	0.03±0.06	-

Table 6

Dependence of the conductivity decline on storage time; measured at 20° C; storage temperature: 10° C; variety: Bintje

$\Lambda_t - \Lambda_{t(180)} \cdot 10^{-4}\ Ohm^{-1}\ cm^{-1}$

Time	0 sec	30 sec	60 sec	120 sec
I. month				
unirradiated	0.78±0.09	0.39±0.40	0.17±0.09	0.05±0.07
10 krad	0.45±0.07	0.31±0.05	0.19±0.04	0.08±0.03
CIPC	0.91±0.22	0.58±0.22	0.29±0.15	0.13±0.66
II. month				
unirradiated	1.10±0.16	0.59±0.20	0.34±0.15	0.09±0.10
10 krad	0.45±0.06	0.28±0.06	0.13±0.06	0.06±0.06
CIPC	0.95±0.10	0.45±0.11	0.20±0.12	0.09±0.05
IV. month				
unirradiated	0.64±0.13	0.32±0.11	0.20±0.06	0.03±0.03
10 krad	0.82±0.13	0.62±0.13	0.30±0.09	0.11±0.06
CIPC	0.95±0.13	0.53±0.10	0.32±0.09	0.18±0.07
VI. month				
unirradiated	0.42±0.18	0.32±0.19	0.14±0.09	-
10 krad	0.89±0.26	0.37±0.23	0.09±0.12	-
CIPC	1.4 ±0.02	0.65±0.20	0.20±0.10	-
VIII. month				
unirradiated	-	-	-	-
10 krad	0.53±0.13	0.29±0.12	0.11±0.04	0.03±0.01
CIPC	0.90±0.30	0.43±0.11	0.23±0.13	0.05±0.02

Table 7

Dependence of the conductivity decline on the temperature during measurement; potato variety: Erstling; storage temperature: 20° C; storage time after irradiation: 5 days.

$\Lambda_t - \Lambda_{t(180)} \cdot 10^{-4}\ \mathrm{Ohm}^{-1}\mathrm{cm}^{-1}$

	0 sec	30 sec	60 sec	120 sec
unirradiated				
0° C	0.43±0.13	0.33±0.13	0.28±0.09	0.10±0.06
20° C	0.72±0.21	0.33±0.12	0.22±0.09	0.11±0.03
35° C	1.0 ±0.26	0.34±0.07	0.16±0.06	0.05±0.04
45° C	0.56±0.13	0.20±0.05	0.16±0.06	-
20 krad				
0° C	0.17±0.05	0.13±0.04	0.10±0.05	0.06±0.04
20° C	0.33±0.14	0.16 ±0.08	0.11±0.06	0.07±0.05
35° C	0.70±0.24	0.25±0.14	0.13±0.07	0.03±0.04
45° C	0.39±0.11	0.17±0.03	0.16±0.03	-

The usefulness of this method for practical purposes was tested. At first, with one variety (Bintje) the $\Lambda_{t(0)} - \Lambda_{t(180)}$ and $\Lambda_{t(30)} - \Lambda_{t(180)}$ differences were measured with samples consisting of 10 potatoes each at six different irradiation doses. The average values as well as the standard deviations are shown in Fig. 5 and 6. With unirradiated potatoes and those treated with low doses, deviations of ± 30 % were obtained.

To be practically useful the effect should be nearly independent of the variety. Calibration curves were obtained by plotting the average values of $\Lambda_{t(0)} - \Lambda_{t(180)}$ and $\Lambda_{t(30)} - \Lambda_{t(180)}$ differences of the four varieties Sirtima, Ostara, Agora and Erstling against the applied dose (Fig. 7 and 8). Thirty seven samples of another two varieties (consisting of five potatoes each), namely "Sieglinde" and "Pfälzer Frühkartoffel" were irradiated and the applied doses were compared with those, which were determined as average from the measurements of the conductivity decrease $\Lambda_{t(0)} - \Lambda_{t(180)}$ and $\Lambda_{t(30)} - \Lambda_{t(180)}$, using the calibration curves at Fig. 7 and 8. The results are shown in table 8.

Table 8

Experimental determination of the irradiation doses of potatoes by the conductivity decline and comparison with the actual dose applied. Variety: "Sieglinde" and "Pfälzer Frühkartoffel"; storage time: 20 days after irradiation; storage temperature: 20° C

Sample	dose determined from $\Lambda_{t(0)}-\Lambda_{t(180)}$	dose determined from $\Lambda_{t(30)}-\Lambda_{t(180)}$	average exptl. determined dose	actual dose applied
Sieglinde				
1.	3.0	8.5	4.2	5
2.	3.0	2.0	2.5	10
3.	15.0	17.5	16.2	20
4.	80.0	80.0	86.0	100
5.	0	0	0	0
6.	11.0	13.0	12.0	5
7.	28.0	18.0	23.0	10
8.	36.5	22.5	29.5	20
9.	40.0	65.0	52.5	50
10.	60.0	100	80	100
11.	4.0	2.0	3.0	5
12.	90.0	90.0	90.0	100
13.	31.0	16.0	23.5	20
14.	0	0	0	0
15.	9.0	17.5	13.0	10
16.	2.0	0	1.0	5
17.	6.0	4.5	15.2	10
18.	40.0	27.5	34.0	50
19.	0	0	0	0
20.	0	0	0	0
21.	6.5	20.0	13.5	5
22.	11.0	22.5	17.0	10
23.	0	0	0	0
24.	6.0	4.5	5.2	5
25.	17.0	16.0	16.5	10

Table 8 (continued)

Sample	dose determined from $\Lambda_{t(0)}-\Lambda_{t(180)}$	dose determined from $\Lambda_{t(30)}-\Lambda_{t(180)}$	average exptl. determined dose	actual dose applied
26.	40.0	35.0	37.5	20
27.	65.0	50.0	57.5	50
28.	2.0	4.0	3.0	5.0
29.	5.0	11.0	8.0	10.0
30.	0	0	0	0
<u>Pfälzer Frühkartoffeln</u>				
31.	6.0	6.0	6.0	5
32.	14.0	12.5	13.7	10
33.	42.5	27.5	35.0	20
34.	2.0	1.0	1.5	0
35.	60.0	55.0	57.5	100
36.	70	75.0	72.5	50
37.	17.0	12.5	14.7	5

b) Apples, carrots, onions, white beets, swedish turnips and asparagus

The results of conductivity measurements on these foods are shown in tables 9 and 10.

Table 9

Dependence of conductivity (immediately after puncturing) of apples, carrots and onions on irradiation dose, measured at 20° C. Storage temperature: 20° C; storage time: 5 days (2 series of measurements for apples) after irradiation. Measurement temperature: 20° C.

	conductivity $\Lambda.10^{-4}$ Ohm^{-1} (for onions 10^{-5} Ohm^{-1}) cm^{-1}				
	0 krad	10 krad	20 krad	50 krad	100 krad
apples (Golden Delicious)	0.96±0.16	0.92±0.08	0.98±0.19	1.15±0.12	1.06±0.16
	1.19±0.16	1.14±0.16	1.15±0.15	1.29±0.16	1.31±0.10
carrots	2.04±0.55	2.14±0.50	1.75±0.56	2.00±0.46	2.42±0.71
onions	2.81±0.25	2.74±0.18	2.28±0.47	2.78±0.51	2.48±0.81

Table 10

Dependence of conductivity of white beets, turnips and asparagus on irradiation dose and on time after puncturing. Storage temperature 20° C. Storage time: 5 days after irradiation. Measurement temperature: 20° C.

$\Delta_t = \Lambda_t - \Lambda_{t(180)}$

$\Lambda \cdot 10^{-4}\ Ohm^{-1} cm^{-1}$

time (sec)	0	30	60	120	180
white beets					
0 krad	2.30±0.62	2.04±0.47	1.96±0.41	1.98±0.43	2.02±0.46
10 "	2.40±0.13	2.06±0.20	1.95±0.20	1.84±0.20	1.80±0.20
20 "	2.76±0.93	2.39±0.68	2.28±0.68	2.20±0.68	2.18±0.66
50 "	2.86±0.69	2.23±0.46	2.03±0.50	1.89±0.50	1.85±0.50
100 "	2.80±0.29	2.48±0.20	2.30±0.18	2.51±0.22	2.51±0.23

	$\Delta_{t(0)}$	$\Delta_{t(30)}$	$\Delta_{t(60)}$	$\Delta_{t(120)}$
0 krad	0.18	0.02	-	-
10 "	0.60	0.26	0.15	0.04
20 "	0.58	0.21	0.10	0.02
50 "	1.01	0.38	0.18	0.04
100 "	0.29	-	-	-

Table 10 (continued)

			Λ. 10^{-3} Ohm^{-1} cm^{-1}		
time (sec)	0	30	60	120	180
Swedish turnips					
0 krad	0.69±0.23	0.66±0.23	0.61±0.24	0.59±0.20	0.56±0.20
10 "	1.01±0.30	0.98±0.29	0.98±0.29	0.97±0.28	0.95±0.28
20 "	0.73±0.22	0.62±0.17	0.60±0.17	0.56±0.17	0.54±0.16
50 "	0.86±0.26	0.83±0.28	0.82±0.26	0.80±0.30	0.80±0.30
100 "	1.04±0.28	1.01±0.32	0.99±0.31	0.94±0.32	0.94±0.32

	$\Delta_t(0)$	$\Delta_t(30)$	$\Delta_t(60)$	$\Delta_t(120)$
0 krad	0.13	0.10	0.05	0.03
10 "	0.06	0.03	0.03	0.02
20 "	0.19	0.08	0.06	0.02
50 "	0.06	0.03	0.02	0
100 "	0.10	0.07	0.05	-

			Λ . 10^{-4} Ohm^{-1} cm^{-1}		
time (sec)	0	30	60	120	180
Asparagus					
0 krad	2.8 ±0.22	2.7 ±0.22	2.74±0.28	2.66±0.26	2.62±0.26
10 "	2.66±0.30	2.55±0.28	2.50±0.27	2.46±0.26	2.44±0.26
20 "	3.13±0.39	2.98±0.38	2.92±0.38	2.82±0.36	2.80±0.36
50 "	2.82±0.41	2.80±0.62	2.74±0.39	2.68±0.38	2.64±0.37
100 "	2.62±0.33	2.56±0.32	2.54±0.30	2.50±0.34	2.54±0.36

	$\Delta_t(0)$	$\Delta_t(30)$	$\Delta_t(60)$	$\Delta_t(120)$
0 krad	0.18	0.12	0.12	0.04
10 "	0.22	0.11	0.06	0.02
20 "	0.33	0.18	0.12	0.02
50 "	0.18	0.16	0.10	0.04
100 "	0.08	0.02	0.02	-

4. Discussion

The values of electric conductivity of potatoes which are measured immediately after puncturing the electrodes into the material are lowered by irradiation to 20 - 50 %, depending on the potato variety. Storage time as well as treatment with chemical sprouting inhibitor CIPC have little influence as long as sprouting does not occur. The effect of temperature during the conductivity measurement is approximately the same in irradiated and unirradiated tubers: higher conductivity at higher temperatures. Because of the dependence on variety, measurements of conductivity obtained immediately after puncturing are not sufficient for the identification of irradiated potatoes.

When the electrodes are left in the potatoes for some time, it is seen that the conductivity of the unirradiated samples decreases during the first three minutes, reaching values which are 30 % below the values which were measured immediately after puncturing. This decline is less pronounced in irradiated tubers and with doses of about 50 krad and higher, conductivity values remain constant during the 3 minutes.

This observation lead to the study of whether or not the slope of this conductivity decline could be used for the distinction between irradiated and unirradiated potatoes.

The differences of conductivity measured at 0 or 30 sec and at 180 sec after puncturing ($\Lambda_{t(0)} - \Lambda_{t(180)}$ and $\Lambda_{t(30)} - \Lambda_{t(180)}$) were determined after irradiation with various doses. The results were relatively independent of the variety of the potatoes. Nevertheless, within one variety deviations of $\pm$ 30 % were observed.

Sprouting diminishes the effect: in unirradiated potatoes which begin to sprout, $\Lambda_{t(0)} - \Lambda_{t(180)}$-values are as low as they are in irradiated potatoes. Treatment of unirradiated potatoes with CIPC (the most commonly used chemical for preventing sprouting) has no influence; the values are equal to those of unirradiated potatoes. As indicated by the results presented in table 7, the effect of irradiation is most pronounced if measurements are made at 0° rather than at higher temperatures.

The present results lead to following conclusion:
By determination of the slope of the conductivity decline it is possible to distinguish, even if the potato variety is unknown, between unirradiated tubers and those which have been irradiated with doses higher than 10 krads. When the variety is known and a calibration curve for this variety is available, the estimation of the applied dose is possible even in the range of 0 to 10 krad. Above 10 krads, the calibration curves become flat and alterations of the dose cause only a small change in the conductivity decline.

The conductivity of the other fruits and vegetables, which have been studied here, showed no consistent alteration by irradiation.

The conductivity decline immediately after puncturing which is so pronounced in unirradiated potatoes was observed to a lesser degree with Swedish turnips, white beets and asparagus. However, no clear-cut effect of irradiation on the slope of this decline was observed.

5. Literature

1. W.J.V. OUSTERHOUT, Bot. Gaz 61, 148 (1916)
2. K. PAECH, Planta 31, 265 (1940)
3. U.P. HANSEN, Atomenergie 12, 447 (1967)

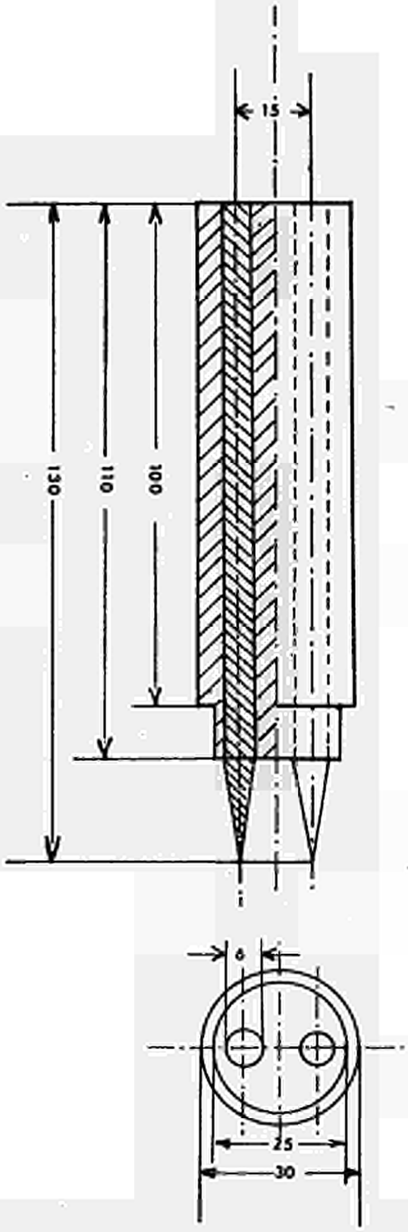

Fig. 1: Puncture electrode

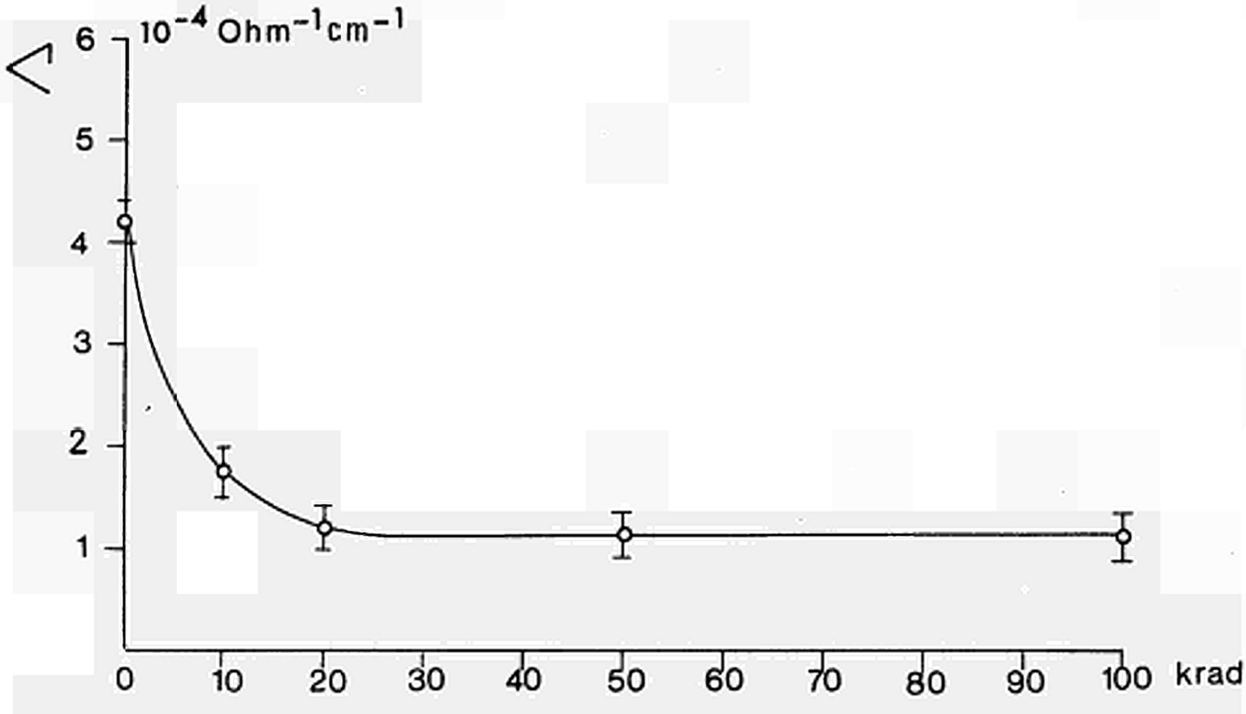

Fig. 2: Dependence of conductivity on irradiation dose for the variety "Bintje" measured at 20° C.

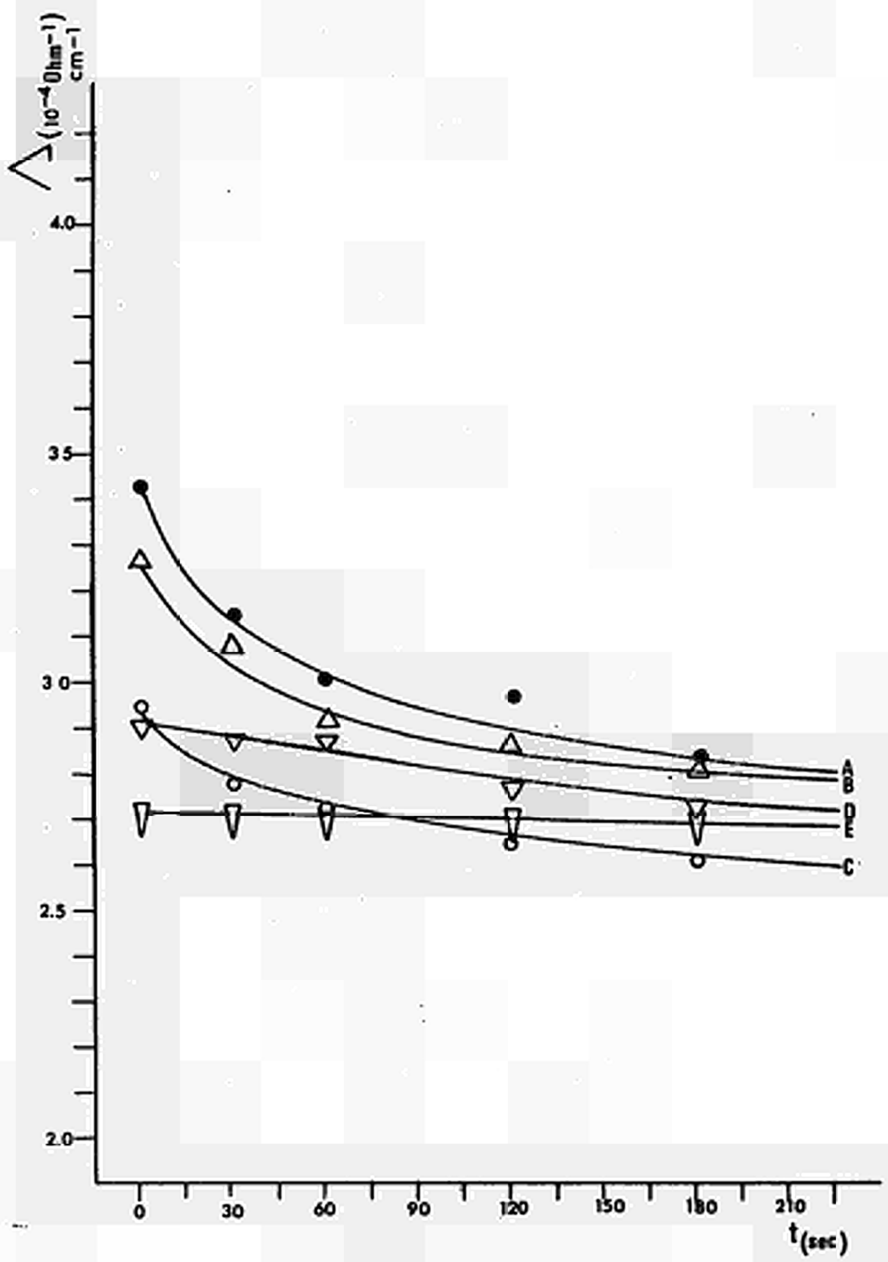

Fig. 3: Dependence of conductivity on the time after sticking the electrode into the potatoes.
Variety Agora; measurement temperature: 20° C, storage temperature: 10° C, storage time:
A(●) unirradiated, B(△) 10 krad, C(○) 20 krad; D(▽) 50 krad, E(▽) 100 krad

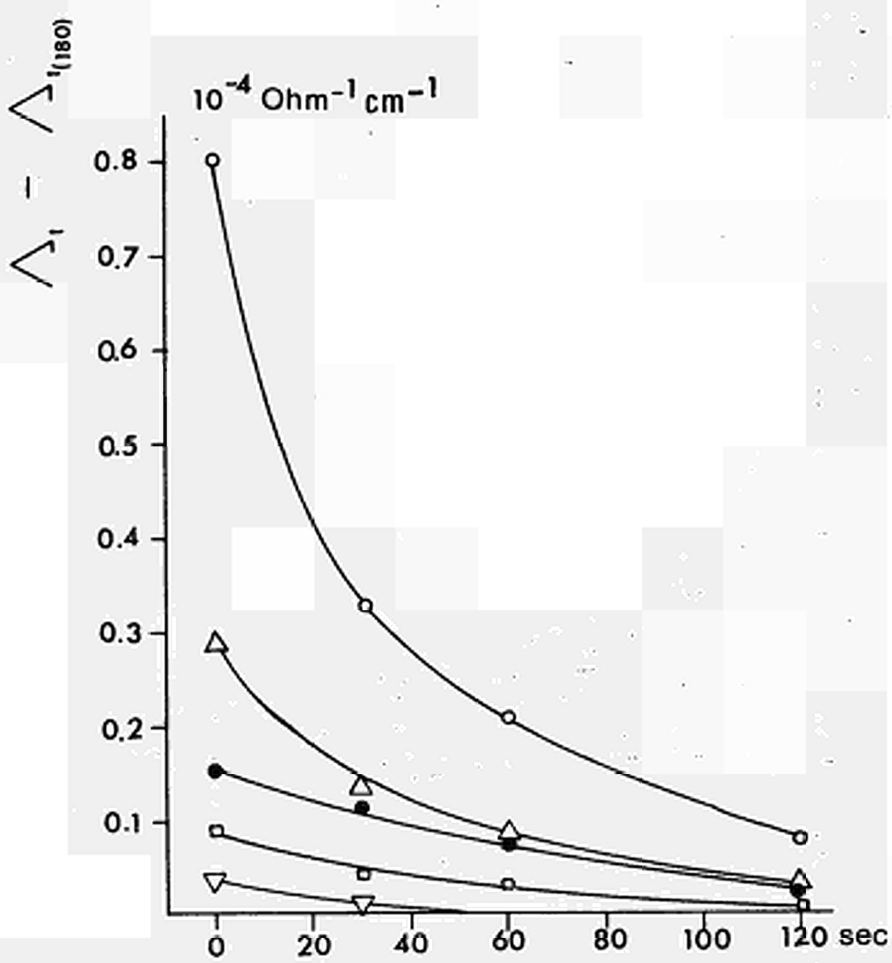

Fig. 4: Dependence of the conductivity decline on irradiation dose for the variety Sirtima: measurement temperature: 20° C, storage temperature: 10° C, storage time: 3 days.

Λ_t = conductivity at indicated time after puncturing the electrode into the tuber

$\Lambda_{t(180)}$ conductivity after 180 seconds

(○) unirradiated, (△) 10 krad, (●) 20 krad, (□) 50 krad, (▽) 100 krad

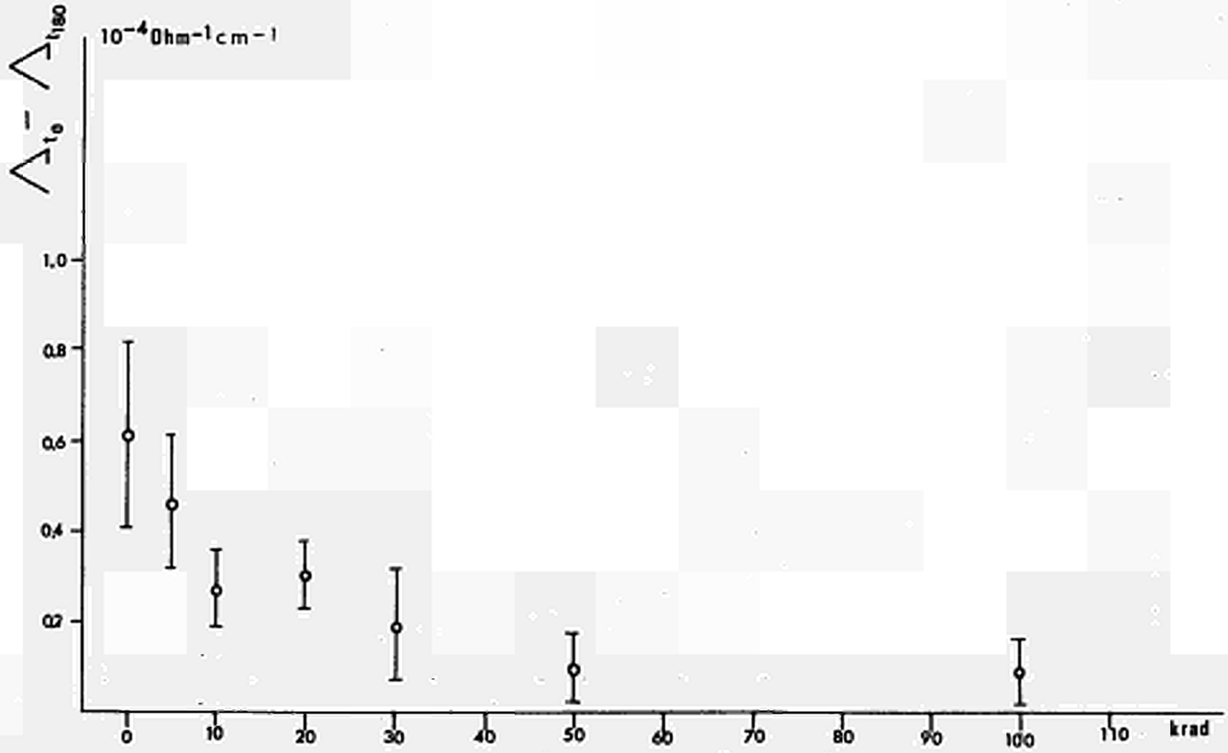

Fig. 5: Dependence of the conductivity differences $\Lambda_{t(0)}-\Lambda_{t(180)}$ on the irradiation dose.
Variety: Bintje; measurement temperature: 20° C, storage temperature: 20° C, storage time: 11 days.

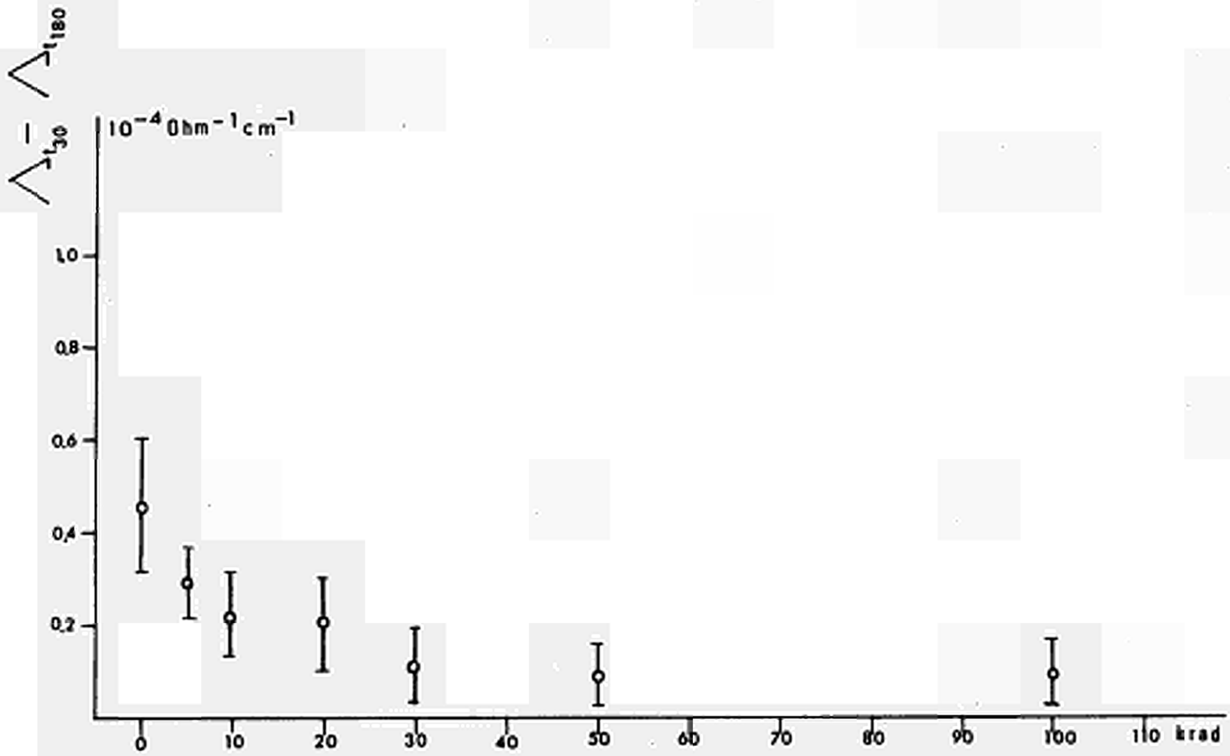

Fig. 6: Dependence of the conductivity differences $\Lambda_{t(30)}-\Lambda_{t(180)}$ on irradiation dose.
Variety: Bintje; measurement temperature: 20° C, storage temperature: 20° C, storage time: 11 days.

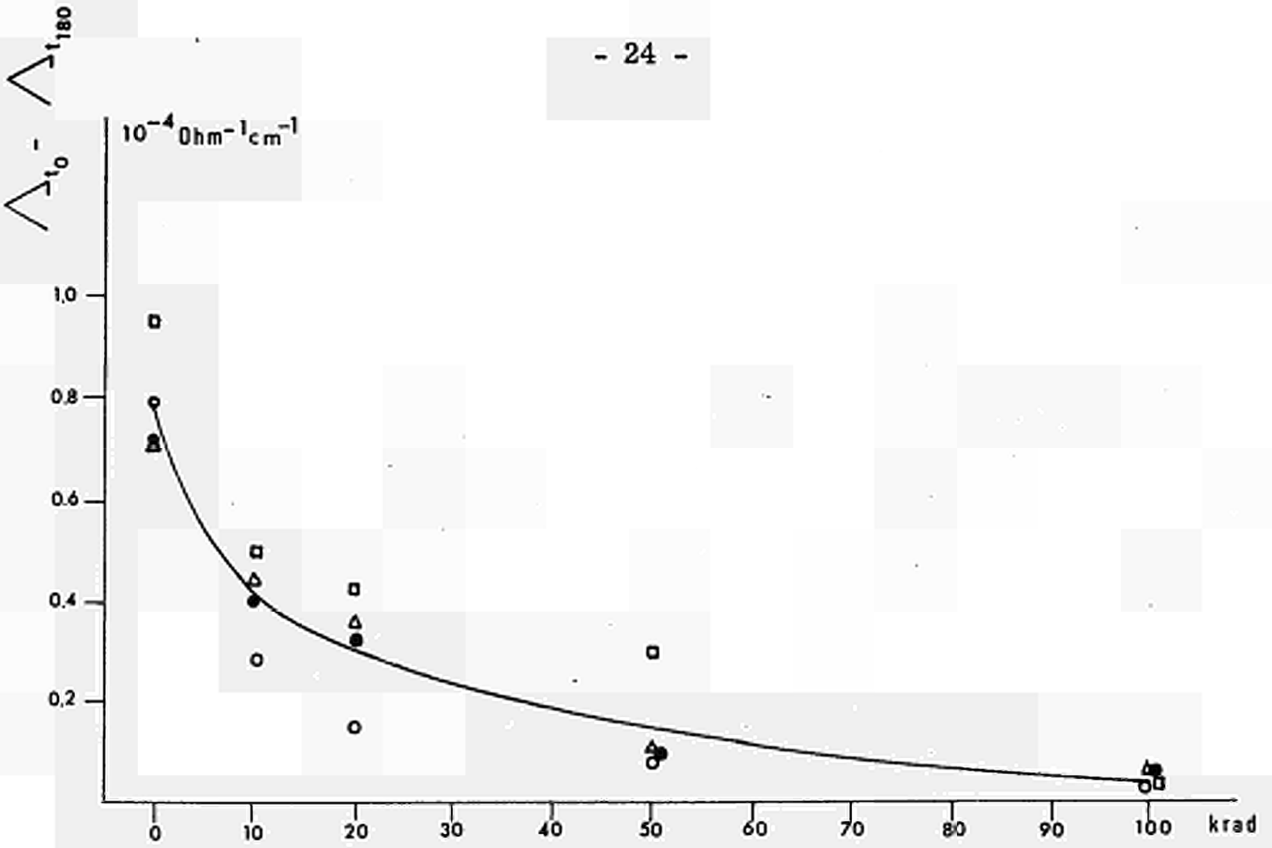

Fig. 7: Dependence of the average values of the conductivity differences $\Lambda_{t(0)}-\Lambda_{t(180)}$ for the four varieties Sirtima, Agora, Ostara and Erstling on the irradiation dose.
(○) Sirtima, (△) Agora, (□) Ostara and (●) Erstling
Measurement temperature: 20° C, storage temperature: 10° C, storage time: 8 - 10 days.

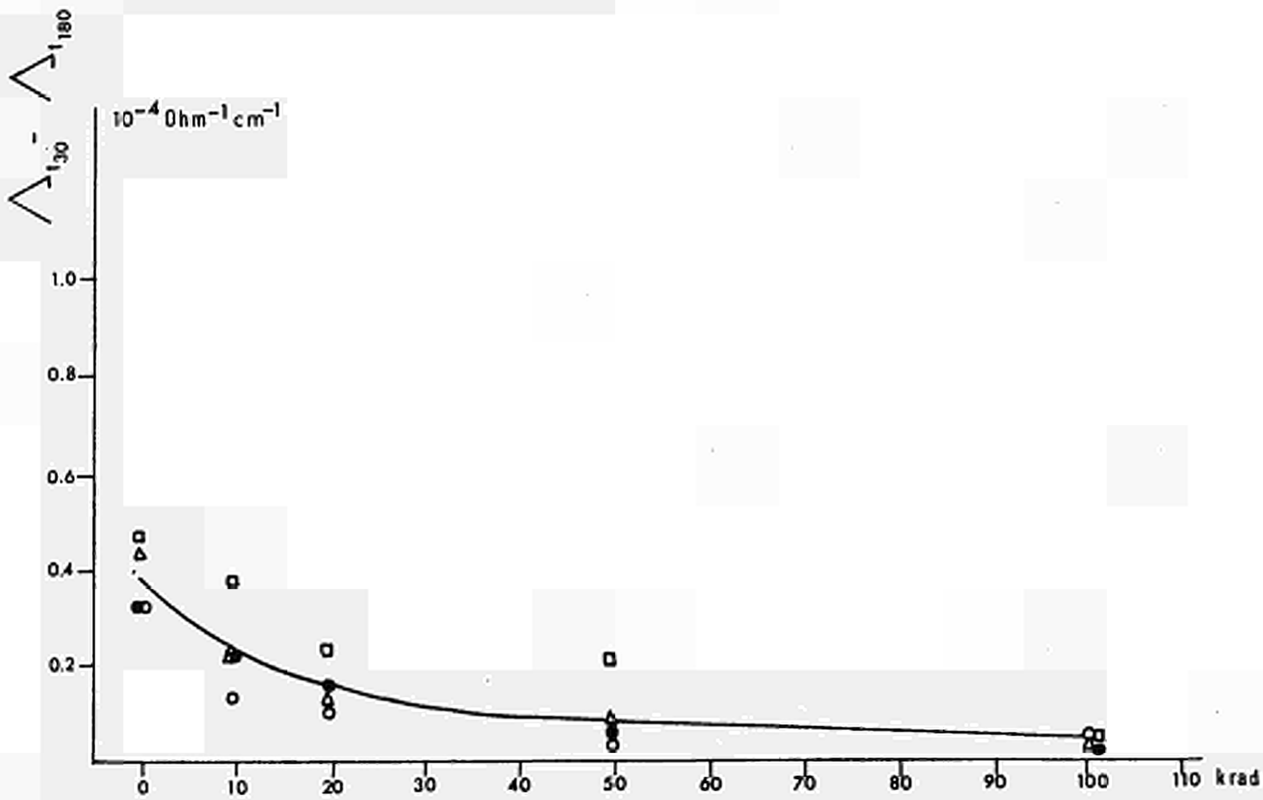

Fig. 8: Dependence of the conductivity differences $\Lambda_{t(30)}-\Lambda_{t(180)}$ on the irradiation dose (same varieties, conditions and symbols as in Fig. 7).

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Alfred Nobel

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