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A Bibliography of Marine Radiation Ecology Prepared for the Seabed Program

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Sandia National Laboratories

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PREFACE

References on the effects of ionizing radiation on aquatic organisms have been obtained from a number of sources. Many were obtained from reviews and other publications. Although the primary purpose of preparing this bibliography was to obtain information related to the nuclear wastes Seabed Disposal Biology Program of Sandia Laboratories, I included freshwater organisms as a matter of convenience and also with the belief that such a bibliography would be of interest to a wider audience than that restricted to the Seabed Program. While compilation of a list in an area broad in scope is often somewhat arbitrary, an attempt was made to reference publications that were related to field or laboratory studies of wild species of plants and animals with respect to radiation effects.

In compiling this list, I have attempted to provide complete information concerning each reference without excessive library search. Since one often finds references listed in the literature that are incompletely cited, it was not always possible to locate the reference for verification or completion of the citation. I have included such references where they appeared to be of possible value. When known, a reference is followed with its Nuclear Science Abstract designation, or rarely other abstract sources. Those desiring additional information should check Nuclear Science Abstracts utilizing the abstract number presented or other abstracting sources. In addition, the language of the article, other than English, is given when it is known to me.

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**SOURCES OF INFORMATION
ON MARINE RADIATION ECOLOGY**

by

Vincent Schultz

The following selected list of bibliographies, proceedings and books concerning or related to marine radiation ecology was prepared to assist the reader interested in furthering his knowledge of the subject.

For those publications that might be considered rather difficult to locate, I have given the Nuclear Science Abstracts (NSA) citation number when known. All titles are presented in English, even though the original title is in another language. If the publication is not available in English, the foreign language involved is indicated.

Aleksakhin, R. M. (ed.). 1977. *Radioecology of Animals. Materials of I All-Union Conference.* A. N. Severtsov Institute of Evolutional Morphology and Ecology of Animals. "Nauka," Moscow. 266 pp. (In Russian).

Ancellin, J., P. Guegueniat and P. Germain. 1979. *Marine Radioecology. Study of Accumulation of Radionuclides Disposed into the Marine Environment and Applications to Radiation Protection.* Librairie de l'Enseignement Technique, Paris. 272 pp.

Andrushaitis, G. P. (ed.). 1973. *Radioecology of Water Organisms. Vol. 2. Distribution and Migration of Radionuclides in Freshwater and Seawater Biocenoses.* "Zinatne," Riga. 339 pp. (English transl., 1975. AEC-tr-7606; iv, 194 pp.). (NSA 30(8); 21082; 32(6); 14310).

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- Anonymous. 1968. International Symposium on the Application of Neutron Activation Analysis in Oceanography. Brussels, Belgium, 17-22 June, 1968. Institut Royal des Sciences Naturelles de Belgique, Bruxelles. 218 pp. (NSA 25(8): 15535).
- Anonymous. 1972. Marine Radioecology. The Cycling of Artificial Radionuclides Through Marine Food Chains. Proc. Second ENEA Seminar, Hamburg, Germany, September 20-24, 1971. Organisation de Cooperation et de Developpement Economiques, Paris. 209 pp. (In English with English and French discussions) (NSA 29(1): 405).
- Baranov, V. I. and L. M. Khitrov (eds.). 1964. Radioactive Contamination of the Seas and Oceans. "Mauka," Moscow. 224 pp. (English transl., 1964. JPRS 26,002 (Partial translation); 1966. AEC-tr-6641; vi, 194 pp.). (NSA 18(19): 33779; 21(6): 8471).
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- Hines, N. O. 1962. Proving Ground: An Account of the Radiobiological Studies in the Pacific, 1946-1961. University of Washington Press, Seattle, WA. xvii, 366 pp.
- International Atomic Energy Agency. 1969. Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters. Proc. of a Symposium, Vienna, 16-20 May, 1966. Vienna, Austria, Publication STI/PUB/126. (viii), 898 pp.
- International Atomic Energy Agency. 1970. Reference Methods for Marine Radioactivity Studies. Vienna, Austria, Tech. Repts. Series No. 118. (vi), 284 pp. (STI/DOC/10/118).
- International Atomic Energy Agency. 1973. Radioactive Contamination of the Marine Environment. Proc. of a Symposium held in Seattle, Washington, USA, 10-14 July, 1972. Vienna, Austria, Publication STI/PUB/313. (xii), 786 pp.
- International Atomic Energy Agency. 1975. Design of Radiotracer Experiments in Marine Biological Systems. Vienna, Austria, Tech. Repts. Series No. 167. (v), 289 pp. (STI/DOC/167).
- International Atomic Energy Agency. 1975. Reference Methods for Marine Radioactivity Studies II. Vienna, Austria, Tech. Repts. Series No. 169. (v), 239 pp. (STI/DOC/10/169).
- International Atomic Energy Agency. 1976. Effects of Ionizing Radiation on Aquatic Organisms and Ecosystems. Vienna, Austria, Tech. Repts. Series No. 172. (vii), 131 pp. (STI/DOC/10/172).
- International Atomic Energy Agency. 1979. Methodology for Assessing Impacts of Radioactivity on Aquatic Ecosystems. Vienna, Austria, Tech. Repts. Series No. 190. (v), 416 pp. (STI/DOC/10/190).
- Ostroumov, E. A. (ed.). 1975. Chemical Analysis of Marine Sediments. "Nauka," Moscow. 160 pp. (In Russian) (NSA 33(5), 8847).
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- Schultz, V. 1976. Russian radioecology: A bibliography of Soviet publications with citations of English translations and abstracts. U. S. ERDA report TID-3915 (Suppl. 2). v, 80 pp.

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SELECTED REVIEW ARTICLES
ON EFFECTS OF IONIZING RADIATION ON AQUATIC ORGANISMS

by

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1979

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EFFECTS OF IONIZING RADIATION ON AQUATIC ORGANISMS:
A BIBLIOGRAPHY

by

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PREFACE

References on the effects of ionizing radiation on aquatic organisms have been obtained from a number of sources. Many were obtained from reviews and other publications. Although the primary purpose of preparing this bibliography was to obtain information related to the nuclear wastes Seabed Disposal Biology Program of Sandia Laboratories, I included freshwater organisms as a matter of convenience and also with the belief that such a bibliography would be of interest to a wider audience than that restricted to the Seabed Program. While compilation of a list in an area broad in scope is often somewhat arbitrary, an attempt was made to reference publications that were related to field or laboratory studies of wild species of plants and animals with respect to radiation effects.

In compiling this list, I have attempted to provide complete information concerning each reference without excessive library search. Since one often finds references listed in the literature that are incompletely cited, it was not always possible to locate the reference for verification or completion of the citation. I have included such references where they appeared to be of possible value. When known, a reference is followed with its Nuclear Science Abstract designation, or rarely other abstract sources. Those desiring additional information should check Nuclear Science Abstracts utilizing the abstract number presented or other abstracting sources. In addition, the language of the article, other than English, is given when it is known to me.

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Symbols

AEC-tr-	U. S. Atomic Energy Commission translation
BA	<u>Biological Abstracts</u>
CA	<u>Chemical Abstracts</u>

CONF	U. S. AEC conference designation
EPA	Environmental Protection Agency (U. S.)
ERA	Energy Research Abstracts
JPRS	Joint Publications Research Service, New York (See also TT-)
NP	Report numbers assigned by U. S. AEC for non-AEC reports
NSA	<u>Nuclear Science Abstracts</u>
NTIS	National Technical Information Service, Springfield, VA. 22151 (formerly CFSTI)
OTS	Office of Technical Services, U. S. Department of Commerce, Washington, DC. 20230 (Most reports listed are now available through NTIS instead of OTS.)
STI/PUB/	International Atomic Energy Agency order numbers
TT-	OTS and NTIS order numbers
U. S. AEC	United States Atomic Energy Commission
U. S. ERDA	United States Energy Research and Development Administration (formerly U. S. AEC)
U. S. DOE	United States Department of Energy

DEDICATION

Dr. G. G. Polikarpov, Institute of Biology of South Seas, Sevastopol, and his many colleagues in the USSR, for contribution to our knowledge of marine radioecology.

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I. PLANTS

A. ALGAE

1. Chlorophyceae

(Acetabularia)

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2. Charaphyceae

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II. ANIMALS

A. INVERTEBRATES

1. Protozoa

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ECOLOGICAL MODELING IN RADIATION ECOLOGY:

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**AQUATIC RADIATION ECOLOGY:
SELECTED REFERENCES ON DOSE AND DOSIMETRY**

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**ECOLOGICAL ASPECTS OF RADIOACTIVE WASTE DISPOSAL
INTO THE SEA: SOME GENERAL REFERENCES**

by

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EFFECTS OF IONIZING RADIATION ON AQUATIC ORGANISMS:

SELECTED TABLES

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TABLE I
EFFECTS OF INCORPORATED RADIONUCLIDES ON DEVELOPING FISH EGGS

Radionuclides	Species	Stage exposure commenced	Biological end point	Concentration ($\mu\text{Ci/ml}$) and observed effects	Reference
^{90}Sr - ^{90}Y	<i>Engraulis encrasicolus</i>	Shortly after fertilization	Hatching Growth rate Abnormalities	2×10^{-4} , decreased Retarded 2×10^{-4} , increased	Polikarpov and Ivanov (1961)
^{90}Sr - ^{90}Y	<i>Serranus scriba</i>	Shortly after fertilization	Hatching Growth rate	2×10^{-4} , no effect 2×10^{-3} , retarded	
^{90}Sr - ^{90}Y	<i>Salmo trutta</i>	Immediately after fertilization	Hatching Abnormal larvae	10^{-4} No effect	
^{90}Sr - ^{90}Y	<i>Plurimectes platessa</i>	Immediately after fertilization	Hatching Abnormal larvae	10^{-4} No effect	Brown and Templeton (1966)
^{90}Sr - ^{90}Y	<i>Scorpena porcus</i>	Developing eggs	Chromosome breaks	10^{-4} , increased	
^{90}Sr - ^{90}Y ^{137}Cs	<i>Salmo salar</i>	Sixth stage	Death of fry and embryos	5×10^{-4} , ^{90}Sr ; 2.5×10^{-4} , ^{137}Cs , increased	Tsyutgina (1971) Fedorov (1962)
^{90}Sr - ^{90}Y	<i>Tinca tinca</i>	Shortly after fertilization	Hatching Abnormalities	1×10^{-4} No effect	
^{90}Sr - ^{90}Y	<i>Mugilurus fossilis</i>	Shortly after fertilization	Mortality	1.0 , ^{90}Sr - ^{90}Y No effect	Kulikov et al. (1968) Shekhanova et al. (1973)
^{137}Cs + ^{90}Sr - ^{90}Y	<i>Salmo clarki</i>	—	Abnormalities	10^{-4} , ^{137}Cs + ^{90}Sr + ^{239}Pu	
^{239}Pu	<i>Oncorhynchus gorbuscha</i>	—	Mitotic index Oxygen consumption	10^{-4} , ^{239}Pu 10^{-4} , ^{90}Sr - ^{90}Y , depressed	
^{90}Sr - ^{90}Y	Caspian salmon	Early stage of development	Mortality	1.75×10^{-4} , increased	Dokholyan et al. (1973)
	Sturgeon	—	Cytological index	Not significant	
	Starred sturgeon	—	—	—	
	White sturgeon	—	Oxygen consumption	Depressed	
Fission products:— ^{137}Cs , ^{140}Ba , ^{141}La , ^{144}Ru , ^{146}Rh	<i>Coregonus peled</i>	Late gastrula	Dead eggs Hatching	Equivalent doses above 500 rads decreased hatching	Mazheva and Sukal'skaya (1973)
Fission products:— ^{137}Cs , ^{90}Sr , ^{146}Co	<i>Dentex canadensis</i> <i>Trachurus trachurus</i> <i>Trichurus lepturus</i>	Shortly after fertilization	Dead eggs Abnormalities	10^{-4} No effect	
^{90}Sr - ^{90}Y	<i>Ctenopharyngodon idella</i>	Shortly after fertilization	Dead eggs Abnormalities	1.10×10^{-4} Increased	Nilev (1973)
^{144}Co - ^{144}Pr	<i>Pimephales promelas</i>	Conads and developing eggs	Abnormalities	1.2×10^{-4} No effects	
^{239}Pu , ^{235}U	<i>Cyprinus carpio</i>	Immediately after fertilization	Hatching Abnormalities	7.5 , ^{239}Pu and 5.0 , ^{235}U , decreased 3.9 , ^{239}Pu and 1.2 , ^{235}U , increased	Trabalka (1971) Till et al. (1970)
^{239}Pu , ^{235}U	<i>Pimephales promelas</i>	Blastula	Hatching Abnormalities	1.3 , ^{239}Pu and 0.5 , ^{235}U , decreased 0.20 , ^{239}Pu and 0.2 , ^{235}U , increased	
^{14}C	<i>Cerastius cerastius</i> <i>Rutilus rutilus</i> <i>Alburnus alburnus</i> <i>Acrinia cernua</i>	8-16 Blastomeres	Hatching Abnormalities Mortality	2×10^{-4} , decreased Increased Increased	

Table I. continued.

Source: Blaylock, B. C. and J. R. Trabalka. 1978. Evaluating the effects of ionizing radiation on aquatic organisms. *Advances in Radiation Biology* 7: 103-152.

TABLE I (Continued)

Radionuclides	Species	Stage exposure commenced	Biological end point	Concentration ($\mu\text{Ci/ml}$) and observed effects	Reference
^{131}I	<i>Cyprinus carpio</i>	Immediately after fertilization	Hatching	518 No effect	Blaylock <i>et al.</i> (1970)
^{90}Sr	<i>Gasterosteus aculeatus</i>	Immediately after fertilization	Mortality Abnormalities Eye diameter	2000 No effect 1000, reduced	Walden (1971)
^{131}I	<i>Salmo gairdneri</i>	Immediately after fertilization	Hatching Abnormalities	10 No effects	Strand <i>et al.</i> (1973)
^{131}I	<i>Paralichthys olivaceus</i>	16-Cell stage	Hatching	10 No effect	Ichikawa and Suyama (1974)
	<i>Fugu niphobles</i>	2-Cell stage	Hatching	10 Decreased	
^{131}I	<i>Salmo gairdneri</i>	6 hrs After fertilization	Immune response of fry	1 Suppressed	Strand <i>et al.</i> (1973)

Source: Bowen, V. T., J. S. Olsen, C. L. Osterbert and J. Ravera. 1971.
 Chp. 8. Ecological interactions of marine radioactivity.
 pp. 200-222. In: Radioactivity in the Marine Environment.
 National Academy of Sciences, Washington, DC.

TABLE 1 Properties of Classes of Marine Ecosystems Relevant to Their Responses to Introduced Radioactivity

Property	Pelagic: Open Ocean	Benthic: Open Ocean	Near-Shore: Benthic and Pelagic
Adsorptive surfaces	Largely biological	Bottom and resuspended sediment	Bottom, resuspended sediment, and terrigenous detritus
Physicochemical stability	Quite stable	Very stable	Maximum variability
Productivity	Only in euphotic-zone plankton	None	Euphotic zone plankton and attached to bottom - generally high
Primary nutrient supply	Largely by water mixing	Not important	Largely from land and bottom
Size range of primary producers	Mostly microscopic	-	Small to very large
Size range of herbivores	Mostly small	-	Moderate to large
Food chain length range	Mostly long	Moderate	Short
Population mobility	Maximum - plankton by currents, benthon by swimming	Very low - most by larval travel	Both high and low
Accessibility to man, both exploitation and effects	Intermediate to minimal	Minimal	Maximal

Source: Chipman, W. A. 1972. Ionizing radiation. pp. 1579-1657. In: Marine Ecology, Volume I, Part 3. (O. Kinne, ed.). Wiley-Interscience, NY.

Table 11-3

Radiation dosage (millirads per year) received by two types of marine organisms from natural sources (After Folsom and HARLEY, 1957; modified)

Type of organism and its location in the sea	Type of radiation			Approx. total dose
	Cosmic	Sea	Internal	
Large fishes				
Near sea surface	35	0.9	28	64
At 100 m depth	0.5	0.9	28	30
Micro-organisms (Mean radius 0.01 mm or less)				
Near sea surface	35	3.6	—*	39
At 100 m depth	0.5	3.6	—*	5
Buried in deep-sea sediment	0.000	40-620**	—*	40-620

* insignificant dose

** dose from radium in clay

Source: Cosgrove, G. E., B. G. Blaylock, G. U. Ulrikson and P. H. Cohen.
1975. Radiation-induced hematopoietic lesions in fish.
pp. 463-476. In: The Pathology of Fishes. (W. E. Ribelin
and G. Migaki, eds.). Univ. of Wisconsin Press, Madison.

Table 19.2. Studies on Hematopoietic Effects of Radiation in Fish^a

Author(s)	Year	Reference number	Organism
Aoki	1963	2	<i>Carassius</i>
Aoki	1966	3	<i>Carassius</i>
Blaylock & Mitchell	1969	5	<i>Gambusia</i>
Bonham et al.	1948	6	Salmon fingerling
Egami	1969	13	<i>Oryzias</i>
Ellinger	1940	18	<i>Carassius</i>
Engel et al.	1966	19	<i>Lagodon</i>
Finstad et al.	1969	24	<i>Myxine, Petromyzon</i>
Hevry et al.	1964	27	<i>Tinca</i>
Nakatani & Foster	1963	34	Rainbow trout
Preston	1959	38	Plaice
Ray	1970	40	<i>Campestris</i>
Sheehmeister et al.	1962	50	<i>Carassius</i>
Stetten et al.	1964	51	<i>Tinca</i>
Watson et al.	1963	55	<i>Carassius</i>
Welander et al.	1948	57	Salmon larvae
Welander et al.	1949	58	Rainbow trout

^aReviews and special articles are not included. Other articles are listed in the References.

Source: Godward, M. B. E. 1962. Invisible radiations. pp. 551-566. In: Physiology and Biochemistry of Algae. (R. A. Lewin, ed.). Academic Press, NY.

TABLE III
SOME CYTOLOGICAL AND OTHER EFFECTS OF X-RAYS ON VARIOUS ALGAE

Effect	Dose (in roentgens × 10 ³)	Alga	Reference
None	2	<i>Spirogyra crassa</i>	Godward (1954a, b)
	3	<i>Pandorina morum</i>	Halberstaedter and Back (1942)
	10	<i>Chlorella pyrenoidosa</i>	Nielsen and Godward (unpublished)
	10	<i>Chara vulgaris</i>	Moutacheu and Dahmen (1956)
Abnormal cells	10	<i>Chlorella vulgaris</i>	Pietschmann (1937)
18% genetic death	40	<i>Atsua longu</i>	Schoenborn (1954)
50% death	0.75	<i>Chlorella</i> sp. (microspores)	Howard and Horsley (1960)
	8 (hard)	<i>Chroococcus</i> sp.	Bonham and Palumbo (1951)
	11	<i>Asterionella</i> sp.	Bonham and Palumbo (1951)
	12	<i>Dunaliella salina</i>	Halston (1939)
	16	<i>Monostichum eukaryotum</i>	Langendorff et al. (1933)
	18	<i>Chlorella</i> sp.	Bonham and Palumbo (1951)
	28	<i>Chroococcus</i> sp.	Bonham and Palumbo (1951)
	40 (soft)	<i>Chlorella</i> sp.	Bonham and Palumbo (1951)
	45	<i>Chlamydomonas reinhardtii</i>	Nyboen (1953); Jacobson (1957)
		<i>C. eugametos</i>	Jacobson (1957)
		<i>C. mucronatus</i>	Jacobson (1957)
	>100	<i>Synechococcus</i> sp.	Bonham and Palumbo (1951)
Death on division	5 to 300	<i>Pandorina morum</i>	Halberstaedter and Back (1942)
Viable gamete formation suppressed	40	<i>Acetabularia mediterranea</i>	Six (1958)
Regeneration suppressed	400	<i>Acetabularia mediterranea</i>	Six (1958)
Hat formation (in eucate portions) suppressed	50 to 100	<i>Acetabularia mediterranea</i>	Six (1958)
"Ultimate survival" (as defined in text)	15	<i>Spirogyra crassa</i>	Godward (1954a, b)
	100	<i>Chlorella</i> sp.	Bonham and Palumbo (1951)
	600	<i>Chara vulgaris</i>	Moutacheu (1957)
"Immediate" death	10	<i>Chlamydomonas reinhardtii</i>	Nyboen (1953)
	600	<i>Pandorina morum</i>	Halberstaedter and Back (1942)
	750	<i>Acetabularia mediterranea</i>	Back et al. (1956)

Source: Ophel, I. L. et al. 1976. Chp. 2. Effects of ionizing radiation on aquatic organisms. pp. 57-86. In: Effects of Ionizing Radiation on Aquatic Organisms and Ecosystems. Intern. Atomic Energy Agency, Vienna, Austria, Tech. Repts. Series No. 172. (STI/DOO/10/172).

TABLE XXXIII. RANGE OF ACUTE LETHAL RADIATION DOSES^a FOR ADULTS OF VARIOUS GROUPS (krad)

Bacteria	4.5 - 735	(LD ₅₀)
Blue green algae	<400 - >1200	(LD ₅₀)
Other algae	3 - 120	(LD ₅₀)
Protozoa	? - 600	(LD ₅₀)
Molluscs	20 - 109	(LD _{50/30})
Crustaceans	1.5 - 56.6	(LD _{50/30})
Fish	1.1 - 5.6	(LD _{50/30})

^aMostly derived from Ref. [139].

TABLE XXXIV.^a ACUTE BETA DOSE ALLOWING ULTIMATE SURVIVAL OF ALGAE (krad)

<i>Chlorella pyrenoidosa</i>	1000
<i>Anabaena</i> sp.	100 - 200
<i>Chaetomorpha melagonium</i> (zoospores)	100
<i>Spinoecyba subochinata</i>	40
<i>Mougeotia</i> sp.	20 - 50
<i>Zygnema cylindricum</i>	20 - 50
<i>Cosmarium subumidum</i>	20 - 50
<i>Eudorina elegans</i>	20 - 50
<i>Spinoecyba etassa</i>	15
<i>Chaetomorpha melagonium</i>	10

^aAfter Godward [141].

Source: Ophel, I. L. et al. 1976. Chp. 2. Effects of ionizing radiation on aquatic organisms. pp. 57-86. In: Effects of Ionizing Radiation on Aquatic Organisms and Ecosystems. Intern. Atomic Energy Agency, Vienna, Austria, Tech. Repts. Series No. 172. (STI/DOC/10/172).

TABLE XXXV. SUMMARY OF EXPERIMENTAL STUDIES ON THE EFFECTS OF RADIONUCLIDES IN WATER ON AQUATIC ORGANISMS

Investigators	(POSITIVE EFFECT: ● or →)							NEGATIVE EFFECT: ○ or ←		Types of effects
	Concentration of radionuclides * (Ci l ⁻¹)									
	10 ⁻¹²	10 ⁻¹⁰	10 ⁻⁸	10 ⁻⁶	10 ⁻⁴	10 ⁻²	1			
Lebedeva, Suvorov [202]					→					Shortened the life-span of adult individuals of <i>Daphnia magna</i>
Telichenko [203]					→					Delay in embryonic development of fish eggs (anchovy)
Pokazayev, Ivanov [170, 171]				→						Increase in the mortality rate of embryos of fish eggs and tendency to be smaller in size of young fish was observed
"				→						Decrease in cell division in gastrula stage and chromosomal aberration of fish eggs (anchovy, stone perch)
"				→						Increase in malformation rate of fish eggs (anchovy, mullet, green wrasse, horse mackerel)
Fedorov et al. [190]		→								Increase in malformation rate of fish eggs (plague, <i>Pleuronectes platessa</i>)
Brown, Templeton [164]				←						No significant increase in mortality or in the production of abnormal larvae (brown trout, <i>Salmo trutta</i>), (plague, <i>Pleuronectes platessa</i>)
Nosovtsev, Podymakhin [192]			←							The rate of development of the egg was the same as the control up to the stage of one-third development of the yolk sac (atlantic salmon, <i>Salmo salar</i>)
Kuklov et al. [201]					→					Morphological abnormalities, delay in development, and mortality (eggs of the fresh water mollusc, <i>Lymnaea stagnalis</i>)
Stekhanova, Pochkurenkov [181]		●	○	○						Non-developing larvae appeared in developing eggs of the trout
Iiyama, Shimizu, Suyama [193]			←							Sharp decrease of the rate on attaining to plateau stage (see anchovy, <i>Pseudocentrotus depressus</i> , <i>Anchoa hepsetus</i>)
"			←							Normal rate of hatching and malformation of eggs (<i>Mytilus macrocephalus</i> and <i>Rivulus marmoratus</i> in sea water)
Egami et al. [194]					○					Normal rate of mortality and abnormality of the embryo (fresh water killifish, <i>Oryzias latipes</i>)
"					→					Effect on gonad was found in fish, exposed in contaminated water, continuously 70 days after hatching (fresh water killifish, <i>Oryzias latipes</i>)
"				←						Damage on seminal glands in fish, exposed 15 - 30 days (fresh water killifish, <i>Oryzias latipes</i>)
Koshcheva [175, 180]			←							Egg mortality during the time of incubation was at the control level in the Atlantic salmon (<i>Salmo salar</i>)
Nelson [200]				←						Significant increases in abnormal larvae (Pacific oyster, <i>Crassostrea gigas</i>)
Tsytulina [186, 187]			●							Significant increase of chromosomal breakages was found in the mull (<i>Scorpaenopsis porcus</i>)
Gulberic and Brusa [206, 207]					→					The testes and ovaries of adults were atrophied when larvae of <i>Aedes aegypti</i> and <i>A. atropalpus</i> were reared in radioactive water.
Scott [208]										
Strand et al. [209, 210]						○				No significant differences on rainbow trout during embryogenesis

Table XXV. continued.

Source: Ophel, I. L. et al. 1976. Chp. 2. Effects of ionizing radiation on aquatic organisms, pp. 57-86. In: Effects of Ionizing Radiation on Aquatic Organisms and Ecosystems. Intern. Atomic Energy Agency, Vienna, Austria, Tech. Repts. Series No. 172. (STI/DOC/10/172).

TABLE XXXV (continued)

Investigators	Concentration of radionuclides (C_1 : C_2)		Types of effects
	10 ⁻¹¹	10 ⁻¹⁰	
Megalowsky [188, 211]	137Cs	10 ⁻¹⁰	No decrease in the percentage of dividing cells was detected in the investigated development stages. In variants with $2 \times 10^{-10} C_1$, there was a reliable increase in the frequency of chromosomal aberrations, beginning with the epithelial blastula stage (Salmo salar)
Williams, Murdock [204]	137Cs	10 ⁻¹⁰	No influence on population density in a population of a copepoda (Tigropus affinis) kept in radioactive water for several years.
White et al. [212]	137Cs	10 ⁻¹⁰	No visible abnormalities on the developing egg and larvae (mummichog, Fundulus heteroclitus)
Il'inpeau [205]	137Cs	10 ⁻¹⁰	No effect on the reproduction of Artemia salina
Kudachva [175, 181]	137Cs	10 ⁻¹⁰	Considerable number of deaths were observed in the Atlantic salmon (Salmo salar) when the eggs were exposed to radioactive water
Megalowsky [176, 177]	137Cs	10 ⁻¹⁰	
Maricheva [184]	137Cs	10 ⁻¹⁰	Damage at early stages of developing eggs of carp and Carassius gibel
Nelson [200]	137Cs	10 ⁻¹⁰	Significant increases in abnormal larvae (Pacific oyster, Crassostrea gigas)
Ilavik, Robertson [213]	137Cs	10 ⁻¹⁰	Photosynthetic oxygen production in fresh-water phytoplankton was sharply reduced by 24 hours exposure to a $10^{-10} C_1$ concentration of $3 \times 10^{-10} C_1$
Akita, Shroya [199]	HTU (tritiated water)	10 ⁻¹⁰	50% attainment to phytos (red sea urchin, Pseudocentrotus depressus)
Etoh, Ueno, Ichikawa [214]	HTU (tritiated water)	10 ⁻¹⁰	50% attainment to phytos (velvet sea urchin, Anthocidaris stansburiana)
Biopfen, Held [215]	HTU (tritiated water)	10 ⁻¹⁰	Slight decrease of the rate of hatching (fresh water killifish, Oryzias latipes)
Walden [217]	HTU (tritiated water)	10 ⁻¹⁰	Reduced percentage of germination of the actually produced seeds (Pennisetum polystachyon)
Fedorova [185]	HTU (tritiated water)	10 ⁻¹⁰	No effects on embryo development of cyprinus carpio
Erskisson [218]	HTU (tritiated water)	10 ⁻¹⁰	No effects on embryo development of Gasterosteus aculeatus
Ichikawa, Soyama [219]	HTU (tritiated water)	10 ⁻¹⁰	No significant effects on mortality growth, male characters, behaviour and thermal death of the guppy fish, Gasterosteus aculeatus
Fedorova [185]	HTU (tritiated water)	10 ⁻¹⁰	Decreases in hatchability were observed and 100% C_1 effects were noted on body shape and eye diameter of larvae of two species of marine fish (Parachanna obscura and Eupomacentrus sp.)
Taymargina [186, 187]	HTU (tritiated water)	10 ⁻¹⁰	Increase of malformed larvae of Carassius gibel, when $10^{-10} C_1$ was added to the water seven days after fertilization
	HTU (tritiated water)	10 ⁻¹⁰	Significant increase of chromosomal breakages was found in the ruff (Scopelogasterus rufus)

Note: * It is important to realize that the quoted conversions do not indicate directly the dose received by organisms and/or organs.

Source: Polikarpov, G. G. 1966. Part III. (continued)

a	DUBININ [1961].	n	GROSCH and SMITH [1957].
b	GODWARD [1960].	o	ELLINGER [1939].
c	BONHAM <i>et al.</i> [1947].	p	BONHAM <i>et al.</i> [1948].
d	BONHAM and PALUMBO [1951].	q	DONALDSON and FOSTER [1957].
e	JACOBSON [1957].	r	WELANDER <i>et al.</i> [1949].
f	NIKITIN [1958].	s	WELANDER [1954].
g	BACK [1939].	t	FOSTER <i>et al.</i> [1949].
h	GLOCKER, LANGENDORFF and RELSS [1933].	u	BROWN and TEMPLETON [1964].
i	HARRIS <i>et al.</i> [1952].	v	BACQ and ALEXANDER [1955].
j	POLIKARPOV [1957a,b].	w	ALLEN <i>et al.</i> [1952].
k	NIKITIN [1938].	x	BLINOV [1956].
l	SCHMIDT [1946].	y	PETERS [1960].
m	BONHAM [1953].		

Table 37
Irradiating radiation for external irradiation of marine and freshwater organisms

Aquatic organisms	Dose (fr) LD ₅₀	LD ₅₀	minimum effective dose	tolerated dose	period of observa- tion (days)
Flagellate bacteria:					
<i>Paramecium</i> sp.	-	-	-	20 000 000	a
<i>Euglena</i> sp.	-	-	-	150 000	b
<i>Paramecium</i> sp.	-	-	-	2 000	b
Green algae:					
<i>Chlorella</i> sp.	-	-	-	100 000 000	b
	-	50 000	10 000	1 000	30 c, d
	-	-	-	100 000	c, d
Eubacteria sp.					
<i>Chlamydomonas reinhardtii</i>	-	4 500	-	-	e
<i>Synechocystis</i> sp.	-	-	-	20 000	b
<i>Zygnema</i> sp.	-	-	-	50 000	b
<i>Monostroma</i> sp.	-	-	-	70 000	b
<i>Cocconeis</i> sp.	-	-	-	70 000	b
<i>Chlamydomonas</i> sp.	-	-	-	50 000	b
<i>Ankistrodesmus</i> sp.	-	-	11 000	-	7 d
<i>Chlamydomonas reinhardtii</i>	4 500	-	-	-	f
	-	-	-	-	125 f
	-	-	-	-	30-40 f
Fungi:					
<i>Aspergillus clavatus</i>	-	50 000	10 000	1 000	30 c
<i>Aspergillus niger</i>	-	8 000	-	-	7 d
<i>Aspergillus fumigatus</i>	-	-	-	8 000	f
Protozoa:					
<i>Paramecium</i> sp.	600 000	-	-	-	30 e
<i>Amoeba</i> sp.	-	-	-	30 000	f
<i>Amoeba</i> sp.	-	31 000	-	-	h
<i>Amoeba</i> sp.	-	120 000	-	-	i
Ciliates:					
<i>Paramecium</i> sp.	12 000	-	-	8 000	63 j
<i>Paramecium</i> sp.	2 000-9 000	-	-	-	35-75 f
Worms:					
<i>Planaria polychaeta</i>	5 500	-	-	-	75 k
<i>Daphnia magna</i>	10 000	-	-	-	60 f
Crustaceans:					
<i>Artemia salina</i>	-	-	-	4 000	f
<i>Artemia salina</i>	-	20 000	-	-	6 d
<i>Artemia salina</i>	-	50 000	-	-	6 d
<i>Artemia salina</i>	6 400	1 000	-	-	35-56 d

^a At a dose-rate of about 25 rads/day.

Source: Polikarpov, G. G. 1966. Part III. The effect of nuclear radiation on marine organisms. pp. 183-249. In: Radiocology of Aquatic Organisms: the Accumulation and Biological Effect of Radioactive Substances. English translation and revised edition. V. Schultz and A. W. Klement, Jr., eds. (Original: 1961. Radiocology of Marine Organisms. Atomizdat, Moscow, 295 pp.). North-Holland, Amsterdam.

Source: Polikarov, G. G. 1977. Experimental methods for radiobiological investigations with developing fish eggs. Paper presented at a Panel Meeting of the International Atomic Energy Agency, Vienna, Austria, October 1977. (in press).

Table 1. Radiobiological investigations of fishes species at stages of developing eggs in marine (M), brackish (B) and fresh (F) water.

Taxonomy	M, B or F water	Sources of ionizing radiations	Doses (rad)	Radionuclides concentrations (Ci/l)	Ref.:
Class Osteichthyes					
Subclass Actinopterygii					
Order Acipenseriformes	F	^{90}Sr (as well as ^{137}Cs and ^{144}Ce)		10^{-10} - 10^{-6}	[87]
Fam. Acipenseridae					
Acipenser güldenstädti					
A. g. persicus		External ^{***} (+ oil 0.01-1mg/l)	800-9000		[97]
A. stellatus	F	External	10000		[107]
Huso huso	F	^{90}Sr (as well as ^{137}Cs and ^{144}Ce)		10^{-10} - 10^{-6}	[87]
Order Clupeiformes					
Suborder Clupeoidei					
Fam. Engraulidae	B,M	^{90}Sr		10^{-14} - 10^{-4}	[11,127]
Engraulis encrasicolus					
Suborder Salmonoidae					
Fam. Salmonidae	F	External	50-350		[137]
Salmo salar		External + ^{90}Sr	350	10^{-5}	[14,15,167]
		^{90}Sr , ^{137}Cs		10^{-9}	[177]
		^{90}Sr , ^{137}Cs , ^{144}Ce		10^{-10} - 10^{-6}	[187]
		^{90}Sr , ^{137}Cs		10^{-10} - 10^{-5}	[197]
		^{90}Sr , ^{137}Cs , ^{144}Ce		10^{-8} - 10^{-5}	[207]
		^{90}Sr	0.06	10^{-7}	[217]

<i>S. gairdnerii</i>	F	External	50-2500	[22]
		External	73-930	[23]
		External	21-203	[24]
		External	100-2000	[25]
<i>S. gairdnerii</i> (contd.)	F	^3H	$10^{-3}-10^{-2}$	[26]
		External	44-2500	[27]
		External	10-1000	[28, 29]
		External	25-400	[30]
		External	200-2000	[31]
(S. irideus)	F	^{90}Sr	$10^{-10}-10^{-6}$	[32]
		^{89}Sr	$10^{-9}-10^{-5}$	
<i>S. trutta</i>	F	^{90}Sr	4-181	$10^{-7}-10^{-5}$ [33]
<i>Oncorhynchus gorbuscha</i>	F	^{59}Fe	10^{-5}	$10^{-5}-10^{-4}$ [34]
		^{90}Sr ^{89}Sr	$10^{-11}-10^{-7}$ $10^{-9}-10^{-5}$	[32]
<i>O. kisutch</i>	F	External	12-2400	[35]
		External	40	[36]
<i>O. tshawytscha</i>	F	External	15-1530	[37]
		External	40	[36]
<i>Coregonus lavaretus ludoga</i>	F	^{90}Sr	$10^{-9}-10^{-5}$	[38]

C. peled	F	Mixture of fission products and ^{131}I , ^{140}Ba , ^{106}Ru	10^{-3} 20000	10^{-9} - 10^{-3}	[39]
		^{14}C	0.85-66.4	10^{-5} - 10^{-4}	[40,41]
Suborder Esocidae	F	External	200		[42]
Fam. Esocidae					
Esoc lucius					
Suborder Esocidae (contd.)	F	External	25-800		[43,44]
Fam. Esocidae					
Esoc lucius					
		$^{90}\text{Sr} + ^{137}\text{Cs}$		10^{-10} - 10^{-5}	[45]
		^{90}Sr		10^{-9} - 10^{-4}	[46]
		$^{137}\text{Cs} + (\text{oil } 0.01-0.5 \text{ mg/l})$		10^{-9}	[47]
		^{90}Sr		10^{-7}	[48]
		^{137}Cs		10^{-8}	[49]
Order Cypriniformes	F	^{238}Pu		10^{-4} - 10^{-2}	
Suborder Cyprinidae		^{232}U	10^3 - 10^4	10^{-3} - 10^{-2}	[50]
Fam. Cyprinidae		^{244}Pu		10^{-3} - 10^{-2}	
Cyprinus carpio		$^{233} + ^{235} + ^{238}\text{U}$		10^{-2} - 10^{-2}	
		External	500-16000		[51]
		^{90}Sr	12-3400	10^{-8} - 10^{-6}	[52]
		^{90}Sr	50-10000	10^{-8} - 10^{-6}	[53]
		External	500-1000		[54]
		External (beta particles)	370		[55]
		^{239}Pu		10^{-7} - 10^{-4}	[56]
		$^{137}\text{Cs} + (\text{oil } 0.05 \text{ mg/l})$		10^{-8}	[57]
		External	48000-70000		[58]

		^{14}C	10^{-5}	$[41]$
<i>Pimephales promelas</i>	F	^{238}Pu ^{232}U ^{244}Pu	10^3-10^4 $10^{-5}-10^{-2}$ $10^{-5}-10^{-2}$ $10^{-6}-10^{-5}$	$[48]$
	F	^{144}Ce	10^{-7}	$[56]$
<i>Carassius carassius</i>	F	^{14}C	$10^{-6}-10^{-4}$	$[52]$
<i>C. auratus</i>	F	^{90}Sr	10^{-9}	$[6]$
<i>C. a. gibelio</i>	F	$^{90}\text{Sr} + ^{137}\text{Cs}$	110-775 10^{-8}	$[4]$
		$^{90}\text{Sr} + ^{137}\text{Cs}$	$10^{-11}-10^{-8}$	$[3]$
<i>Tinca tinca</i>	F	External	A 25-1200	$[58]$
		External	25-250	$[59, 60]$
<i>Pseudorasbora parva parva</i>	F	Ash from H-bomb test	10^{-6}	$[61]$
<i>Ctenopharingodon idella</i>	F	^{90}Sr	5.10^{-4} -5.6 $10^{-10}-10^{-4}$	$[62]$
<i>Aristichthys nobilis</i>	F	^{90}Sr	$10^{-10}-10^{-6}$	$[8]$
<i>Rutilus rutilus</i>	F	^{14}C	$10^{-6}-10^{-4}$	$[57]$
		$^{90}\text{Sr} + ^{137}\text{Cs}$	$10^{-7}+10^{-8}$	$[5]$
<i>Alburnus alburnus</i>	F	^{14}C	$10^{-6}-10^{-4}$	$[57]$
<i>Brachiodanio rerio</i>	F	Ash from H-bomb test	$10^{-10}-10^{-8}$	$[63]$
Fam. Cobitidae				
<i>Misgurnus fossilis</i>	F	External	100-3000	$[64]$
		External	10000	$[10]$

External	50-500		[65]
^{90}Sr	0.83	10^{-10} - 10^{-4}	[66]
F External (colchicine)	1500-50000		[67]
^{90}Sr	$5 \cdot 10^{-4}$ -50	10^{-10} - 10^{-4}	[68]
^{239}Pu		10^{-11} - 10^{-8}	
$^{239}\text{Pu} + ^{90}\text{Sr} + ^{137}\text{Cs}$		10^{-10} - 10^{-6}	[69]
^{90}Sr		10^{-10} - 10^{-3}	
^{90}Sr		10^{-10} - 10^{-6}	[70]

Order Gasterosteiformes

Fam. Gasterosteidae

Gasterosteus aculeatus

F	^3H	0.5	[71]
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Order Cyprinodontiformes

Suborder Cyprinodontoides

Fam. Cyprinodontidae

Fundulus heteroclitus

F	External	100-2000	[72]
	External	2000	[73]
	External	1000-200000	[74]

Oryzias latipes

F	External	1000	[75]
	External (fast neutrons, x-rays)	100-8000 15-7600	[76]
	^{90}Sr	10^{-6} - 10^{-5}	[77]

Order Perciformes

Suborder Percoidei

Fam. Serranidae

Serranus scriba

	^{90}Sr	10^{-8} - 10^{-4}	
B, H	^{91}Y	10^{-10} - 10^{-4}	[11, 12]
	^{144}Ce	10^{-10} - 10^{-4}	

Fam. Percidae

Perca fluviatilis

F	$^{90}\text{Sr} + ^{137}\text{Cs}$	10^{-7} 10^{-8}	[17]
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<i>Lucioperca lucioperca</i>	F	External (+ chloro- phos 0.001-0.5 mg/l)	100		[787]
<i>Acerina cernua</i>	F	^{14}C		$10^{-6}-10^{-4}$	[527]
Fam. <i>Carangidae</i>	M	^{90}Sr	$10^{-2}-10^{-1}$	$10^{-6}-10^{-5}$	[797]
<i>Trachurus trachurus</i>		^{137}Cs		$10^{-6}-10^{-5}$	
<i>T. mediterraneus ponticus</i>	B,M	^{90}Sr		$10^{-14}-10^{-4}$	[11, 127]
Fam. <i>Mullidae</i>	B,M	^{90}Sr		$10^{-14}-10^{-4}$	[11, 127]
<i>Mullus barbatus ponticus</i>					
Fam. <i>Sparidae</i>	M	^{90}Sr	$10^{-2}-10^{-1}$	10^{-5}	[797]
<i>Lentex canariensis</i>		^{137}Cs		10^{-6}	
<i>Mylio macrocephalus</i>	M	^{90}Sr		$10^{-13}-10^{-3}$	[807]
Fam. <i>Cichlidae</i>		^{90}Sr		$10^{-10}-10^{-6}$	[81, 827]
<i>Tilapia mossambica</i>	F,B				
Suborder Trichiuroidei		^{137}Cs		$10^{-6}-10^{-5}$	
Fam. Trichiuridae		^{90}Sr	30	$10^{-6}-10^{-5}$	[797]
<i>Trichiurus lepturus</i>	M	^{144}Ce		$10^{-6}-10^{-5}$	
Suborder Gobioidaei		^{45}Ca		$10^{-9}-10^{-5}$	[837]
Fam. Gobiidae	B,M				
<i>Neogobius melanostomus</i>					
Suborder Cottoidei		^{90}Sr	0.003-0.01	$10^{-11}-10^{-5}$	
Fam. Scorpaenidae		^{91}Y	(for ^{90}Sr -	$10^{-11}-10^{-5}$	[847]
<i>Scorpaena porcus</i>	B,M	^{89}Sr	2.10 $^{-8}$,	$10^{-8}-10^{-4}$	
		^{14}C	^{91}Y -3.10 $^{-8}$,	$10^{-8}-10^{-6}$	
			^{14}C -3.10 $^{-7}$,		
			^{137}Cs -2.10 $^{-6}$)		
		^{91}Y (+ strap- tomicin)		10^{-6}	[857]
Suborder Anabantoidaei					
Fam. Anabantidae	F	External	1000-5000		[867]
<i>Macropodus opercularis</i>					

Order Pleuronectiformes					
Fam. Bothidae	B	^{91}Y ^{137}Cs		$10^{-8}-10^{-4}$ 10^{-4}	[87]
Scophthalmus maeoticus maeoticus					
Fam. Pleuronectidae	M	External	30-150		[88]
Pleuronectes platessa					
		^{90}Sr ^{137}Cs		$10^{-11}-10^{-10}$ $10^{-11}-10^{-10}$	[17]
		^{90}Sr	0.004-230 0.63-492.5	$10^{-10}-10^{-4}$	[33]
Paralichthys olivaceus	M	^3H		$10^{-8}-10$	[89]
Order Tetradontiformes					
Fam. Monacanthidae	M	^{90}Sr		$10^{-13}-10^{-3}$	[80]
Rudario ercodes					
Fam. Tetradontidae					
Fugu niphobles	M	^3H		$10^{-8}-10$	[89]

* If there is a series of publications, then the last and generalized one is being cited.

***External - gamma or X-rays. If other external radiations (neutrons, beta-particles), they are specified.

Source:

Nico, T. R. and D. A. Wolfe, 1971. Radioactivity - chemical and biological aspects, pp. 325-379. In: Impingement of Man on the Oceans. (D. W. Hood, ed.). Wiley-Interscience, NY.

**Table 12.10. Amounts of Radiation
Required to Kill 50 Per Cent of the
Rainbow Trout, *Salmo gairdneri*,
Irradiated at Various States
in Their Life Cycle**

Stage in Life Cycle	LD-50 (R)
Gametes	50-100
1 cell	58
32 cell	313
Germ ring	454-461
Eye	415-904
Adult	1500

From Welander (1954).

Source: Rice, T. R. and J. P. Baptist, 1974. Chp. 10. Ecologic effects of radioactive emissions from nuclear power plants. pp. 373-439. In: Human and Ecologic Effects of Nuclear Power Plants. (L. A. Sagan, ed.). Charles C Thomas, Springfield, IL.

TABLE 10.XIII COMPARISON OF THE RADIATION SENSITIVITIES OF VARIOUS AQUATIC ORGANISMS AS INDICATED BY LETHAL DOSES*

Species	Radiation	Dose Rate	Temp. °C	Sex	LD-50 days	LD-50 dose	Reference
FISH							
<i>Carpas auratus</i>	x-ray	1,000 r/min	20-25	0	30	2,315 r	Schoenmeister et al., 196
<i>Salmo gairdnerii</i>	x-ray	—	—	—	30	1,600 r	Welander, 1954
<i>Dacorynchus kiasch</i>	x-ray	100 r/min	—	0	150	25 r	Barnum and Welander, 1963
eggs 50% incub.	x-ray	—	—	—	—	807 r	—
<i>Fundulus heteroclitus</i>	gamma	480 rad/min	21	—	30	1,120 rad	White and Angelovic, 196
					50	1,075 rad	
<i>Mytilus cephalus</i>	gamma	480 rad/min	18	—	30	1,410 rad	White and Angelovic, 196
<i>Eucinostomus sp.</i>	gamma	480 rad/min	22	—	30	8,500 rad	White and Angelovic, 196
					50	1,375 rad	
<i>Lagodon rhomboides</i>	gamma	480 rad/min	18	—	30	2,000 rad	White and Angelovic, 196
					50	2,250 rad	
<i>Micropterus undulatus</i>	gamma	480 rad/min	19	—	30	1,080 rad	White and Angelovic, 196
					50	—	
<i>Parachanna lethostigma</i>	gamma	480 rad/min	14	—	30	8,850 rad	White and Angelovic, 196
					50	1,925 rad	
CRUSTACEA							
<i>Gammarus salinus</i>	x-ray	420 r/min	15	10	30	1,700 r	Hoppenheit, 1969
<i>G. rostratus</i>	x-ray	420 r/min	15	10	30	1,700 r	Hoppenheit, 1969
<i>G. duebeni</i>	x-ray	420 r/min	15	10	30	3,800 r	Hoppenheit, 1969
<i>G. duebeni</i>	x-ray	420 r/min	15	10	30	3,800 r	Hoppenheit, 1969
<i>Palaeomonetes pugio</i>	gamma	1,900 r/min	—	—	30	1,455 r	Rees, 1962
<i>P. pugio</i>	gamma	360 rad/min	20	53	30	750 rad	J.C. White, unpublished
					40	215 rad	
<i>Uca pugnax</i>	gamma	1,900 r/min	—	—	30	8,200 r	Rees, 1962
<i>U. pugnax</i>	gamma	360 rad/min	20	30	40	16,600 rad	D.W. Engel, unpublished
<i>U. pugnax</i>	gamma	360 rad/min	20	30	40	9,800 rad	D.W. Engel, unpublished
<i>U. minax</i>	gamma	360 rad/min	20	30	40	12,800 rad	D.W. Engel, unpublished
<i>Callinectes sapidus</i>	gamma	360 rad/min	20	30	40	42,800 rad	Engel, 1967
MOLLUSCA							
<i>Mytilus mercenaria</i>	gamma	8,800 r/min	—	—	30	116,000 r	Price, 1966
					50	67,000 r	
<i>Crassostrea virginica</i>	gamma	8,800 r/min	—	—	30	100,000 r	Price, 1966
					50	<18,000 r	
<i>Austrotheris globatus</i>	x-ray	1,800-1,500 r/min	—	0	30	23,800 r	Perkins and Brumley, 1964
					50	18,300 r	
					60	12,800 r	
<i>Unio pictus cinereus</i>	x-ray	—	—	—	30	40,000 r	Hargis et al., 1966
					50	20,000 r	
<i>U. cinereus</i>	x-ray	—	—	—	30	47,000 r	Hargis et al., 1966
					50	26,000 r	
<i>Manuscript aboetus</i>	gamma	480 rad/min	18	—	30	27,000 rad	White and Angelovic, 196
					50	14,000 rad	

* Compiled by David W. Engel.

† Immature stage.

Source:

Seymour, A. H. et al. 1975. Aquatic environment, pp. 103-161. In: Long-Term Worldwide Effects of Multiple Nuclear-Weapons Detonations. (Committee to Study the Long-Term Worldwide Effects of Multiple Nuclear-Weapons Detonations). National Research Council, National Academy of Sciences, Washington, DC.

TABLE 4.9 Ranges of Acute Lethal Radiation Doses for Various Groups (kilorads)^a

Organism	Radiation Dose
Bacteria	4.5-735 (LD ₉₀)
Blue-green algae	<400->1200 (LD ₉₀)
Other algae	3-120 (LD ₅₀)
Protozoa	1-600 (LD ₅₀)
Mollusks	20-109 (LD _{50/30})
Crustaceans	1.5-14.5 (LD _{50/30})
Fish	1.1-5.6 (LD _{50/30})

^aFrom Reference 71.

Source: Seymour, A. H., et al. 1975. Aquatic environment, pp. 103-161. In: Long-term Worldwide Effects of Nuclear-Weapons Detonations. (Committee to Study the Long-term Worldwide Effects of Nuclear-Weapons Detonations). National Research Council, National Academy of Sciences, Washington, DC.

TABLE 4.15 Estimated Whole-Body Radiation Doses to Selected Biota, mrad/year

Type	Internal	External	Total
<i>A. Northern Latitude--Surface (Mixed Layer)</i>			
Fish	0.8	0.01 ^a	0.8
Crustacea	2.	70. ^b	70.
Mollusks	2.	70. ^b	70.
Plants	10.	0.04 ^a	10.
Bird (plant diet)	50.	0.007 ^c	50.
Bird (fish diet)	4.	0.007 ^c	4.
<i>B. Northern Latitude--Middepth</i>			
Fish	0.3	0.005	0.3
Crustacea	1.	30.	30.
Mollusks	1.	30.	30.
Algae	8.	0.01	8.
<i>C. Northern Latitude--Deep Water</i>			
Fish	0.4	0.006	0.4
Crustacea	1.	30.	30.
Mollusks	1.	30.	30.
Algae	20.	0.02	20.
<i>D. Southern Latitude--Surface (Mixed Layer)</i>			
Fish	0.4	0.006	0.4
Crustacea	1.	30.	30.
Mollusks	1.	30.	30.
Plants	16.	0.02	16.
Bird (plant diet)	20.	0.003	20.
Bird (fish diet)	2.	0.003	2.
<i>E. Southern Latitude--Middepth</i>			
Fish	0.08	0.001	0.08
Crustacea	0.3	7.	7.
Mollusks	0.3	7.	7.
Plants	2.	0.003	2.
<i>F. Southern Latitude--Deep Water</i>			
Fish	0.05	0.0008	0.05
Crustacea	0.2	5.	5.
Mollusks	0.2	2.	2.
Plants	1.	0.002	1.

^a External dose from water immersion.

^b External dose at water-sediment interface.

^c Immersion dose if 50% of time is spent in water.

Source: Seymour, A. H. et al. 1975. Aquatic environment, pp. 103-161. In: Long-term Worldwide Effects of Nuclear-Weapons Detonations. (Committee to Study the Long-term Worldwide Effects of Nuclear-Weapons Detonations). National Research Council, National Academy of Sciences, Washington, DC.

TABLE 4.16 Estimated Radiation Doses to People Consuming Seafood, mrem/year^a

Food	Total Body	GI-LLI ^b	Thyroid	Bone ^c
Harvested from:				
A. Northern Hemisphere--Surface (Mixed Layer)				
Fish	0.06	0.06	0.9	0.07
Crustacea	0.008	0.02	0.4	0.009
Mollusks	<u>0.004</u>	<u>0.03</u>	<u>0.8</u>	<u>0.005</u>
TOTAL	0.07	0.1	2.	0.08
50-yr dose ^d	4	5	100	4
B. Northern Hemisphere--Middepth				
Fish	0.02	0.02	0.3	0.03
Crustacea	0.005	0.006	0.1	0.004
Mollusks	<u>0.002</u>	<u>0.01</u>	<u>0.3</u>	<u>0.003</u>
TOTAL	0.03	0.04	0.7	0.04
C. Northern Hemisphere--Deep Water				
Fish	0.03	0.03	0.4	0.03
Crustacea	0.04	0.007	0.2	0.005
Mollusks	<u>0.04</u>	<u>0.015</u>	<u>0.4</u>	<u>0.0004</u>
TOTAL	0.1	0.05	1.0	0.04
D. Southern Hemisphere--Surface (Mixed Layer)				
Fish	0.03	0.02	0.4	0.03
Crustacea	0.003	0.007	0.2	0.004
Mollusks	<u>0.002</u>	<u>0.01</u>	<u>0.4</u>	<u>0.002</u>
TOTAL	0.04	0.04	1.0	0.04
E. Southern Hemisphere--Middepth				
Fish	0.005	0.006	0.09	0.007
Crustacea	0.0008	0.002	0.04	0.0009
Mollusks	<u>0.0004</u>	<u>0.003</u>	<u>0.08</u>	<u>0.0005</u>
TOTAL	0.006	0.01	0.2	0.008
F. Southern Hemisphere--Deep Water				
Fish	0.0035	0.004	0.06	0.004
Crustacea	0.0005	0.001	0.02	0.0006
Mollusks	<u>0.0002</u>	<u>0.002</u>	<u>0.05</u>	<u>0.0004</u>
TOTAL	0.004	0.007	0.1	0.005

^aTotals are rounded off to avoid suggesting undue accuracy.

^bEntrance to lower large intestine.

^cMineral bone.

^dDose accumulated over a 50-year period from continuous ingestion of contaminated seafood at the same concentrations as the first year.

Source: Templeton, W. L., R. F. Nakatani and E. F. Held, 1971. Radiation effects. pp. 223-239. In: Radioactivity in the Marine Environment. (Panel on Marine Radioactivity in the Marine Environment). National Academy of Sciences, Washington, DC.

TABLE 1 Radiation Dose Rates in mrad/Week in Various Tissues of Cod (*Gadus callarias*) and Haddock (*Gadus aeglefinus*), from the Decay of ^{40}K and ^{226}Ra ^a

Radioisotope	Cod				Haddock	
	Muscle	Skin	Bone	Fine	Muscle	Skin
^{40}K						
β	0.43	0.25	0.28	0.16	0.36	0.25
γ	0.03	.01	0.01	0.01	0.03	0.01
^{226}Ra	-	0.020	-	-	-	0.040

^aAfter Federov (1965).

TABLE 2 Estimates of Natural-Radiation Dose Rates to Plaice (*Pleuronectes platessa*) in the Irish Sea^a

Source	Type of Radiation	Dose in mR/week
Natural activity in seawater (^{40}K only)	γ	0.07
	β	0.10
Natural activity in seabed (estimate)	$\beta\gamma$	1.00
Cosmic radiation at 20 m		0.10
^{40}K in fish	γ	0.01
	β	0.12
Total		1.38 mR/week or 0.001 R/year

^aData from Woodhead (personal communication).

Source: Tsytsugina, V. G., N. S. Risik and G. E. Lazorenko. 1975. Chp. II. Karyology of marine fish and the effect of radionuclides on their chromosome apparatus. pp. 16 - 39. In: Artificial and Natural Radionuclides in Marine Life. "Naukova Dumka", Kiev. (English transl. TT 75-50010, U. S. Dept. of Commerce, National Technical Information Service).

Chronic effect of low doses of incorporated radionuclides on the chromosome apparatus of animals and plants (the excess over and above the absorbed dose supplied by cosmic radiation is indicated in parentheses).

Object	Frequency of anomalous mitoses, % of control	Reference
	3-10 mrad (up to 10^3)	
Scorpionfish and turbot (embryos)	115-226	Our data
	10^3-10^4 mrad (up to 10^5)	
Rats (bone marrow)	136	Nikulinov, 1968
Scorpionfish and turbot (embryos)	128-188	Our data
	10^4-10^5 mrad (up to 10^6)	
Rats (bone marrow)	175	Nikulinov, 1968
Scorpionfish and turbot (embryos)	128-242	Our data
	10^5-10^6 mrad (up to 10^7)	
Rats (bone marrow)	236-816	Nikulinov, 1968
Rats (lymphocytes)	700-3,600	Khustar and Tokin, 1969
Scorpionfish (embryos)	230	Our data
Peas, Kapital strain (seedless grown from seeds soaked in radionuclide solution)	296	Lachnukh, 1968
Wheat beans (apical meristem)	1,168-1,263	Kuzin et al., 1962
	10^6-10^7 mrad (up to 10^8)	
Rats (bone marrow)	312	Boerha and Lincski, 1968
Rats (epithelium of small intestine mucosa)	196	Zhomo and Pavlitkaya, 1968
Turbot (embryos)	165	Our data
Peas, Kapital strain (seedless grown from seeds soaked in radionuclide solution)	227-469	Lachnukh, 1968

Source: Tsytsgina, V. G., N. S. Risik and G. F. Lazorenko. 1975. Chp. II. Karyology of marine fish and the effect of radionuclides on their chromosome apparatus. pp. 16 - 39. In: Artificial and Natural Radionuclides in Marine Life. "Naukova Dumka", Kiev. (English transl. TT 75-50010, U. S. Dept. of Commerce, National Technical Information Service).

TABLE 7. Sensitivity of fish at different stages of ontogenesis to external irradiation

Species	Dose, r	Effect	Reference
<i>Carassius auratus</i>			
Adults	870	80% mortality	Giltinger, 1939
<i>Tinca tinca</i>			
Embryos at stage of cleavage	50	Morphological anomalies in larvae	Kulikov, Timofeeva, and Shishenkova, 1968
The same	400	100% egg mortality	The same
<i>Misgurnus fossilis</i>			
Embryos at early blastula stage	50-100	Death of embryos, increased number of morphological anomalies and nuclear disruptions. Slackening of mitotic activity	Schlyueva and Pokrovskaya, 1958, 1959
<i>Salmo salar</i>			
Embryos at blastomeric blastula stage	368	Increased mitotic activity	Migalovskaya, 1969
<i>S. gairdnerii</i>			
Adults	1,500	50% mortality	Wolander et al., 1949
Embryos at ocellus stage	1,000	" "	Wolander et al., 1948
Embryos at ocellus stage	415-904	" "	Wolander, 1954
Embryos at germ band stage	484-461	" "	" "
Embryos at 32-cell stage	315	" "	" "
Embryos at 1-cell stage	58	" "	" "
Gametes in fish	50-100	" "	Foster et al., 1949
<i>Oncorhynchus kisutch</i>			
Zygotes in water of mineau	16	" "	Donaldson and Foster, 1957
<i>O. tshawytscha</i>			
Larvae	1,000	" "	Bonham et al., 1948
Young	1,250-2,500	" "	Bonham et al., 1948
Embryos	Total dose 68	Reduced number of vertebrae in specimens of the first generation, increased fertility	Bonham and Donaldson, 1966
<i>Pleuronectes platessa</i>			
Embryos	500 rad for 19 days	Damaging effect not found	Templeton, 1966
Beginning of cleavage	25	Morphological anomalies in larvae	Templeton, 1966

Source: Tsytugina, V. G., N. S. Risik and G. E. Lazorenko, 1975. Chp. II. Karyology of marine fish and the effect of radionuclides on their chromosome apparatus. pp. 16-19. In: Artificial and Natural Radionuclides in Marine Life. "Naukova Dumka", Kiev. (English transl. TT 75-50010, U. S. Dept. of Commerce, National Technical Information Service).

TABLE 8. Sensitivity of fish embryos to incorporated radionuclides

Species	Concentration, curie/liter	Effect	Reference
^{84}Sr			
<i>Carassius auratus</i> , <i>Rutilus rutilus</i> , <i>Alburnus alburnus</i> , <i>Acerina cernua</i>	$2 \cdot 10^{-5}$ – $2 \cdot 10^{-4}$	Egg mortality, morphological anomalies in larvae, increased rapidly of hatching of larvae	Fedorova, 1964
<i>Coregonus paied</i>	$2 \cdot 10^{-5}$ – $2 \cdot 10^{-4}$	Egg mortality, morphological anomalies in larvae	Fedorova, 1965
<i>Scorpaena porcus</i>	10^{-5} – 10^{-3}	Increased frequency of nuclear disruption	Trymagina, 1969c
^{90}Sr			
<i>Lebistes xiphophorus</i>	$2 \cdot 10^{-4}$	Degradation of generative tissue	Vivian, 1953
^{90}Sr – ^{90}Y			
<i>Cyprinus carpio</i> **	$5 \cdot 10^{-5}$ – $5 \cdot 10^{-4}$	Suppressed growth	Lebedeva, 1968
<i>Tinca tinca</i>	10^{-10} – 10^{-5}	No damaging effect found, rate of development unchanged	Kulikov, Timofeeva, and Shitenkova, 1968
<i>Esox lucius</i>	10^{-10} – 10^{-5}	No mortality or increased number of morphological anomalies observed	Timofeeva and Al'bits, 1970
	10^{-7} – 10^{-5}	Increased number of chromosome aberrations	The same
<i>Misgurnus fossilis</i>	10^{-10} , 10^{-4}	Egg mortality, morphological anomalies in larvae	Shekhanova and Fechlaurenkov, 1968
	10^{-5} , 10^{-4}	No damaging effect found	The same
<i>Coregonus lavaretus</i> †	$2 \cdot 10^{-10}$ – $2 \cdot 10^{-5}$	Death of larvae at the transition to exogenous feeding	Fedorova, 1963
<i>Salmo salar</i>	10^{-5} – 10^{-4}	Egg mortality, morphological anomalies in larvae, accelerated tempo of development	Nemtsov and Podynskina, 1966b
	10^{-10}	Accelerated maturation of blood cells, pathology not noted	Nemtsov, 1966
	10^{-10} – 10^{-6}	Disruption of mitotic division, destructive changes in blood	Koshelova, 1969
	10^{-4}	Chromosome breakages in cells of embryos and larvae	Migalevskaya, 1969

* Young and sexually mature fish

** Young-of-the-year

† Larvae

Table 8 continued.

Source: Tsytsugina, V. G., N. S. Risik and G. E. Lazorenko. 1975. Chp. II. Karyology of marine fish and the effect of radiomucides on their chromosome apparatus. pp. 16-19. In: Artificial and Natural Radiomucides in Marine Life. "Naukova Dumka", Kiev. (English transl. TT 75-50010, U. S. Dept. of Commerce, National Technical Information Service).

TABLE 8 (continued)

Species	Concentration, curie/liter	Effect	Reference
<i>Salmo salar</i>	10^{-10} - 10^{-8}	Reduced number of primary sex cells (PSC) up to stage of bispermic closure	Megalovskii, 1969
	10^{-10}	Increased number of PSC in day-old larvae	" "
	10^{-8}	Reduced number of PSC at all stages of embryogenesis	" "
<i>S. trutta</i>	10^{-7}	Reduced number of hatched larvae, increased number of deformed larvae	Brown and Templeton, 1964; Templeton, 1968
	10^{-8}	Increased number of hatched larvae, reduced number of deformed larvae	The same
<i>Pleuronectes platessa</i>	10^{-1} , 10^{-4}	Reduced number of hatched larvae and reduced number of deformed larvae	" "
	10^{-10}	Mortality, morphological anomalies in larvae	Fedorov et al., 1964
<i>Scorpaena porcus</i> , <i>Engraulis encrasicolus</i> , <i>Trachurus mediterraneus</i> ponticus, <i>Mullus barbatus</i> ponticus, <i>Serranus scriba</i>	$2 \cdot 10^{-10}$ - $2 \cdot 10^{-4}$	Morphological anomalies in larvae	Polikarpov and Ivanov, 1961, 1962a, c
<i>Scorpaena porcus</i> , <i>Sargus annularis</i> , <i>Mullus barbatus</i> ponticus, <i>Trachurus mediterraneus</i> ponticus	$2 \cdot 10^{-10}$ - 10^{-4} 10^{-10} - 10^{-10}	Egg mortality Morphological anomalies in larvae	Ivanov, 1965 Polikarpov and Guseva, 1968
<i>Scorpaena porcus</i>	10^{-8} - 10^{-5}	Increased frequency of nucleus disruptions	Tyringina, 1970b
<i>Scorpaena porcus</i> , <i>Engraulis encrasicolus</i> , <i>Trachurus mediterraneus</i> ponticus, <i>Mullus barbatus</i> ponticus, <i>Serranus scriba</i>	$2 \cdot 10^{-10}$ - $2 \cdot 10^{-4}$	Morphological anomalies in larvae	Ivanov, 1965
<i>Scorpaena porcus</i> , <i>Scaphthalmus maculatus</i>	$2 \cdot 10^{-10}$ - $2 \cdot 10^{-4}$	Increased frequency of nucleus disruptions	Tyringina, 1969b, 1970b

Table 8 continued.

Source: Tsytsugina, V. G., N. S. Risik and G. E. Lazorenko. 1975. Chp. II. Karyology of marine fish and the effect of radionuclides on their chromosome apparatus. pp. 16-19. In: Artificial and Natural Radionuclides in Marine Life. "Naukova Dumka", Kiev. (English transl. TT 75-50010, U. S. Dept. of Commerce, National Technical Information Service).

TABLE 8 (continued)

Species	Concentration, curie/liter	Effect	Reference
^{137}Cs			
<i>Pleuronectes platessa</i>	10^{-11}	Mortality, morphological anomalies in larvae	Fedorov et al., 1964
<i>Scophthalmus macroticus macroticus</i>	$10^{-6}-10^{-5}$	Increased frequency of nuclear disruptions	Tsytsugina, 1969c
^{134}Cs			
<i>Scorpaena porcus</i> , <i>Engraulis encrasicolus</i> , <i>Trachurus mediterraneus</i> , <i>porcus</i> , <i>Mullus barbatus ponticus</i> , <i>Serranus scriba</i>	$10^{-10}-10^{-4}$	Morphological anomalies in larvae	Ivanov, 1965
Extract of radioactive ash			
<i>Pseudorasbora parva parva</i>	10^{-6}	100% larval mortality, morphological anomalies	Ishiya and Yagi, 1956
Radionuclide mixture of unknown composition			
<i>Zebra danio</i>	$5.1 \cdot 10^{-6}$	100% egg mortality	Mikami, Watanabe and Takano, 1956
	$4.3 \cdot 10^{-8}$	Suppressed growth and differentiation, delayed hatching, morphological anomalies	The same

Source: Woodhead, D. S. 1973. Levels of radioactivity in the marine environment and dose commitment to marine organisms. pp. 499-521. In: Radioactive Contamination of the Marine Environment. Intern. Atomic Energy Agency, Vienna, Austria, publication STI/PUB/313.

TABLE XV. SUMMARY OF DOSE RATES ($\mu\text{rad h}^{-1}$) TO MARINE ORGANISMS FROM ENVIRONMENTAL RADIOACTIVITY

Source	Phytoplankton 20 m depth, remote from sea bed	Zooplankton 20 m depth, remote from sea bed	Mollusca 20 m depth, on the sea bed	Crustacea 20 m depth, on the sea bed	Fish 20 m depth, remote from sea bed	20 m depth, on the sea bed
NATURAL BACKGROUND						
Cosmic radiation	0.5	0.5	0.5	0.5	0.5	0.5
Internal activity	1.9-7.3	2.6-15.7	7.4-14.9	7.9-21.4	2.7-4.2	2.7-4.2
Water activity	0.4	0.3	0.1	0.1	0.1	0.1
Sediment activity, γ	-	-	1.9-16.0	1.5-16.0	-	1.5-16.0
Sediment activity, β	-	-	1.6-21.0	1.6-21.0	-	1.6-21.0
Total	2.8-8.2	3.3-16.4	9.5-31.5	10.0-38.9	3.3-4.8	4.8-28.8
FALLOUT						
Internal activity, ^{239}Pu , ^{240}Pu	0.01-0.88	0.12-12.4	0.04-0.22	0.04-0.897	0.02-0.06	0.02-0.06
Water activity	0.25-24.6	1.2-124	0.04-2.7	0.28	0.12-1.7	0.12-1.7
Coastal activity	5.2-18-5.8-116	0.18-0.011	(0.7-25) $\times 10^{-4}$	(0.7-25) $\times 10^{-4}$	(0.2-25) $\times 10^{-4}$	(0.2-25) $\times 10^{-4}$
Sediment activity	0.32-24.5	1.4-107	0.10-2.0	0.36-0.48	0.14-1.8	0.14-1.8
Total						
WASTE DISPOSAL						
Wastewater	200-2100	530-5000	15.3-50.9	6.9-57.9	0.5-1.5	0.5-1.5
Internal activity	0.2-2.3	0.2-2.0	0.05-1.2	0.05-1.2	0.05-1.2	0.05-1.2
Water activity	-	-	36.4-2340	36.4-2340	-	36.4-2340
Sediment activity, γ	-	-	297-2300	297-2300	-	297-2300
Sediment activity, β	-	-	21.8-2400	43.3-2400	-	21.8-2340
Total	200-2100	530-5000				
Releases						
Internal activity	-	-	1.37-1.01	-	-	-
Water activity	-	-	1.69	1.69	-	1.69
Sediment activity, γ	-	-	1.33	1.33	-	1.33
Sediment activity, β	-	-	2.1-3.5	1.7	-	1.7
Total	-	-				

Source: Seymour, A. H. et al. 1975. Aquatic environment. pp. 103-161. In: Long-term Worldwide Effects of Nuclear-Weapons Detonations. (Committee to Study the Long-term Worldwide Effects of Nuclear-Weapons Detonations). National Research Council, National Academy of Sciences, Washington, DC.

TABLE 4.10 Comparison of the Radiation Sensitivities of Various Aquatic Organisms as Indicated by Lethal Doses^a

Species	Radiation	Dose Rate	Temp. (°C)	Salinity (ppt)	LD ₅₀ Days	LD ₅₀ Dose
FISH						
<i>Carassius auratus</i>	X ray	1080 rad/min	20-25	0	30	2,315 rad
<i>Salmo gairdnerii</i>	X ray	-	-	-	30	1,500 rad
<i>Oncorhynchus kisutch</i>	X ray	100 rad/min	-	-	150	25 rad
eggs 50% incub.	X ray	-	-	-	-	607 rad
<i>Fundulus heteroclitus</i> ^b	Gamma ray	480 rad/min	21	-	30	1,120 rad
					50	1,075 rad
<i>Mugil cephalus</i> ^b	Gamma ray	480 rad/min	18	-	30	1,450 rad
					50	-
<i>Eucinostomus</i> sp. ^b	Gamma ray	480 rad/min	22	-	30	3,500 rad
					50	1,575 rad
<i>Lagodon rhomboides</i> ^b	Gamma ray	480 rad/min	18	-	30	3,000 rad
					50	2,250 rad
<i>Micropterus salmoides</i> ^b	Gamma ray	480 rad/min	18	-	30	1,050 rad
					50	-
<i>Paralichthys lethostigma</i> ^b	Gamma ray	480 rad/min	14	-	30	5,550 rad
					50	1,925 rad
CRUSTACEA						
<i>Gammarus salinus</i>	X ray	420 rad/min	15	10	30	1,700 rad
<i>G. saccardi</i>	X ray	420 rad/min	15	10	30	1,700 rad
<i>G. duebeni</i>	X ray	420 rad/min	15	10	30	3,900 rad
<i>G. duebeni</i>	X ray	420 rad/min	15	10	30	3,500 rad
<i>Palaeomonetes pugio</i>	Gamma ray	1950 rad/min	-	-	30	1,455 rad
<i>P. pugio</i>	Gamma ray	350 rad/min	20	30	30	750 rad
					40	215 rad
<i>Uca pugnax</i>	Gamma ray	1950 rad/min	-	-	30	8,209 rad
<i>U. pugnax</i>	Gamma ray	350 rad/min	20	30	40	15,500 rad
<i>U. pugilator</i>	Gamma ray	350 rad/min	20	30	40	9,800 rad
<i>U. minax</i>	Gamma ray	350 rad/min	20	30	40	13,500 rad
<i>Callinectes sapidus</i>	Gamma ray	350 rad/min	20	30	40	42,000 rad

Table h.10. continued.

Source: Seymour, A. H. et al. 1975. Aquatic environment, pp. 103-161. In: Long-term Worldwide Effects of Nuclear-Weapons Detonations. (Committee to Study the Long-term Worldwide Effects of Nuclear-Weapons Detonations). National Research Council, National Academy of Sciences, Washington, DC.

Species	Radiation	Dose Rate	Temp. (°C)	Salinity (ppt)	LD ₅₀ Days	LD ₅₀ Dose
MOLLUSCA						
<i>Mercenaria mercenaria</i>	Gamma ray	5800 rad/min	-	-	30	115,000 rad
					60	67,000 rad
<i>Crassostrea virginica</i>	Gamma ray	5800 rad/min	-	-	30	100,000 rad
					60	<10,000 rad
<i>Australorbis glabratus</i>	X ray	1000-1500 rad/min	-	0	30	23,800 rad
					60	16,300 rad
					90	13,800 rad
<i>Urosalpinx cinerea</i>	X ray	-	-	-	30	40,000 rad
					60	20,000 rad
<i>U. cinerea</i>	X ray	-	-	-	30	47,000 rad
					60	32,000 rad
<i>Nassarius obsoletus</i>	Gamma ray	480 rad/min	18	-	30	37,500 rad
					50	14,000 rad

^aData from Reference 34. (Rice, T. A. and J. P. Baptist, 1974)

^bImmature stage.

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