International Journal of RADIATION BIOLOGY
and related studies in Physics, Chemistry and Medicine

Editor: DAVID SCOTT

Associate Editors: JOLYON H. HENDRY and EDWARD J. LAND

Editorial Office: Paterson Institute for Cancer Research, Christie Hospital & Holt Radium Institute, Manchester M20 9BX

Editorial Board

G. E. Adams, U.K.
G. Ahnström, Sweden
K.-D. Asmus, F.R. Germany
R. R. Atayan, U.S.S.R.
D. Averbeck, France
E. Ben-Hur, Israel
N. M. Bleehen, U.K.
J. J. Broerse, The Netherlands
P. Bryant, U.K.
J. Cadet, France
M. Edgren, Sweden
M. M. Elkind, U.S.A.
S. B. Field, U.K.
J. F. Fowler, U.K.
G. B. Gerber, Belgium
D. T. Goodhead, U.K.
M. N. Gould, U.S.A.
G. R. ter Haar, U.K.
D. G. Harnden, U.K.
K. Held, U.S.A.
T. Hermann, G.D.R.
D. Kessel, U.S.A.
J. Kiefer, F.R. Germany
C. J. Koch, Canada

A. W. T. Konings, The Netherlands
A. Lehmann, U.K.
J. B. Little, U.S.A.
H. Loman, The Netherlands
S. Okada, Japan
N. L. Oleinick, U.S.A.
R. B. Painter, U.S.A.
M. Quintiliiani, Italy
I. R. Radford, Australia
J. L. Redpath, U.S.A.
R. Saunders, U.K.
Shen Xun, China
G. Silini, Austria
B. B. Singh, India
C. von Sonntag, F.R. Germany
G. G. Steel, U.K.
I. Szumiel, Poland
A. Tallentire, U.K.
D. M. Taylor, F.R. Germany
H. D. Thames, U.S.A.
H. Utsumi, Japan
P. Wardman, U.K.
R. L. Warters, U.S.A.
G. F. Whitmore, Canada

Subscription Information

International Journal of Radiation Biology (ISSN 0020-7616) is published monthly by Taylor & Francis Ltd, 4 John Street, London WC1N 2ET, UK.

Annual subscription 1988 £255, $460.

Second class postage paid at Jamaica, New York 11431.


Air freight and mailing in the USA by Publications Expediting Inc., 200 Meacham Avenue, Elmont, New York 11003.

Printed in the UK by Taylor & Francis (Printers) Ltd, Rankine Road, Basingstoke, Hampshire RG24 0PR, UK.

Dollar rates apply to subscribers in all countries except the UK and the Republic of Ireland where the pound Sterling price applies.

All subscriptions are payable in advance and all rates include postage. Journals are sent by air to the USA, Canada and Mexico, India, Japan and Australasia at no extra cost. Subscriptions are entered on an annual basis, i.e. from January to December. Payment may be made by sterling cheque, dollar cheque, international money order or National Giro, or by credit card (AMEX, VISA, Mastercard/Access).

Orders originating in the following territories should be sent direct to the local distributors:

Australia R. Hill & Son Ltd, 117 Wellington Street, Windsor, Victoria 3181.
India Universal Subscription Agency Pvt. Ltd, 101-102 Community Centre, Malviya Nagar Extn, Post Bag No. 8, Saket, New Delhi 110017.
Japan Kinokuniya Company Ltd, Journal Department, PO Box 55, Chitose, Tokyo 156.
USA, Canada and Mexico Taylor & Francis Inc., 242 Cherry Street, Philadelphia, Pennsylvania 19106-1906.
UK and all other territories Taylor & Francis Ltd, Rankine Road, Basingstoke, Hampshire RG24 0PR.

Advertisements

All enquiries to Taylor & Francis Ltd, Basingstoke (0256) 840366 or Taylor & Francis, New York, Inc. (212) 867 1490.
Contents

Editorial ................................................................. 825

REVIEW
Interaction of factors modifying the radiosensitivity of dormant seeds:
A review R. R. Atayan ............................................... 827

RAPID COMMUNICATIONS
A radioprotector: cysteamine, inhibits oxygen transport in lipidic
membranes. A. Vachon, V. Roman, C. Lecomte, G. Folcher,
M. Fatôme, P. Braquet and F. Berleur ............................ 847

Use of 'nuclear monolayers' to identify factors influencing DNA double-
strand breakage by X-rays. I. R. Radford ........................ 853

LOW DOSE AND DOSE RATE
Absence of a dose-rate effect in the transformation of C3H 10T1/2 cells by
α-particles. L. Hieber, G. Ponsel, H. Roos, S. Fenn, E. Fromke and
A. M. Kellerer ........................................................... 859

PLUTONIUM
The effect of $^{238}$Pu α-particles on the mouse fibroblast cell line C3H
10T1/2: characterization of source and RBE for cell survival. 
C. J. Roberts and D. T. Goodhead ................................. 871

Differences in the uptake of transferrin bound $^{239}$Pu and $^{59}$Fe into
multicellular spheroids of hepatocytes from adult male rats. F. Schuler,
C. Csovcsics and D. M. Taylor ..................................... 883

DNA DAMAGE
The relationship between radiation-induced DNA double-strand breaks
and cell kill in hamster V79 fibroblasts irradiated with 250 kVp X-rays,
2.3 MeV neutrons or $^{238}$Pu α-particles. K. M. Prise, S. Davies and
B. D. Michael .............................................................. 893

FRACTIONATION
The kinetics of repair in mouse lung after fractionated irradiation.
E. L. Travis, H. D. Thames, T. L. Watkins and I. Kiss .................. 903

SENSITIZATION
Radiation sensitization of E. coli B/r by mixtures of oxygen and nitrous
oxide. D. Ewing ............................................................ 921

HYPERTHERMIA
Interaction of whole-body hyperthermia and irradiation in the treatment
of AKR mouse leukemia. R. A. Steeves, H. I. Robins, K. Miller,
P. Martin, L. Shecterle and W. Dennis ................................ 935

VIRUSES
Activation of endogeneous retroviruses in mouse cells by thermal
neutrons. O. Niwa, T. Saigusa, T. Ikushima and T. Sugahara ......... 949

continues inside
RADIONUCLIDES
Evaluation of radiation dose resulting from the ingestion of $[^3H]$- and $[^{14}C]$thyminde in the rat. **H. Takeda and T. Iwakura**

Letter to the editor
Does initial haemoglobin level modify the efficacy of radiosensitizers? An analysis of the MRC Misonidazole studies in head and neck cancer and cervix cancer. **MRC Sensitizer Advisory Group**

Meeting statement
Statement from the 1987 Como meeting of the International Commission on Radiological Protection

Book Reviews
*Fractionation in Radiotherapy.* By H. D. Thames and J. H. Hendry (Reviewed by J. Dutreix)
*The Chemical Basis of Radiation Biology.* By C. Von Sonntag (Reviewed by P. O'Neill)

Diary of events
Forthcoming papers
Absence of a dose-rate effect in the transformation of C3H 10T1/2 cells by $\alpha$-particles

L. HIEBER, G. PONSEL, H. ROOS, S. FENN, E. FROMKE, and A. M. KELLERER

Institut für Medizinische Strahlenkunde, Universität Würzburg, D 8700 Würzburg, FR Germany

(Second version received 24 July 1987; accepted 14 August 1987)

The findings of Hill et al. (1984) on the greatly enhanced transformation frequencies at very low dose rates of fission neutrons induced us to perform an analogous study with $\alpha$-particles at comparable dose rates. Transformation frequencies were determined with $\gamma$-rays at high dose rate (0.5 Gy/min), and with $\alpha$-particles at high (0.2 Gy/min) and at low dose rates (0.83–2.5 mGy/min) in the C3H 10T1/2 cell system.

$\alpha$-particles were substantially more effective than $\gamma$-rays, both for cell inactivation and for neoplastic transformation at high and low dose rates. The relative biological effectiveness (RBE) for cell inactivation and for neoplastic transformation was of similar magnitude, and ranged from about 3 at an $\alpha$-particle dose of 2 Gy to values of the order of 10 at 0.25 Gy. In contrast to the experiments of Hill et al. (1984) with fission neutrons, no increased transformation frequencies were observed when the $\alpha$-particle dose was protracted over several hours.

1. Introduction

Experiments on oncogenic transformation have been performed in a variety of cell systems and with different ionizing radiations.

Extensive information has been obtained for sparsely ionizing radiations, such as $\gamma$- and $x$-rays, e.g. by Borek and Hall (1973), Terzaghi and Little (1976), Miller et al. (1979), Han et al. (1980), Miller and Hall (1978), and others; for densely ionizing radiation data are more limited. For $\alpha$-particles results have been given by Robertson et al. (1983) for Balb/c 3T3 cells, and by Lloyd et al. (1979) and Hall and Hei (1985) for C3H 10T1/2 cells. Yang et al. (1985) have reported data for heavy ions of intermediate to high LET. There have also been a number of studies with neutrons (Borek et al. 1978, Barendsen and Gaiser 1985). Of particular importance are the results of Hill, Elkind and co-workers, who found that small doses of fission neutrons have greatly increased transformation efficiency when they are applied at low dose rates (Hill et al. 1984) or fractionated over several hours (Hill et al. 1985). The potential implications of these results and the tentative nature of attempted explanations led us to perform similar experiments with other densely ionizing radiations, and $\alpha$-particles seemed to be a suitable modality that would permit highly controlled experimental conditions.

2. Materials and methods

2.1. Cell culture and irradiation procedures

The studies were performed with the C3H 10T1/2 mouse-embryo fibroblasts system developed by Reznikoff et al. (1973). Our cells were from the cell stock of Hall and Miller transferred in 1981 to the GSF, München, and kindly subcultured for us...
by Dr R. Trott. The cells were maintained in Eagle's basal medium supplemented with 10 per cent heat-inactivated fetal bovine serum (Biochrom, Berlin), 50 u/ml penicillin, and 50 μg/ml streptomycin (BRL, Karlsruhe). Cells of passage 12 were cultured in 75 cm$^2$ flasks (Falcon) and incubated in a humidified gas atmosphere (95 per cent air, 5 per cent CO$_2$) at 37°C. The plating efficiency of control cultures was between 20 and 30 per cent. Twenty-four hours before the exposures the cells were plated in 25 cm$^2$ flasks for γ-irradiation, or in special dishes consisting of a glass ring of 5 cm diameter and a foil bottom of 2 μm thickness (Hostaphan, Kalle Chemie Wiesbaden) for α-irradiation. In order to avoid settlement at the edge of the dishes where they may not be reached by the α-particles, cells were plated only in the centre area (3.8 cm diameter) with a small amount of medium (0.5 ml). Three hours later, when the cells were attached, 4.5 ml of culture medium were added. The beginning of the irradiation, both for the low dose-rate and high dose-rate experiments, was 24 ± 2 h after plating.

During the time of irradiation the cells were in exponential growth. This was verified by (a) growth curves, (b) flow-cytometry measurement of the DNA content, and (c) the determination of cells in S-phase by labelling with [$^3$H]thymidine (37 kBq/ml, 20 min).

The growth curves were exponential from about 10 to 12 h after plating, up to at least 48 h. The doubling time was about 18 h.

By flow-cytometry measurement of the DNA content the cell cycle distribution was determined at different times after plating. At 8 h, 64 per cent of the cells were in G1-, 18 per cent in S- and 18 per cent in G2 + M-phase; subsequently the fraction of G1-phase cells decreased and the fraction of S-phase cells increased. At least from 20 to 40 h, there was a constant cell-cycle distribution of 41 per cent G1-, 38 per cent S- and 21 per cent G2 + M-cells.

The labelling index increased from about 30 per cent at 4 h to 45 per cent at 15 h after plating; afterwards it remained constant at roughly 40 per cent, up to at least 40 h. The growth characteristics were equal in the flasks and the special dishes. At the beginning of the exposures the cell density was about $10^4$/cm$^2$.

Gamma-ray exposures were from a cobalt-60 unit at a dose rate of 0.5 Gy/min. For the α-particle exposures the cells were irradiated from an americium-241 source (a disc of 85 mm diameter with 0.37 GBq) through the bottom foil of the dishes which were positioned on the exit foil (figure 1). The highest dose rate was 0.2 Gy/min. The lower dose rates were achieved by micro-fractionation, i.e. by periodic brief opening (0.66 s) of a computer-controlled metal-disc shutter (see figure 1;6). The dose per microfraction was 2.2 mGy. For dose rates of 2.5, 1.7 and 0.83 mGy/min the fractions were separated by 50, 102, and 154 s, respectively. On the basis of measured nuclear cross-sections (mean value 250 μm$^2$) the frequency of α-particles traversing the cell nucleus was calculated to be about 11/Gy, i.e. one out of 40 cells was hit in its nucleus per microfraction.

The most likely energy of α-particles emerging from the bottom foil was 2.7 MeV (see figure 2), their dose mean LET was 147 keV/μm and their frequency mean 144 keV/μm. The relatively narrow energy distribution and very narrow LET-distribution was due to a high degree of collimation; the collimator of the α-irradiator has channels of length 15 mm and channel diameters of 3 mm. The track-etch diagram in figure 3 confirms the absence of obliquely incident α-particles. Figure 4 shows the enhancement of LET with increasing penetration of the α-particles into the cell. The absorbed dose is determined as the average over 2 μm depth of
Cell transformation by α-particles

Figure 1. Diagram of the α-irradiation device: 1: $^{241}$Am Source (0.37 GBq), 2: collimator, 3: exit foil, 4: incubation chamber, 5: thermal insulator, 6: shutter, 7,8: wobble axes, 9: rotating source disc, 10: source chamber flushed with helium.

Figure 2. Measured spectra of the energy of α-particles after traversal of the exit foil (solid line) and after additional traversal of the bottom foil (Hostaphan, an equivalent of mylar) of a culture dish (dotted line).
Figure 3. Comparison of C3H 10T1/2 cells at density $10^4$/cm$^2$ with the distribution of $\alpha$-particles at a dose of 0.125 Gy.
Panel A: 400 $\mu$m $\times$ 275 $\mu$m field of an etched CR 39 foil exposed to an $\alpha$-particle fluence of $5.4 \times 10^5$/cm$^2$, corresponding to a dose of 0.125 Gy. This is calculated to correspond roughly to 1.3 $\alpha$-particles per cell nucleus.
Panel B: 400 $\mu$m $\times$ 275 $\mu$m field with C3H 10T1/2 cells from a 24 h culture with the cell density of $10^4$/cm$^2$. 
During the exposure the cells were held in a chamber with temperature adjusted to 37°C, and with gas flow of 6 per cent CO₂ and 94 per cent air to achieve optimal pH and growth conditions. More detailed information on the α-irradiator is given elsewhere (Roos and Kellerer 1986).

2.2. Survival and transformation assay

After irradiation the cells were trypsinized and cell densities were determined with a Coulter Counter. If more than about 10⁵ cells were necessary for the transformation and the survival assay at a specified dose—especially at higher doses—two or three dishes were irradiated successively. For the high dose-rate experiments the two or three dishes were trypsinized together and pooled. For low dose-rate experiments the cells from every dish were always plated separately. For the survival assay the numbers of plated cells were chosen to attain about 80 viable cells per 25 cm² flask. The flasks were incubated for 10 days. After staining with 10 per cent Giemsa, colonies with more than 50 cells were counted as survivors. For the transformation assay the cells were plated in 25 cm² flasks with about 300 viable cells per flask. At high doses the numbers of viable cells were lower, because of the lower surviving fraction, and not more than 20 000 cells per flask were plated in order to avoid feeder effects. The cells were incubated for 6 weeks; after an incubation time of 2 weeks, with no medium change, they reached confluency, and were then re-fed once a week. For the determination of transformed foci the cultures were washed with phosphate-buffered saline, fixed with methanol, and stained with 10 per cent Giemsa. Only foci of type 2 and 3, as described by Reznikoff et al. (1973), were scored as transformants.

3. Results

3.1. Inactivation by γ-rays and α-particles

The survival relation of C3H 10T1/2 cells after exposure to γ-rays has a pronounced shoulder (figure 5). The curve corresponds to a fit of the natural
logarithm of survival to a linear-quadratic dependence with the coefficients $\alpha = 0.142/\text{Gy}$ and $\beta = 0.048/\text{Gy}^2$.

Inactivation by the densely ionizing $\alpha$-particles follows, down to a surviving fraction of about 0.05, an exponential relation. At higher doses the surviving fraction levelled off to about 0.001. The tail of the survival curve may be due to unattached mitotic cells not reached by the $\alpha$-particles.

At low dose rates there was no detectable change in survival; the data for high and low dose rates are fitted by the same relation with $\alpha = 1.65/\text{Gy}$.

### 3.2. Oncogenic transformation by $\gamma$-rays and $\alpha$-particles

Table 1 shows the data for transformation after exposure to $\alpha$-particles at high and low dose rates. The surviving fractions were taken from the survival relations in figure 5; for doses of 2.5 and 3.0 Gy the estimates were interpolated from observed fractions. The mean number of foci per flask was estimated from the total number, $m$, of foci and the number, $M$, of flasks:

$$\lambda = \frac{m}{M} \pm \sqrt{\frac{m}{M}}$$  \hspace{1cm} (1)

Two flasks were assigned one focus only because their number of foci (10 and 11 at doses of 0.25 Gy and 1.0 Gy, respectively) were in evident conflict with a Poisson distribution. With this correction the dispersion, $\Delta$ (sample variance divided by the mean), was not indicative of a systematic overdispersion ($\Delta > 1$); it therefore appeared justified to base the estimates on the total number of observed foci.

However, the choice of the estimate is not critical. Table 2 gives the results based on the 'null method' of Han and Elkind (1979) which utilizes only the ratio of the
Table 1. Transformation rates after exposure of C3H 10T1/2 cells to α-particles at low and high dose rates.

<table>
<thead>
<tr>
<th>(D) (mGy/min)</th>
<th>(D) (Gy)</th>
<th>(S)</th>
<th>(N_s)</th>
<th>(M)</th>
<th>(m)</th>
<th>(t \pm SE) ((10^{-4}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.125</td>
<td>0.81</td>
<td>314</td>
<td>172</td>
<td>1</td>
<td>0.0058 0.19±0.19</td>
</tr>
<tr>
<td>0.25</td>
<td>0.66</td>
<td>321</td>
<td>369</td>
<td>15</td>
<td>1</td>
<td>0.0407 1.27±0.33</td>
</tr>
<tr>
<td>0.5</td>
<td>0.44</td>
<td>323</td>
<td>384</td>
<td>26</td>
<td>1</td>
<td>0.0677 2.10±0.41</td>
</tr>
<tr>
<td>0.75</td>
<td>0.29</td>
<td>342</td>
<td>239</td>
<td>52</td>
<td>1</td>
<td>0.218   6.4±0.9</td>
</tr>
<tr>
<td>1</td>
<td>0.19</td>
<td>291</td>
<td>222</td>
<td>64</td>
<td>1</td>
<td>0.288   9.9±1.2</td>
</tr>
<tr>
<td>1.25</td>
<td>0.13</td>
<td>353</td>
<td>83</td>
<td>21</td>
<td>1</td>
<td>0.253   7.2±1.6</td>
</tr>
<tr>
<td>2</td>
<td>0.084</td>
<td>305</td>
<td>103</td>
<td>59</td>
<td>1</td>
<td>0.573   18.8±2.4</td>
</tr>
<tr>
<td>2.5</td>
<td>0.037</td>
<td>128</td>
<td>121</td>
<td>72</td>
<td>1</td>
<td>0.595   26.0±3.0</td>
</tr>
<tr>
<td>3</td>
<td>0.018</td>
<td>91</td>
<td>75</td>
<td>34</td>
<td>1</td>
<td>0.453   56.0±10.0</td>
</tr>
<tr>
<td>0.83</td>
<td>0.25</td>
<td>375</td>
<td>264</td>
<td>9</td>
<td>1</td>
<td>0.0341  0.91±0.30</td>
</tr>
<tr>
<td>0.5</td>
<td>0.44</td>
<td>348</td>
<td>16</td>
<td>1</td>
<td>1</td>
<td>0.0625  1.8±1.8</td>
</tr>
<tr>
<td>0.75</td>
<td>0.29</td>
<td>396</td>
<td>131</td>
<td>26</td>
<td>1</td>
<td>0.199   5.0±1.0</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
<td>343</td>
<td>202</td>
<td>14</td>
<td>1</td>
<td>0.0693  2.0±0.5</td>
</tr>
<tr>
<td>2.5</td>
<td>0.29</td>
<td>308</td>
<td>71</td>
<td>18</td>
<td>1</td>
<td>0.254   8.2±1.9</td>
</tr>
</tbody>
</table>

\(D\): absorbed dose rate, \(D\): absorbed dose, \(S\): surviving fraction (values from the fitted curve in figure 5, except at 2.5 and 3.0 Gy, where observed fractions are used), \(N_s\): survivors per flask, \(M\): number of flasks, \(m\): number of foci, \(X\): foci per flask, \(t\): transformation frequency per \(10^4\) survivors with standard error (SE).

Table 2. Transformation rates obtained from the modified estimate (equation 2).

<table>
<thead>
<tr>
<th>(D) (mGy/min)</th>
<th>(D) (Gy)</th>
<th>(n)</th>
<th>(\Delta)</th>
<th>(\lambda)</th>
<th>(t \pm SE) ((10^{-4}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.125</td>
<td>171</td>
<td>1.0</td>
<td>0.0040</td>
<td>0.12±0.07</td>
</tr>
<tr>
<td>0.25</td>
<td>0.96</td>
<td>354</td>
<td>0.94</td>
<td>0.0387</td>
<td>1.21±0.32</td>
</tr>
<tr>
<td>0.5</td>
<td>0.94</td>
<td>358</td>
<td>0.94</td>
<td>0.0701</td>
<td>2.17±0.43</td>
</tr>
<tr>
<td>0.75</td>
<td>1.13</td>
<td>195</td>
<td>1.13</td>
<td>0.204</td>
<td>6.0±0.9</td>
</tr>
<tr>
<td>1</td>
<td>0.98</td>
<td>168</td>
<td>0.98</td>
<td>0.279</td>
<td>9.5±1.3</td>
</tr>
<tr>
<td>1.25</td>
<td>0.95</td>
<td>64</td>
<td>0.95</td>
<td>0.260</td>
<td>7.4±1.7</td>
</tr>
<tr>
<td>1.5</td>
<td>1.17</td>
<td>63</td>
<td>1.17</td>
<td>0.492</td>
<td>16.1±2.5</td>
</tr>
<tr>
<td>2</td>
<td>1.14</td>
<td>71</td>
<td>1.14</td>
<td>0.685</td>
<td>30.0±4.0</td>
</tr>
<tr>
<td>2.5</td>
<td>0.83</td>
<td>42</td>
<td>0.83</td>
<td>0.529</td>
<td>40.0±7.0</td>
</tr>
<tr>
<td>3</td>
<td>1.15</td>
<td>48</td>
<td>1.15</td>
<td>0.446</td>
<td>55.0±11.0</td>
</tr>
<tr>
<td>0.83</td>
<td>0.97</td>
<td>255</td>
<td>0.97</td>
<td>0.0347</td>
<td>0.92±0.31</td>
</tr>
<tr>
<td>0.5</td>
<td>1.0</td>
<td>15</td>
<td>1.0</td>
<td>0.0645</td>
<td>1.9±1.9</td>
</tr>
<tr>
<td>0.75</td>
<td>0.89</td>
<td>106</td>
<td>0.89</td>
<td>0.212</td>
<td>5.3±1.1</td>
</tr>
<tr>
<td>1.7</td>
<td>0.94</td>
<td>188</td>
<td>0.94</td>
<td>0.0718</td>
<td>2.1±0.6</td>
</tr>
<tr>
<td>2.5</td>
<td>0.87</td>
<td>54</td>
<td>0.87</td>
<td>0.274</td>
<td>8.9±2.2</td>
</tr>
</tbody>
</table>

\(D\): absorbed dose rate, \(D\): absorbed dose, \(n\): number of flasks without foci, \(\Delta\): dispersion, \(\lambda\): foci per flask (modified estimate), \(t\): transformation frequency per \(10^4\) survivors with standard error (SE).
number, \( n \), of flasks without foci to the total number, \( M \), of flasks and thereby avoids any bias due to satellite colonies. These estimates, with their somewhat larger standard errors (see Balcer-Kubiczek et al. 1987):

\[
\lambda = -\ln(n/M) \pm \sqrt{1/n - 1/M} \tag{2}
\]

are in general agreement with the data in table 1.

As shown in figure 6, \( \alpha \)-particles induce transformations substantially more effectively than \( \gamma \)-rays. The RBE for transformation varies from about 3 at 2-0 Gy to somewhat larger values at low doses. These RBE values are not inconsistent with the values of 2-3 to 9 obtained by Hall and Hei (1985). They are somewhat higher than values reported by Robertson et al. (1983) for Balb/c 3T3 cells. The \( \gamma \)-ray data, which were not a main objective of this study, are still subject to considerable uncertainties, and they are therefore not fitted to a numerical relation.

The results for high dose-rates of \( \alpha \)-particles are, in figure 7, compared to those for low dose rates. There is no evidence of increased transformation frequencies at low dose rates. The broken line corresponds to a linear-quadratic relation for the number, \( T \), of transformants per \( 10^4 \) survivors:

\[
T = 0.01 + 2.9 \frac{D}{Gy} + 5.4 \left( \frac{D}{Gy} \right)^2 \tag{3}
\]

The solid curves permit a comparison with the results obtained for fission neutrons.

![Figure 6. Transformation frequencies per surviving cells after \( \gamma \)- (closed circles) and \( \alpha \)-irradiation (open circles) at high dose rates. The broken curve corresponds to equation (3).](image)
4. Discussion

The results of Hill et al. (1984) were highly unexpected in view of accepted biophysical considerations (Barendsen, 1985), and they are of sufficient pragmatic importance that analogous investigations with other densely ionizing radiations are mandatory. The present study has been designed to parallel closely the experiments of Hill et al. (1984), so that any differences in the results would reflect differences in the effectiveness of the radiations.

Up to now there have been only tentative explanations (Rossi and Kellerer 1986, Burch and Chesters 1986, Elkind and Hill 1986) of the dose-rate effects, or of the analogous results with fractionated neutron exposures (Hill et al. 1985). The results for α-particles appear to exclude these explanations and there is no obvious reason why the somewhat more densely ionizing α-particles should not show, at all, a phenomenon which is so strikingly present with neutrons. Nevertheless one must note certain differences between the radiations.

Event frequencies are larger in the neutron experiments. As pointed out earlier (Rossi and Kellerer 1986), there are about six recoil particles in the nucleus of a 10T1/2 cell at a dose of 100 mGy of fission neutrons. This is substantially more than the number of about 1.1 α-particles traversing the nucleus at a dose of 100 mGy in our experiments. If, for example, the dose-rate effect were caused by a short phase in the cell cycle of greatly enhanced sensitivity (Rossi and Kellerer 1986) one would nevertheless expect to see the effect at higher α-particle doses where there are multiple events in the cell and its nucleus.
While this has not been considered in proposed models, there might be an influence of the fact that neutrons produce a more varied spectrum of moderately high and high LET than the α-particles. Furthermore it might be of importance that the range of some of the neutron recoils, and particularly the heavier recoils, are shorter than the dimensions of the cell nucleus. Another difference is that the α-exposures are virtually free of an accompanying γ-ray component, while such a component is always present with neutron irradiations. Although there is at present no evidence that a contribution of γ-rays can account for a sensitization of the cells in the low dose-rate experiments with densely ionizing radiations, we have initiated limited experiments to investigate this aspect. In one group of three experiments at low dose rate with α-particle doses of 0.25, 0.5, and 0.75 Gy a γ-contribution of about 4 per cent (from a small caesium-137 source) was applied simultaneously. The observed transformation rates (with a total number of only three transformants) were insignificantly lower than those obtained in the low dose-rate experiments without the γ-component. In a further group of two experiments at α-doses of 0.25 and 0.75 Gy an equal dose of γ-rays from a cobalt-60 source was administered in six fractions during the α-exposures; the result of these combined exposures (with a total number of six transformants) was again not larger than the rates seen in the α-particle exposures at 0.25 and 0.75 Gy.

The α-particle doses were applied in multiple fractions of 2.2 mGy. However, this should be of no consequence since each of the cell nuclei experiences an α-particle in only about 1 out of 40 fractions. Even for the whole cell the number of particles per fraction is less than unity (for illustration see figure 3).

It is uncertain whether any remaining differences in the experimental procedure might contribute to the differences in the observed results. A discrepancy between our experiments and those of Hill et al. (1984) lies in the fact that we exposed the cells at somewhat higher densities (roughly 10⁴/cm²), in order to obtain a sufficient number of α-irradiated cells. However, as emphasized, a number of criteria have been evaluated to ascertain that the cells were in asynchronous growth at the time of irradiation.

Hill et al. (1984, 1985) have pointed out that their observation are in line with certain in vivo studies, which indicate a similar reversed dose-rate effect for neutrons. The absence of an analogous result in our studies with α-particles must therefore not detract from the importance of the earlier studies. Instead it appears desirable to extend the investigations to other radiation modalities.

Acknowledgments
This work was supported by the Deutsche Forschungsgemeinschaft (DFG), Sonderforschungsbereich 172, C-1. We are indebted to Dr Mortimer M. Elkind for his critical comments on the manuscript and his helpful suggestions. We are also particularly grateful to our colleague Dr Heike Wulf, who had begun the cell transformation studies at the laboratory.

References
Cell transformation by α-particles


### INDEX OF AUTHORS (with titles)

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abe, M., see Shibamoto, Y.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abelidis, S., Moore, J. S., and Chakravarty, A.: Zinc release from irradiated yeast alcohol dehydrogenase</td>
<td></td>
<td>413</td>
</tr>
<tr>
<td>Adams, G. E., see Walling, J. M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adams, G. E. D., see Freedman, L. S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Albertini, G., Fanelli, E., Guidoni, L., Ianzini, F., Mariani, P., Masella, R., Rustichelli, F., and Viti, V.: Studies of structural modifications induced by γ-irradiation in distearoylphosphatidylcholine liposomes</td>
<td></td>
<td>145</td>
</tr>
<tr>
<td>Anderstam, B., see Harms-Ringdahl, M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armstrong, D. A., see Surdhar, P. S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asmus, K.-D., see Möning, J.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atayan, R. R.: Interaction of factors modifying the radiosensitivity of dormant seeds: A review</td>
<td></td>
<td>827</td>
</tr>
<tr>
<td>Atlante, A., see Moreno, G.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Averbeck, D., see Dardalhon, M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Awa, A. A., see Ban, S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balla, I., Michel, C., and Fritz-Niggli, H.: Synergistic interaction between vindesine and X-rays in the prenatal development of mice</td>
<td></td>
<td>371</td>
</tr>
<tr>
<td>Balzi, M., see Becciolini, A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baugnet-Mahieu, L., see Grinfeld, S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baumgärtel, H., see Ehrlich, W.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beauvallet, M., see Fritsch, P.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beauvallet, M., see Fritsch, P.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Becker, W., see Dikomey, E.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berleur, F., see Vachon, A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bertaud, A. J., see Dardalhon, M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bettega, D., Calzolari, P., and Lombardi, L. T.: Effects of split-dose irradiation on survival and oncogenic transformation induced by 31 MeV protons in C3H10T1/2 cells</td>
<td></td>
<td>761</td>
</tr>
<tr>
<td>Birch, D. A.: see Bryant, P. E.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bjerring, P.: Intratumoural light distribution in an experimental mouse tumour irradiated by a diffuse-light irradiator compared with unilateral helium-neon light for photodynamic therapy</td>
<td></td>
<td>191</td>
</tr>
<tr>
<td>Bleehen, N. M., see Freedman, L.S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bobrovski, K., and Holcman, J.: Formation of three-electron bonds in one-electron oxidized methionine dipeptides: a pulse radiolytic study</td>
<td></td>
<td>139</td>
</tr>
<tr>
<td>Bors, W., see Erben-Russ, M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boyle, S.: Letter to the Editor: Radiation Standards and the ICRP meeting on 8 September 1987</td>
<td></td>
<td>499</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Title and Details</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------</td>
<td></td>
</tr>
<tr>
<td>Braquet, P.</td>
<td>see Vachon, A.</td>
<td></td>
</tr>
<tr>
<td>Brenner, D. J.</td>
<td>Letter to the Editor: Concerning the nature of the initial damage required for the production of radiation-induced exchange aberrations</td>
<td></td>
</tr>
<tr>
<td>Brizgys, L. M.</td>
<td>see Warters, R. L.</td>
<td></td>
</tr>
<tr>
<td>Bryant, P. E., Birch, D. A., and Jeggo, P. A.</td>
<td>High chromosomal sensitivity of Chinese hamster xrs 5 cells to restriction endonuclease induced DNA double-strand breaks</td>
<td></td>
</tr>
<tr>
<td>Bubeniková, D.</td>
<td>see Svoboda, V.</td>
<td></td>
</tr>
<tr>
<td>Bush, C.</td>
<td>see Schlappack, O. K.</td>
<td></td>
</tr>
<tr>
<td>Calzolari, P.</td>
<td>see Bettega, D.</td>
<td></td>
</tr>
<tr>
<td>Cameron Mitchell, J., and Norman, A.</td>
<td>The induction of micronuclei in human lymphocytes by low doses of radiation</td>
<td></td>
</tr>
<tr>
<td>Cametti, C.</td>
<td>see Bonincontro, A.</td>
<td></td>
</tr>
<tr>
<td>Camplejohn, R. S.</td>
<td>see Penhaligon, M.</td>
<td></td>
</tr>
<tr>
<td>Carsten, A. L.</td>
<td>Book review</td>
<td></td>
</tr>
<tr>
<td>Chakravarty, A.</td>
<td>see Abelidis, S.</td>
<td></td>
</tr>
<tr>
<td>Chan, P. K. L., Skov, K. A., and James, B. R.</td>
<td>Further studies on toxic and radiosensitizing properties of ruthenium complexes of 4-nitroimidazoles</td>
<td></td>
</tr>
<tr>
<td>Clark, A. W.</td>
<td>see Yatvin, M. B.</td>
<td></td>
</tr>
<tr>
<td>Clarkson, J. M.</td>
<td>see Mitchell, D. L.</td>
<td></td>
</tr>
<tr>
<td>Courteille, F.</td>
<td>see Fatome, M.</td>
<td></td>
</tr>
<tr>
<td>Courtenay, V. D.</td>
<td>see Penhaligon, M.</td>
<td></td>
</tr>
<tr>
<td>Csovcsics, C.</td>
<td>see Schuler, F.</td>
<td></td>
</tr>
<tr>
<td>Darai, G.</td>
<td>see Rösen, A.</td>
<td></td>
</tr>
<tr>
<td>Dardalhon, M., Averbeck, D., More, C., Berteaud, A. J., and Ravary, V.</td>
<td>Thermal effects of 2-45 GHz microwaves on survival and viability of Chinese hamster V-79 cells</td>
<td></td>
</tr>
<tr>
<td>Darden Jr., E. B.</td>
<td>see Friedberg, W.</td>
<td></td>
</tr>
<tr>
<td>Davids, J. A. G.</td>
<td>see Gasinska, A.</td>
<td></td>
</tr>
<tr>
<td>Davies, S.</td>
<td>see Prise, K. M.</td>
<td></td>
</tr>
<tr>
<td>Davies, S. E.</td>
<td>see O'Neill, P. O.</td>
<td></td>
</tr>
<tr>
<td>De Haas, M. P.</td>
<td>see Visscher, K. J.</td>
<td></td>
</tr>
<tr>
<td>De Ruiter-Bootsma, A.</td>
<td>see Gasinska, A.</td>
<td></td>
</tr>
<tr>
<td>Deal Jr, R. B.</td>
<td>see Friedberg, W.</td>
<td></td>
</tr>
<tr>
<td>Dean, S. W.</td>
<td>Some aspects of glutathione metabolism in ataxia-telangiectasia fibroblasts</td>
<td></td>
</tr>
<tr>
<td>Delic, J. I.</td>
<td>see Schlappack, O. K.</td>
<td></td>
</tr>
<tr>
<td>Dennis, M. F.</td>
<td>see Watts, M. E.</td>
<td></td>
</tr>
<tr>
<td>Dennis, W.</td>
<td>see Steeves, R. A.</td>
<td></td>
</tr>
<tr>
<td>Dikomey, E., Becker, W., and Wielckens, K.</td>
<td>Reduction of DNA-polymerase ß activity of CHO cells by single and combined heat treatments</td>
<td></td>
</tr>
<tr>
<td>Dische, S.</td>
<td>see Freedman, L. S.</td>
<td></td>
</tr>
<tr>
<td>Dutreix, J.</td>
<td>Book review</td>
<td></td>
</tr>
<tr>
<td>Eady, J. J.</td>
<td>see Stephens, T. C.</td>
<td></td>
</tr>
<tr>
<td>Eckardt-Schupp, F.</td>
<td>see Frankenberg, D.</td>
<td></td>
</tr>
<tr>
<td>Eguchi, K., Inada, T., Yaguchi, M., Satoh, S., and Kaneko, I.</td>
<td>Induction and repair of DNA lesions in cultured human melanoma cells exposed to a nitrogen-ion beam</td>
<td></td>
</tr>
<tr>
<td>Ehrlich, W., Mangir, M., Nothelfer, R., Baumgärtel, H., and Lochmann, E.-R.</td>
<td>Thiopyronine-sensitized photodynamic effect on cell growth, RNA and DNA synthesis of Chinese hamster ovary cells</td>
<td></td>
</tr>
<tr>
<td>Erben-Russ, M., Bors, W., and Saran, M.</td>
<td>Reactions of linoleic acid peroxyl radicals with phenolic antioxidants: a pulse radiolysis study</td>
<td></td>
</tr>
<tr>
<td>Ewing, D.</td>
<td>Radiation sensitization of E. coli B/r by mixtures of oxygen and nitrous oxide</td>
<td></td>
</tr>
<tr>
<td>Fanelli, E., see Albertini, G.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farrell, N. P., see Skov, K. A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatome, M., Courtelie, F., Laval, J. D., and Roman, V.: Radioprotective activity of ethylcellulose microspheres containing WR 2721, after oral administration</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Fatome, M., see Vachon, A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faulkner, D. N., see Friedberg, W.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feinendegen, L. E., and Mühlensiepen, H.: In vivo enzyme control through a strong stationary magnetic field—the case of thymidine kinase in mouse bone marrow cells</td>
<td>469</td>
<td></td>
</tr>
<tr>
<td>Feinendegen, L. E., see Schneeweiss, F. H. A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fen, S., see Hieber, L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feola, J. M., see Goud, S. N.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiedlen, E. M., see Austen, K. R. J.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Folcher, G., see Vachon, A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Folkard, M., see Gasinska, A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forni, L. G., see Mönig, J.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fowler, J. F., see Gasinska, A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frankenberg, D., see Frankenberg-Schwager, M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frankenberg-Schwager, M., Frankenberg, D., and Harbich, R.: Possible occurrence of DNA double-strand breaks during repair of u.v.-induced damage in yeast</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td>Friends of the Earth: Letter to the Editor</td>
<td>499</td>
<td></td>
</tr>
<tr>
<td>Fritsch, P., Beaumalvet, M., Jouiniaux, B., Moutairou, K., Metivier, H., and Masse, R.: Effects of the chemical forms and valency states of neptunium on its jejunal transfer in the rat</td>
<td>505</td>
<td></td>
</tr>
<tr>
<td>Fritsch, P., Beaumalvet, M., Moutairou, K., Metivier, H., and Masse, R.: Acute lesions induced by α-irradiation of intestine after plutonium gavage of neonatal rats</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Fritz-Niggli, H., see Balla, I.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fromke, F., see Hieber, L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gilles, J., see Grinfeld, S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gipp, J. J., see Mulcahy, R. T.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goodhead, D. T., and Nikjoo, H.: Physical mechanism for inactivation of metalloenzymes by characteristic X-rays: analysis of the data of Jawad and Watt</td>
<td>651</td>
<td></td>
</tr>
<tr>
<td>Goodhead, D. T., see Roberts, C. J.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grdina, D. J., see Hanson, W. R.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green, M. H. L., and Lowe, J. E.: Failure to detect a DNA repair-related defect in the transfection of ataxia-telangiectasia cells by enzymatically restricted plasmid</td>
<td>437</td>
<td></td>
</tr>
<tr>
<td>Grie, M. L. Book review</td>
<td>343</td>
<td></td>
</tr>
<tr>
<td>Author(s)</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Grinfeld, S., Gilles, J., Jacquet, P., and Baugnet-Mahieu, L.</td>
<td>Late division kinetics in relation to modification of protein synthesis in mouse eggs blocked in the G&lt;sub&gt;2&lt;/sub&gt; phase after X-irradiation</td>
<td>77</td>
</tr>
<tr>
<td>Guidoni, L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guidoni, L., see Albertini, G.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haipek, C. A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haipek, C. A., see Mitchell, D. L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hanson, W. R., and Grdina, D. J.</td>
<td>Radiation-induced DNA single-strand breaks in the intestinal mucosal cells of mice treated with the radioprotectors WR-2721 or 16-16 dimethyl prostaglandin E&lt;sub&gt;2&lt;/sub&gt;</td>
<td>67</td>
</tr>
<tr>
<td>Harbich, R., see Frankenberg-Schwager, M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harms-Ringdahl, M., Anderstam, B., and Vaca, C.</td>
<td>Heat-induced changes in the incorporation of [H&lt;sup&gt;3&lt;/sup&gt;]acetate in membrane lipids</td>
<td>315</td>
</tr>
<tr>
<td>Harms-Ringdahl, M., Skog, S., and Tribukait, B.</td>
<td>Membrane fatty acid composition and radiation response of Bp8 sarcoma ascites tumor cells</td>
<td>615</td>
</tr>
<tr>
<td>Hartmann, H., see Schuessler, H.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haustein, K., see Schneeweiss, F. H. A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hempel, K., and Mildenberger, E.</td>
<td>Determination of G-values for single and double strand break induction in plasmid DNA using agarose gel electrophoresis and a curve-fitting procedure</td>
<td>125</td>
</tr>
<tr>
<td>Hendry, J. H.</td>
<td>Book reviews</td>
<td>344,820</td>
</tr>
<tr>
<td>Henk, J. M., see Freedman, L. S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herskind, C.</td>
<td>Single-strand breaks can lead to complex configurations of plasmid DNA in vitro</td>
<td>565</td>
</tr>
<tr>
<td>Hodgkiss, R. J., Roberts, I. J., Watts, M. E., and Woodcock, M.</td>
<td>Rapid-mixing of radiosensitivity with thiol-depleted mammalian cells</td>
<td>735</td>
</tr>
<tr>
<td>Holcman, J., see Bobrowski, K.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Honess, D. J., see Freedman, L. S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hotz, G., and Seidel, A.</td>
<td>Association of plutonium with lysosomal, lipofuscin-like granules in Chinese hamster hepatocytes: evidence from electron microscopic and biochemical studies with &lt;sup&gt;241&lt;/sup&gt;Pu and &lt;sup&gt;239&lt;/sup&gt;Pu</td>
<td>723</td>
</tr>
<tr>
<td>Huutilainen, J., Lara, E., and Saali, K.</td>
<td>Relationship between field strength and abnormal development in chick embryos exposed to 50 Hz magnetic fields</td>
<td>787</td>
</tr>
<tr>
<td>Ianzini, F., see Albertini, G.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iida, S., see Ban, S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ikushima, T., see Niwa, O.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iliakis, G., Pantelias, G. E., Okayasu, R., and Seaner, R.</td>
<td>&lt;sup&gt;125&lt;/sup&gt;IdUrd-induced chromosome fragments, assayed by premature chromosome condensation, and DNA double-strand breaks have similar repair kinetics in G&lt;sub&gt;1&lt;/sub&gt;-phase CHO-cells</td>
<td>705</td>
</tr>
<tr>
<td>Inada, T., see Eguchi, K.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ishikawa, M., see Takakura, K.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ito, T., see Takakura, K.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iwakura, T., see Takeda, H.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jacquet, P., see Grinfeld, S.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>James, B. R., see Chan, P. K. L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jeggo, P. A., see Bryant, P. E.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jenner, T. J., see Austen, K. R. J.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Johanson, K. J., see Östling, O.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jones, N. R., see Watts, M. E.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jouniaux, B., see Fritsch, P.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juutilainen, J., Läärä, E., and Saali, K.</td>
<td>Relationship between field strength and abnormal development in chick embryos exposed to 50 Hz magnetic fields</td>
<td>787</td>
</tr>
</tbody>
</table>
Kagiya, T., see Shibamoto, Y.
Kaneko, I., see Eguchi, K.
Kano, E., see Kondo, T.
Kargačin, B., see Kostial, K.
Kellerer, A. M., see Hieber, L.
Kiss, I., see Travis, E. L.
Kistler, M., see Frankenber, D.
Kondo, T., and Kano, E.: Absence of synergistic enhancement of non-thermal effects of ultrasound on cell killing induced by ionizing radiation. 627
Konings, A. W. T., see Ruifrok, A. C. C.
\[^{141}\text{Ce}\] retention in suckling rats. 501
Kypěnová, H., see Svoboda, V.
Läärå, E., see Juutilainen, J.
Landeka, M., see Kostial, K.
Lanini, A., see Becciolini, A.
Laval, J. D., see Fatome, M.
Lecomte, C., see Vachon, A.
Lochmann, E.-R., see Ehrlich, W.
Loman, H., see Visscher, K. J.
Lombardi, L. T., see Bettega, D.
Louw, W. K. A., see van Rensburg, E. J.
Lowe, J. E., see Green, M. H. L.
Lyons, B. W., see Warters, R. L.

Mangir, M., see Ehrlich, W.
Mariani, P., see Albertini, G.
Martin, P., see Steeves, R. A.
Maruyama, Y., see Goud, S. N.
Masella, R., see Albertini, G.
Mason, K., see Taylor, J. M. G.
Masse, R., see Fritsch, P.
Masse, R., see Fritsch, P.
Metivier, H., see Fritsch, P.
Metivier, H., see Fritsch, P.
Metwally, M. M. K., and Moore, J. S.: Oxygen uptake during the \[\gamma\]-irradiation of fatty acids. 253
Mi, F., see Shibamoto, Y.
Michael, B. D., see Prise, K. M.
Michel, C., see Balla, I.
Mildenberger, E., see Hempel, K.
Miller, K., see Steeves, R. A.
Mönig, H., see Prütz, W. A.
Moore, J. S., see Abelidis, S.
Moore, J. S., see Metwally, M. M. K.
More, C., see Dardalhon, M.
Moreno, G., Atlante, A., Salet, C., Santus, R., and Vinzens, F.: Photosensitivity of DNA replication and respiration to haematoporphyrin derivative (Photofrin II) in mammalian CV-1 cells. 213
Morse, M. L., and Smith, D. S.: Cold-shock modification of the oxygen enhancement ratio of \textit{Escherichia coli} cells. 171
### Index of authors (with titles)

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moutairou, K., see Fritsch, P.</td>
<td></td>
</tr>
<tr>
<td>Moutairou, K., see Fritsch, P.</td>
<td></td>
</tr>
<tr>
<td>Mühlensiepen, H., see Feinendegen, L. E.</td>
<td></td>
</tr>
<tr>
<td>Mulcahy, R. T., Gipp, J. J., and Tanner, M. A.: Enhancement of misonidazole chemopotentiation by mild hyperthermia (41°C) <em>in vitro</em> and selective enhancement <em>in vivo</em></td>
<td>57</td>
</tr>
<tr>
<td>Neas, B. R., see Friedberg, W.</td>
<td></td>
</tr>
<tr>
<td>Nenot, J. C.</td>
<td>Book review</td>
</tr>
<tr>
<td>Nikjoo, H., see Goodhead, D. T.</td>
<td></td>
</tr>
<tr>
<td>Nishimoto, S., see Shibamoto, Y.</td>
<td></td>
</tr>
<tr>
<td>Niwa, O., Saigusa, T., Ikushima, T., and Sugahara, T.: Activation of endogeneous retroviruses in mouse cells by thermal neutrons</td>
<td>949</td>
</tr>
<tr>
<td>Norman, A., see Cameron Mitchell, J.</td>
<td></td>
</tr>
<tr>
<td>Nothelfer, R., see Ehrlich, W.</td>
<td></td>
</tr>
<tr>
<td>O'Neill, P. O., and Davies, S. E.: Pulse radiolytic study of the interaction of SO₄ with deoxynucleosides. Possible implications for direct energy deposition</td>
<td>577</td>
</tr>
<tr>
<td>O'Neill, P.</td>
<td>Book review</td>
</tr>
<tr>
<td>O'Neill, P. O., see Austen, K. R. J.</td>
<td></td>
</tr>
<tr>
<td>Okayasu, R., see Iliakis, G.</td>
<td></td>
</tr>
<tr>
<td>Orr, J. Stewart</td>
<td>Book review</td>
</tr>
<tr>
<td>Östling, O., and Johanson, K. J.: Bleomycin, in contrast to gamma irradiation, induced extreme variation of DNA strand breakage from cell to cell</td>
<td>683</td>
</tr>
<tr>
<td>Pantelias, G. E., see Iliakis, G.</td>
<td></td>
</tr>
<tr>
<td>Parker, D. E., see Friedberg, W.</td>
<td></td>
</tr>
<tr>
<td>Peacock, J. H., see Stephens, T. C.</td>
<td></td>
</tr>
<tr>
<td>Penhaligon, M., Courtenay, V. D., and Camplejohn, R. S.: Tumour Bed Effect: hypoxic fraction of tumours growing in preirradiated beds</td>
<td>635</td>
</tr>
<tr>
<td>Plonka, A.: Letter to the Editor: Kinetics of hydroxyl radical induced poly(U) strand break formation in pulse-irradiated aqueous solutions in the presence of oxygen</td>
<td>337</td>
</tr>
<tr>
<td>Pochin, E. E.: Meeting report: Health effects of low-dose ionising radiation—recent advances and their implications</td>
<td>659</td>
</tr>
<tr>
<td>Ponsel, G., see Hieber, L.</td>
<td></td>
</tr>
<tr>
<td>Porciani, S., see Becciolini, A.</td>
<td></td>
</tr>
<tr>
<td>Prise, K. M., Davies, S., and Michael, B. D.: The relationship between radiation-induced DNA double-strand breaks and cell kill in hamster V79 fibroblasts irradiated with 250kVp X-rays, 2-3 MeV neutrons or ²³⁸Pu α-particles</td>
<td>893</td>
</tr>
<tr>
<td>Radford, I. R.: Use of 'nuclear monolayers' to identify factors influencing DNA double-strand breakage by X-rays</td>
<td>853</td>
</tr>
<tr>
<td>Raju, M. R., see Freyer, J. P.</td>
<td></td>
</tr>
<tr>
<td>Ravary, V., see Dardalhon, M.</td>
<td></td>
</tr>
<tr>
<td>Roberts, C. J., and Goodhead, D. T.: The effect of ²³⁸Pu α-particles on the mouse fibroblast CEII line C3H 10T1/2: characterization of source and RBE for cell survival</td>
<td>871</td>
</tr>
<tr>
<td>Roberts, I. J., see Hodgkiss, R. J.</td>
<td></td>
</tr>
<tr>
<td>Robins, H. I., see Steeves, R. A.</td>
<td></td>
</tr>
<tr>
<td>Roman, V., see Fatome, M.</td>
<td></td>
</tr>
<tr>
<td>Roman, V., see Vachon, A.</td>
<td></td>
</tr>
<tr>
<td>Roos, H., see Hieber, L.</td>
<td></td>
</tr>
</tbody>
</table>
Rosi, A., see Bonincontro, A.
Rowley, R.: Comment on the paper by Grinfeld et al. ........................................ 87
Ruifrok, A. C. C., and Konings, A. W. T.: Effects of amiloride on hyperthermic cell killing of normal and thermotolerant mouse fibroblast LM cells ........... 385
Rustichelli, F., see Albertini, G.

Saali, K., see Juutilainen, J.
Saigusa, T., see Niwa, O.
Salet, C., see Moreno, G.
Santus, R., see Moreno, G.
Saran, M., see Erben-Russ, M.
Sasai, F., see Shibamoto, Y.
Sato, S., see Eguchi, K.
Sawada, S., see Ban, S.
Schuessler, H., and Hartmann, H.: The effect of a protein on the radiolysis of DNA studied by HPLC and pulse radiolysis ........................................ 269
Schuler, F., Csovcsics, C., and Taylor, D. M.: Differences in the uptake of transferrin bound 239Pu and 59Fe into multicellular spheroids of hepatocytes form adult male rats ........................................ 883
Schull, W. J. Book review ........................................ 497
Seener, R., see Iliakis, G.
Sedlak, A., see Svoboda, V.
Seidel, A., see Hotz, G.
Shecterle, L., see Steves, R. A.
Shibamoto, Y., Nishimoto, S., Mi, F., Sasai, K., Kagiya, T., and Abe, M.: Evaluation of various types of new hypoxic cell sensitizers using the EMT6 single cell-spheroid-solid tumour system ........................................ 347
Siegel, F. L., see Yatvin, M. B.
Skog, S., see Harms-Ringdahl, M.
Skov, K. A., and Farrell, N. P.: Binding mode of 2-amino-5-nitrothiazole (ANT) in platinum complexes, trans-[PtCl2(ANT)2], affects DNA binding, toxicity and radiosensitizing ability ........................................ 289
Skov, K. A., see Chan, P. K. L.
Smith, D. S., see Morse, M. L.
Smith, H.: Statement from the 1987 Como meeting of the International Commission on Radiological Protection ........................................ 969
Sportelli, L., see Bonincontro, C.
Stanley, J. A., see Schlappack, O. K.
Steel, G. G., see Schlappack, O. K.
Steel, G. G., see Stephens, T. C.
Stratford, I. J., see Walling, J. M.
<table>
<thead>
<tr>
<th>Name(s)</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stratford, M. R. L., see Watts, M. E.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugahara, T., see Niwa, O.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surdhar, P. S., and Armstrong, D. A.</td>
<td>Reduction of substituted flavins by (^{13}CO_2) and cyclic disulphide anions</td>
<td>419</td>
</tr>
<tr>
<td>Svoboda, V., Sedlak, A., Kypenova, H., and Budeníková, D.</td>
<td>Long-term effects of low-level (^{239}\text{Pu}) contamination on murine bone-marrow stem cells and their progeny</td>
<td>517</td>
</tr>
<tr>
<td>Takeda, H., and Iwakura, T.</td>
<td>Evaluation of radiation dose resulting from the ingestion of (^{3}\text{H})- and (^{14}\text{C})thymidine in the rat</td>
<td>957</td>
</tr>
<tr>
<td>Tanner, M. A., see Mulcahy, R. T.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taylor, D. M., see Rösen, A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taylor D. M., see Schuler, F.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taylor, J. M. G., Withers, H. R., Vegesna, V., and Mason, K.</td>
<td>Fitting the linear-quadratic model using time of occurrence as the end-point for quantal response multifraction experiments</td>
<td>459</td>
</tr>
<tr>
<td>Thames, H. D., see Travis, E. L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tisljar-Lentulin, G., see Schneeweiss, F. H. A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travis, E. L., Thames, H. D., Watkins, T. L., and Kiss, I.</td>
<td>The kinetics of repair in mouse lung after fractionated irradiation</td>
<td>903</td>
</tr>
<tr>
<td>Tribukait, B., see Harms-Ringdahl, M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twentyman, P.</td>
<td>Meeting report: Third International Conference on Spheroids in Cancer Research</td>
<td>811</td>
</tr>
<tr>
<td>Vaca, C., see Harms-Ringdahl, M.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vachon, A., Roman, V., Lecomte, C., Folcher, G., Fatôme, M., Braquet, P., and Berleur, F.</td>
<td>A radioprotector: cysteamine, inhibits oxygen transport in lipidic membranes</td>
<td>847</td>
</tr>
<tr>
<td>Van der Merwe, K. J., see van Rensburg, E. J.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegesna, V., see Taylor, J. M. G.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vinzens, F., see Moreno, G.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visscher, K. J., de Haas, M. P., Loman, H., Vojnovic, B., and Warman, J. M.</td>
<td>Fast protonation of adenosine and of its radical anion formed by hydrated electron attack; a nanosecond optical and de-conductivity pulse radiolysis study</td>
<td>745</td>
</tr>
<tr>
<td>Viti, V., see Albertini, G.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vojnovic, B., see Visscher, K. J.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walling, J. M., Stratford, I. J., and Adams, G. E.</td>
<td>Radiosensitization by the 2,4-dinitro-5-aziridinyl benzamide CB 1954: a structure/activity study</td>
<td>31</td>
</tr>
<tr>
<td>Warman, J. M., see Visscher, K. J.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watkins, T. L., see Travis, E. L.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watts, M. E., see Hodgkiss, R. J.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wielckens, K., see Dikomey, E.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Wilder, M. E., see Freyer, J. P.
Willson, R. L., see Mönig, J.
Withers, H. R., see Taylor, J. M. G.
Woodcock, M., see Hodgkiss, R. J.

Yaguchi, M., see Eguchi, K.
Yatvin, M. B., Clark, A. W., and Siegel, F. L.: Major \textit{E. coli} heat-stress proteins do not translocate: implications for cell survival .................................. 603

Yonnis, A.-R. S., see Watt, D.E.
**SUBJECT INDEX**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstracts (ARR/BIR meeting)</td>
<td>481</td>
</tr>
<tr>
<td>Abstracts (Netherlands Radiobiological Society)</td>
<td>643</td>
</tr>
<tr>
<td>Adenosine and its radial anion</td>
<td>745</td>
</tr>
<tr>
<td>Adenosine protonation</td>
<td>745</td>
</tr>
<tr>
<td>Adenosine radial anion protonation</td>
<td>745</td>
</tr>
<tr>
<td>Agarose electro-phoresis</td>
<td>667</td>
</tr>
<tr>
<td>AKR mouse leukemia</td>
<td>935</td>
</tr>
<tr>
<td>Alcohol dehydrogenase</td>
<td>413</td>
</tr>
<tr>
<td>Alpha irradiation</td>
<td>1, 859, 893</td>
</tr>
<tr>
<td>Amiloride</td>
<td>385</td>
</tr>
<tr>
<td>3-aminobenzamide</td>
<td>7</td>
</tr>
<tr>
<td>Anopthalmia</td>
<td>223</td>
</tr>
<tr>
<td>Antioxidants</td>
<td>393</td>
</tr>
<tr>
<td>ARR/BIR meeting (Abstracts)</td>
<td>481</td>
</tr>
<tr>
<td>Ataxia-telangiectasia</td>
<td>437</td>
</tr>
<tr>
<td>Auger electrons</td>
<td>651, 814</td>
</tr>
<tr>
<td>Bacteria, sensitisation</td>
<td>921</td>
</tr>
<tr>
<td>Biochemical indicators of tissue injury</td>
<td>767</td>
</tr>
<tr>
<td>BIR/ARR meeting (Abstracts)</td>
<td>481</td>
</tr>
<tr>
<td>Bleomycin, DNA damage</td>
<td>683</td>
</tr>
<tr>
<td>Bone marrow cells, thymidine kinase</td>
<td>469</td>
</tr>
<tr>
<td>Buthionine sulphoximine</td>
<td>735</td>
</tr>
<tr>
<td>C3H 10T1/2 cells</td>
<td>871</td>
</tr>
<tr>
<td>Californium-252, lethal and mutagenic effects</td>
<td>245</td>
</tr>
<tr>
<td>Californium-252, sperm abnormalities</td>
<td>755</td>
</tr>
<tr>
<td>Cavitation</td>
<td>627</td>
</tr>
<tr>
<td>CB1954</td>
<td>31</td>
</tr>
<tr>
<td>$^{141}$Ce</td>
<td>501</td>
</tr>
<tr>
<td>Cell age</td>
<td>91</td>
</tr>
<tr>
<td>Cell cycle</td>
<td>77, 87</td>
</tr>
<tr>
<td>Cell growth, photodynamic effects</td>
<td>207</td>
</tr>
<tr>
<td>Cell inactivation, $^{232}$Pu</td>
<td>871</td>
</tr>
<tr>
<td>Chain reactions</td>
<td>253</td>
</tr>
<tr>
<td>Chemopotentiation</td>
<td>57</td>
</tr>
<tr>
<td>Chernobyl (book review)</td>
<td>177</td>
</tr>
<tr>
<td>Chick embryos</td>
<td>787</td>
</tr>
<tr>
<td>Chinese hamster cells, sensitization</td>
<td>49</td>
</tr>
<tr>
<td>Chinese hamster ovary cells, photodynamic effects</td>
<td>207</td>
</tr>
<tr>
<td>CHO cells, hyperthermia</td>
<td>775</td>
</tr>
<tr>
<td>Chromatin superstructure</td>
<td>683</td>
</tr>
<tr>
<td>Chromosomal aberrations</td>
<td>517, 537, 805</td>
</tr>
<tr>
<td>Chromosome exchanges</td>
<td>805</td>
</tr>
<tr>
<td>Chromosome repair</td>
<td>705</td>
</tr>
<tr>
<td>Circadian effects</td>
<td>767</td>
</tr>
<tr>
<td>Cold-shock modification</td>
<td>171</td>
</tr>
<tr>
<td>Colony forming units (CFU)</td>
<td>935</td>
</tr>
<tr>
<td>Copper as radiosensitizer</td>
<td>677</td>
</tr>
<tr>
<td>Cyclobutane dimers</td>
<td>201</td>
</tr>
<tr>
<td>Cysteamine</td>
<td>847</td>
</tr>
<tr>
<td>Cysteine as radioprotector</td>
<td>677</td>
</tr>
<tr>
<td>Subject</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Dc conductivity</td>
<td>745</td>
</tr>
<tr>
<td>Deoxynucleoside radicals</td>
<td>577</td>
</tr>
<tr>
<td>Deuterons</td>
<td>795</td>
</tr>
<tr>
<td>Dicentric chromosome aberrations</td>
<td>805</td>
</tr>
<tr>
<td>Diet and radiation response</td>
<td>615</td>
</tr>
<tr>
<td>Diffuse visible-light irradiation</td>
<td>191</td>
</tr>
<tr>
<td>Dihydroreduced flavins</td>
<td>419</td>
</tr>
<tr>
<td>16-16 dimethyl prostaglandin E$_2$</td>
<td>67</td>
</tr>
<tr>
<td>Dispersive kinetics, poly(U) strand breaks</td>
<td>337</td>
</tr>
<tr>
<td>Dithiothreitol radical</td>
<td>419</td>
</tr>
<tr>
<td>Diurnal effects, polyamines in spleen</td>
<td>767</td>
</tr>
<tr>
<td>DNA damage by auger emitters</td>
<td>814</td>
</tr>
<tr>
<td>DNA double-strand breaks</td>
<td>107, 125, 185, 537, 555, 853, 893</td>
</tr>
<tr>
<td>DNA effects (ARR/BIR abstracts)</td>
<td>481</td>
</tr>
<tr>
<td>DNA polymerase $\beta$, hyperthermia</td>
<td>775</td>
</tr>
<tr>
<td>DNA radiation inactivation</td>
<td>677</td>
</tr>
<tr>
<td>DNA radiolysis, protein effect</td>
<td>269</td>
</tr>
<tr>
<td>DNA repair</td>
<td>115, 299, 437, 693, 705</td>
</tr>
<tr>
<td>DNA repair cell cycle</td>
<td>555</td>
</tr>
<tr>
<td>DNA replication, photosensitivity</td>
<td>213</td>
</tr>
<tr>
<td>DNA single-strand breaks</td>
<td>67, 125, 565</td>
</tr>
<tr>
<td>DNA strand breaks, periodical pattern</td>
<td>491</td>
</tr>
<tr>
<td>DNA transfection</td>
<td>437</td>
</tr>
<tr>
<td>DNA-protein crosslinking</td>
<td>269</td>
</tr>
<tr>
<td>DNA-unwinding technique</td>
<td>491</td>
</tr>
<tr>
<td>Dose assessment, biological indicators</td>
<td>177</td>
</tr>
<tr>
<td>Dose-rate effect, tumours</td>
<td>157</td>
</tr>
<tr>
<td>DTPA, $^{141}$Ce retention</td>
<td>501</td>
</tr>
<tr>
<td>E. coli</td>
<td>171, 603, 921</td>
</tr>
<tr>
<td>Electronic volume cell sorting</td>
<td>91</td>
</tr>
<tr>
<td>Embryonic development</td>
<td>787</td>
</tr>
<tr>
<td>Embryotoxicity</td>
<td>371</td>
</tr>
<tr>
<td>EMT6 cells</td>
<td>347</td>
</tr>
<tr>
<td>Enzyme demetallization</td>
<td>413</td>
</tr>
<tr>
<td>Erythrocyte membranes</td>
<td>447</td>
</tr>
<tr>
<td>ESR spin labelling</td>
<td>847</td>
</tr>
<tr>
<td>Excencephalia</td>
<td>223</td>
</tr>
<tr>
<td>Experimental mouse tumours</td>
<td>191</td>
</tr>
<tr>
<td>Experimental tumour systems</td>
<td>157</td>
</tr>
<tr>
<td>Far UV radiation</td>
<td>667</td>
</tr>
<tr>
<td>$^{59}$Fe, hepatocyte spheroid uptake</td>
<td>883</td>
</tr>
<tr>
<td>Flavin radicals</td>
<td>419</td>
</tr>
<tr>
<td>Flavones</td>
<td>393</td>
</tr>
<tr>
<td>Formate radicals</td>
<td>419</td>
</tr>
<tr>
<td>Fractionation, tumours and lung</td>
<td>157, 903</td>
</tr>
<tr>
<td>Free radicals, fatty acids</td>
<td>253</td>
</tr>
<tr>
<td>Friends of the Earth/ICRP letter</td>
<td>499</td>
</tr>
<tr>
<td>$G$-values</td>
<td>125</td>
</tr>
<tr>
<td>Glutathione</td>
<td>43, 185, 853</td>
</tr>
</tbody>
</table>
### Subject index

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haematoporphyrin derivative</td>
<td>213</td>
</tr>
<tr>
<td>Haemoglobin, membranes</td>
<td>447</td>
</tr>
<tr>
<td>Haemopoietic CFU-S</td>
<td>517</td>
</tr>
<tr>
<td>Heat stress proteins</td>
<td>603</td>
</tr>
<tr>
<td>Hepatocyte spheroids</td>
<td>883</td>
</tr>
<tr>
<td>Hepatocytes</td>
<td>723</td>
</tr>
<tr>
<td>Herpes simplex virus</td>
<td>795</td>
</tr>
<tr>
<td>Homeoviscous adaptation</td>
<td>315</td>
</tr>
<tr>
<td>HPLC, DNA radiolysis</td>
<td>269</td>
</tr>
<tr>
<td>Human organ systems, sensitivity</td>
<td>820</td>
</tr>
<tr>
<td>Human fibroblasts, glutathione</td>
<td>43</td>
</tr>
<tr>
<td>Hyperthermia</td>
<td>57, 299, 315, 385, 775</td>
</tr>
<tr>
<td>Hypoxic cell sensitizer</td>
<td>347</td>
</tr>
<tr>
<td>Hypoxic fraction</td>
<td>635</td>
</tr>
<tr>
<td>Hypoxic toxicity, platinum</td>
<td>289</td>
</tr>
<tr>
<td>ICRP</td>
<td>499, 969</td>
</tr>
<tr>
<td>Indirect action</td>
<td>651, 657</td>
</tr>
<tr>
<td>Infectivity of viral DNA</td>
<td>795</td>
</tr>
<tr>
<td>Intestinal absorption</td>
<td>505</td>
</tr>
<tr>
<td>Intratumoural dosimetry</td>
<td>191</td>
</tr>
<tr>
<td>Iodine-125</td>
<td>705</td>
</tr>
<tr>
<td>$^{125}$Iododeoxyuridine</td>
<td>517</td>
</tr>
<tr>
<td>Late effects</td>
<td>459</td>
</tr>
<tr>
<td>Late responding tissue</td>
<td>903</td>
</tr>
<tr>
<td>Leukemia</td>
<td>935</td>
</tr>
<tr>
<td>Linear quadratic model</td>
<td>459</td>
</tr>
<tr>
<td>Linoleic acid peroxyl radicals</td>
<td>393</td>
</tr>
<tr>
<td>Lipid biosynthesis</td>
<td>315</td>
</tr>
<tr>
<td>Lipid peroxidation</td>
<td>253</td>
</tr>
<tr>
<td>Lipophilicity</td>
<td>359</td>
</tr>
<tr>
<td>Liposomes</td>
<td>145</td>
</tr>
<tr>
<td>Logistic regression</td>
<td>459</td>
</tr>
<tr>
<td>Low dose rate</td>
<td>859</td>
</tr>
<tr>
<td>Low energy X-rays</td>
<td>651, 657</td>
</tr>
<tr>
<td>Low-dose ionizing radiation</td>
<td>659</td>
</tr>
<tr>
<td>Lung</td>
<td>903</td>
</tr>
<tr>
<td>Lymphocyte subpopulations</td>
<td>693</td>
</tr>
<tr>
<td>Lysosomes</td>
<td>723</td>
</tr>
<tr>
<td>Magnetic fields</td>
<td>469, 787</td>
</tr>
<tr>
<td>Mechanisms of sensitisation</td>
<td>921</td>
</tr>
<tr>
<td>Meeting reports</td>
<td>659, 811, 814, 969</td>
</tr>
<tr>
<td>Melanoma, DNA lesions</td>
<td>115</td>
</tr>
<tr>
<td>Membrane fatty acid composition</td>
<td>615</td>
</tr>
<tr>
<td>Membrane lipids</td>
<td>615</td>
</tr>
<tr>
<td>Membranes</td>
<td>315, 447, 603</td>
</tr>
<tr>
<td>Metal uptake, spheroids</td>
<td>883</td>
</tr>
<tr>
<td>Metallo-enzymes, inactivation</td>
<td>651, 657</td>
</tr>
<tr>
<td>Methionine dipeptides</td>
<td>139</td>
</tr>
<tr>
<td>Microspheres, WR2721</td>
<td>21</td>
</tr>
<tr>
<td>Microwaves</td>
<td>325</td>
</tr>
<tr>
<td>Military radiobiology (book review)</td>
<td>344</td>
</tr>
<tr>
<td>Misonidazole</td>
<td>57, 281, 965</td>
</tr>
<tr>
<td>Mouse eggs, G2 block</td>
<td>77</td>
</tr>
<tr>
<td>Mouse fibroblasts, amiloride effects</td>
<td>385</td>
</tr>
<tr>
<td>Subject Index</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Multiple chromosome breaks, mechanism</td>
<td>805</td>
</tr>
<tr>
<td>Mutant cell line, restriction enzymes</td>
<td>537</td>
</tr>
<tr>
<td>Mutation, Californian 252</td>
<td>245</td>
</tr>
<tr>
<td>Neoplastic transformation</td>
<td>859</td>
</tr>
<tr>
<td>Neptunium</td>
<td>505</td>
</tr>
<tr>
<td>Netherlands Radiobiological Society (Abstracts)</td>
<td>643</td>
</tr>
<tr>
<td>Neutron-induced DNA damage</td>
<td>893</td>
</tr>
<tr>
<td>Neutrons</td>
<td>237, 755</td>
</tr>
<tr>
<td>Nitrogen-ion beam</td>
<td>115</td>
</tr>
<tr>
<td>Nitrotriazole</td>
<td>347</td>
</tr>
<tr>
<td>2-nitroimidazole nucleoside</td>
<td>347</td>
</tr>
<tr>
<td>2-nitroimidazoles</td>
<td>359</td>
</tr>
<tr>
<td>Nitroimidazoles</td>
<td>49</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>921</td>
</tr>
<tr>
<td>Non-thermal effects</td>
<td>627</td>
</tr>
<tr>
<td>Nuclear matrix</td>
<td>299</td>
</tr>
<tr>
<td>Nucleoids</td>
<td>299, 693</td>
</tr>
<tr>
<td>Oral therapy, Zn-DTPA</td>
<td>501</td>
</tr>
<tr>
<td>Organ, human sensitivity</td>
<td>820</td>
</tr>
<tr>
<td>Oxygen, sensitisation</td>
<td>921</td>
</tr>
<tr>
<td>Oxygen addition, thyl radicals</td>
<td>589</td>
</tr>
<tr>
<td>Oxygen effect, DNA degradation</td>
<td>677</td>
</tr>
<tr>
<td>Oxygen effect in seeds</td>
<td>827</td>
</tr>
<tr>
<td>Oxygen enhancement ratio</td>
<td>171, 185</td>
</tr>
<tr>
<td>Oxygen modifiers (ARR/BIR abstracts)</td>
<td>481</td>
</tr>
<tr>
<td>Oxygen transport in membranes</td>
<td>847</td>
</tr>
<tr>
<td>Oxygen uptake, fatty acids</td>
<td>253</td>
</tr>
<tr>
<td>Photodynamic effect</td>
<td>207</td>
</tr>
<tr>
<td>Photodynamic therapy</td>
<td>191</td>
</tr>
<tr>
<td>(6—4) photoproducts</td>
<td>201</td>
</tr>
<tr>
<td>Photosensitivity</td>
<td>213</td>
</tr>
<tr>
<td>Plasmid col El DNA</td>
<td>667</td>
</tr>
<tr>
<td>Plasmid DNA, single strand breaks.</td>
<td>565</td>
</tr>
<tr>
<td>Platinum</td>
<td>289</td>
</tr>
<tr>
<td>Plutonium 239</td>
<td>517, 723, 883</td>
</tr>
<tr>
<td>Plutonium 238</td>
<td>1</td>
</tr>
<tr>
<td>Poly(U)</td>
<td>337</td>
</tr>
<tr>
<td>Polyamines</td>
<td>767</td>
</tr>
<tr>
<td>Premature chromosome condensation</td>
<td>705</td>
</tr>
<tr>
<td>Prenatal mortality</td>
<td>223</td>
</tr>
<tr>
<td>Proportional hazards model</td>
<td>459</td>
</tr>
<tr>
<td>Protonation</td>
<td>745</td>
</tr>
<tr>
<td>Protons</td>
<td>761</td>
</tr>
<tr>
<td>Protracted irradiation</td>
<td>859</td>
</tr>
<tr>
<td>$^{238}$Pu $\alpha$-particles</td>
<td>871</td>
</tr>
<tr>
<td>Pulse radiolysis</td>
<td>139, 577, 745</td>
</tr>
<tr>
<td>Radiation protection</td>
<td>21, 67</td>
</tr>
<tr>
<td>Radiation sensitivity mechanisms, E. coli</td>
<td>921</td>
</tr>
<tr>
<td>Radiation sensitizers</td>
<td>31, 49</td>
</tr>
<tr>
<td>Radioimmunoassay, (6-4) photoproducts in XP cells</td>
<td>201</td>
</tr>
<tr>
<td>Radiological protection, ICRP</td>
<td>969</td>
</tr>
<tr>
<td>Radionuclide ingestion, dosimetry</td>
<td>957</td>
</tr>
<tr>
<td>Radiosensitivity, glutathione metabolism</td>
<td>43</td>
</tr>
<tr>
<td>Subject index</td>
<td>PAGE</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Radiosensitization</td>
<td>281, 677</td>
</tr>
<tr>
<td>Radiosensitizer, platinum</td>
<td>289</td>
</tr>
<tr>
<td>Radiosensitizers, 2-nitroimidazoles</td>
<td>359</td>
</tr>
<tr>
<td>Rapid-mix, sensitisation</td>
<td>281</td>
</tr>
<tr>
<td>Rate constants, thiyl radicals</td>
<td>589</td>
</tr>
<tr>
<td>Relative biological effectiveness (RBE)</td>
<td>237, 245, 871</td>
</tr>
<tr>
<td>Repair, nuclear matrix protein</td>
<td>299</td>
</tr>
<tr>
<td>Repair kinetics, strand breaks and lung</td>
<td>491, 903</td>
</tr>
<tr>
<td>Repair of potentially lethal damage</td>
<td>705</td>
</tr>
<tr>
<td>Respiration, photosensitivity</td>
<td>213</td>
</tr>
<tr>
<td>Restriction endonuclease, chromosome breaks</td>
<td>537</td>
</tr>
<tr>
<td>RNA and DNA synthesis, thiopyronine photosenzitisation</td>
<td>207</td>
</tr>
<tr>
<td>RSU 1069, rapid mix</td>
<td>281</td>
</tr>
<tr>
<td>Ruthenium, complexes</td>
<td>49</td>
</tr>
<tr>
<td>Sarcoma ascites tumour cells</td>
<td>615</td>
</tr>
<tr>
<td>SCE sensitizers</td>
<td>481</td>
</tr>
<tr>
<td>Seeds</td>
<td>827</td>
</tr>
<tr>
<td>Single-strand DNA breaks</td>
<td>667</td>
</tr>
<tr>
<td>Skin, radiation damage</td>
<td>481</td>
</tr>
<tr>
<td>Soft X-rays</td>
<td>805</td>
</tr>
<tr>
<td>Sperm shape abnormalities</td>
<td>755</td>
</tr>
<tr>
<td>Spermatogonia</td>
<td>7, 237</td>
</tr>
<tr>
<td>Spermidine</td>
<td>767</td>
</tr>
<tr>
<td>Spermine</td>
<td>767</td>
</tr>
<tr>
<td>Spheroids</td>
<td>347, 811, 883</td>
</tr>
<tr>
<td>Spleen</td>
<td>767</td>
</tr>
<tr>
<td>Split dose effects</td>
<td>761</td>
</tr>
<tr>
<td>Storage effect in seeds</td>
<td>822</td>
</tr>
<tr>
<td>Strand breakage in poly (U)</td>
<td>337</td>
</tr>
<tr>
<td>Structural modification in liposomes</td>
<td>145</td>
</tr>
<tr>
<td>Structure/activity relationship, sensitizers</td>
<td>31</td>
</tr>
<tr>
<td>Substituted flavins</td>
<td>419</td>
</tr>
<tr>
<td>Suckling rats, $^{141}$Ce retention</td>
<td>501</td>
</tr>
<tr>
<td>Sulphate radical anion</td>
<td>577</td>
</tr>
<tr>
<td>Supercoiling of DNA</td>
<td>693</td>
</tr>
<tr>
<td>T1-cells, DNA repair</td>
<td>491</td>
</tr>
<tr>
<td>Targetting, platinum</td>
<td>289</td>
</tr>
<tr>
<td>Temperature effects on seed sensitivity</td>
<td>827</td>
</tr>
<tr>
<td>Testis, spermatogonical sensitivity</td>
<td>7, 237</td>
</tr>
<tr>
<td>Testis weight, Californium 252</td>
<td>755</td>
</tr>
<tr>
<td>6-TGr, Californium 252</td>
<td>245</td>
</tr>
<tr>
<td>Thermal effects of microwaves</td>
<td>325</td>
</tr>
<tr>
<td>Thermal neutrons, viruses</td>
<td>949</td>
</tr>
<tr>
<td>Thermosensitization</td>
<td>775</td>
</tr>
<tr>
<td>Thermotolerance</td>
<td>315, 385, 775</td>
</tr>
<tr>
<td>Thiol-depleted mammalian cells</td>
<td>735</td>
</tr>
<tr>
<td>Thiols, DNA breaks</td>
<td>853</td>
</tr>
<tr>
<td>Thiopyronine, photodynamic effects</td>
<td>207</td>
</tr>
<tr>
<td>Thiyl radicals, oxygen effect</td>
<td>589</td>
</tr>
<tr>
<td>Three-electron bond, methionine dipeptides</td>
<td>139</td>
</tr>
<tr>
<td>$^{14}$C-thymidine, dosimetry after ingestion</td>
<td>957</td>
</tr>
<tr>
<td>$^3$H thymidine, dosimetry after ingestion</td>
<td>957</td>
</tr>
<tr>
<td>Thymidine kinase, magnetic fields</td>
<td>469</td>
</tr>
<tr>
<td>Total body irradiation (TBI), leukaemia</td>
<td>935</td>
</tr>
<tr>
<td>Transferrin, spheroids</td>
<td>883</td>
</tr>
<tr>
<td>Subject index</td>
<td>PAGE</td>
</tr>
<tr>
<td>---------------</td>
<td>------</td>
</tr>
<tr>
<td>Transformation, proton induced</td>
<td>761</td>
</tr>
<tr>
<td>Translocation, heat stress protein</td>
<td>603</td>
</tr>
<tr>
<td>Tumour bed effect</td>
<td>635</td>
</tr>
<tr>
<td>U.V. damage</td>
<td>107</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>627</td>
</tr>
<tr>
<td>Vacuum UV radiation, DNA breaks</td>
<td>667</td>
</tr>
<tr>
<td>Valency states, neptunium</td>
<td>505</td>
</tr>
<tr>
<td>Vasculature (BIR/ARR abstracts)</td>
<td>481</td>
</tr>
<tr>
<td>Vindesine, prenatal development</td>
<td>371</td>
</tr>
<tr>
<td>Virus induction, thermal neutrons</td>
<td>949</td>
</tr>
<tr>
<td>Water content of seeds</td>
<td>827</td>
</tr>
<tr>
<td>Whole body hyperthermia (WBH)</td>
<td>935</td>
</tr>
<tr>
<td>WR-2721</td>
<td>21, 67</td>
</tr>
<tr>
<td>X-rays and vindesine, prenatal development</td>
<td>371</td>
</tr>
<tr>
<td>Xeroderma pigmentosum</td>
<td>201</td>
</tr>
<tr>
<td>Yeast</td>
<td>107, 185</td>
</tr>
<tr>
<td>Zn-DTPA, $^{141}$Ce retention</td>
<td>501</td>
</tr>
</tbody>
</table>