such as gallium-68 and [^{18}F]fluorodeoxyglucose have been available for some time and have been shown to have a certain tumor-localizing capability. These agents have not made any impact on clinical oncologic practice, and it is unlikely that the newly prepared agent by Fujiwara et al. would achieve clinical success as a PET tumor imaging agent.

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REFERENCES

1. Beck RN. A theoretical evaluation of brain scanning systems. *J Nucl Med* 1960; 1:105.
2. Bender MA, Blau M. Autofluoroscopy: the use of a non-scanning device for tumor localization with radioisotopes. *J Nucl Med* 1960; 1:105.
3. Blau M, Bender MA. Clinical evaluation of ^{203}Hg neohydrin and ^{131}I albumin in brain tumor localization. *J Nucl Med* 1960; 1:106.
4. Paul W, Botterell EH. An appraisal of As-74 for localization of brain tumors. *J Nucl Med* 1960; 1:126.
5. Bell RL. Concentration of labeled triiodothyronine and radioactive albumin in human cerebral neoplasms. *J Nucl Med* 1960; 1:180–185.
6. Blau M, Manske RF. The pancreas specificity of ^{75}Se-selenomethionine. *J Nucl Med* 1961; 2:102–105.
7. Blau M, Bender MA. Radiomercury (^{203}Hg)-labeled neohydrin: a new agent for brain tumor localization. *J Nucl Med* 1962; 3:83–92.
8. Winkelman J, McAfee JG, Wagner HN, Long RG. The synthesis of ^{57}Co-tetraphenylporphine sulfonate and its use in the scintillation scanning of neoplasms. *J Nucl Med* 1962; 3:249–253.
9. Aronow S, Brownell GL, Lovo SL, Sweet WH. Scanning for brain tumor localization. *J Nucl Med* 1962; 3:198.
10. McAfee JG, Fueger CF, Stern HS, Wagner HN Jr, Migita T. [^{99m}Tc]pertechnetate for brain scanning. *J Nucl Med* 1964; 5:811–827.
11. Quinn JL III, Hauser W, Ciric I. Analysis of 100 consecutive abnormal brain scans using ^{99m}Tc as pertechnetate. *J Nucl Med* 1965; 6:333.
12. Witcofski R, Maynard D, Meschan I. The utilization of ^{99m}Tc in brain scanning. *J Nucl Med* 1965; 6:121–130.
13. Soloway AH, Hatanaka H, Davis MA. Penetration of brain and brain tumor. VII. Tumor-binding sulfhydryl boron compounds. *J Med Chem* 1967; 10:714.
14. Holman BL, Kaplan WD, Dewanjee MK, et al. Tumor detection and localization with ^{99m}Tc-tetracycline. *Radiology* 1974; 112:147.
15. Order SE, Bloomer WD, Jones AG, et al. Radionuclide immunoglobulin lymphangiography: a case report. *Cancer* 1975; 35:1487.
16. Froelich JW. MRI's impact minimal on nuclear medicine. *Diagnostic Imaging* 1990; 12(6):73–77.
17. McAfee JG, Kopecky RT, Frymoyer PA. Nuclear medicine comes of age: its present and future role in diagnosis. *Radiology* 1990; 174:609–620.

SELF-STUDY TEST

Radiobiology and Radiation Protection

Questions are taken from the *Nuclear Medicine Self-Study Program I*, published by The Society of Nuclear Medicine

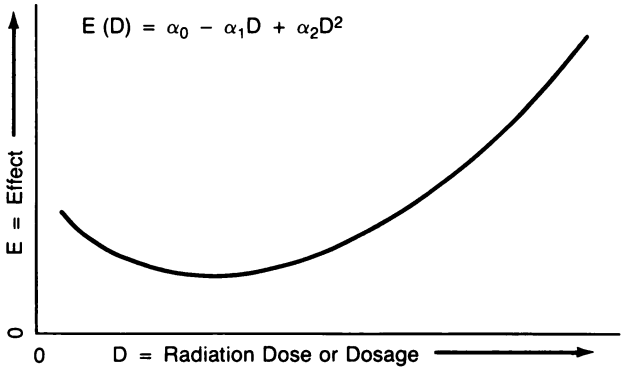
DIRECTIONS

The following items consist of a question or an incomplete statement followed by five lettered answers or completions. Select the *one* lettered answer or completion that is *best* in each case. The answers may be found on page 1692.

1. The shape of the dose-response curve for radiation exposure at occupational dose levels is uncertain and controversial. The curve shown in Figure 1 illustrates which of the hypotheses that have been suggested?

A. hyperbolic
B. quadratic
C. hormesis
D. linear-quadratic
E. supralinear

Note: For further in-depth information, please refer to the syllabus pages included at the beginning of *Nuclear Medicine Self-Study Program I: Part I.*



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section radiography: fundamentals. *Radiol Clin North Am* 1963; 1:229–244.
4. Vallebona A. A method of taking roentgenograms which makes it possible to eliminate shadows. *Fortschr. a.d. Geb. d. Roentgenstrahlen* 1933; 48:599–605.
5. Kuhl DE, Edwards RQ. Image separation radioisotope scanning. *Radiology* 1963; 80:653–662.
6. Anger HO. Tomographic gamma-ray scanner with simultaneous readout of several planes. Lawrence Radiation Laboratory Report UCRL-16899, 1966.
7. Patton JA, Brill AB, Erickson JJ, et al. A new approach to the mapping of three-dimensional radionuclide distributions. *J Nucl Med* 1969; 10:363.
8. Koral KF. Partial angle emission computed tomography. In: Williams LE, ed. *Nuclear medical physics, Volume II.* Boca Raton: CRC Press; 1987:155–175.
9. Rangayyan R, Dhawan AP, Gordon R. Algorithms for limited-view computed tomography: an annotated bibliography and a challenge. *Appl Opt* 1985; 24:4000–4012.
10. Davison ME. The ill-conditioned nature of the limited angle tomography problem. *SIAM J Applied Math* 1983; 43:428–448.
11. Edholm P, Granlund G, Knutsson H, Petersson C. Ectomography–a new radiographic method for reproducing a selected slice of varying thickness. *Acta Radiol Diag* 1980; 21:433–442.
12. Knutsson HE, Edholm P, Granlund GH, Petersson CU. Ectomography—a new radiographic reconstruction method—I. Theory and error estimates. *IEEE Trans Biomed Eng* 1980; 27:640–648.

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2. A 30-year-old married woman had a 10-year history of ulcerative colitis. Periodic barium enemas were performed to monitor her disease and to look for the presence of maligancy. Her most recent barium enema was judged to be suboptimal and the examination was repeated 3 weeks later. The patient was subsequently found to be pregnant (2 weeks at the time of the first barium enema). The radiation dose to the embryo from each procedure was 3.1 rads (0.031 Gy). Which *one* of the following statements is correct?

A. The likelihood of a radiation-induced congenital abnormality in the child is negligible.
B. There is a high risk of mental retardation in the child.
C. There is a high risk only for skeletal anomalies in the child.
D. The likelihood of congenital abnormalities is dependent on the total dose of 6.2 rads.
E. Therapeutic abortion should be advised.

3. Medical radiation doses to the public average about 100 mrems/year/person. Which *one* of the following statements is correct concerning the need to reduce medical doses even further?

A. There is no need to reduce doses further because the doses are only 2% of the legal occupational dose limit.
B. Doses should be reduced further, because nonstochastic effects can be seen after many years of exposure at these dose levels.
C. The U.S. Congress mandated a federal effort to reduce medical doses in the Atomic Energy Act of 1954.
D. The collective dose is quite high and of concern on a population-wide basis.
E. The only real concern is dose from nuclear medicine procedures, because of the internal deposition of the radioactive material.

SELF-STUDY TEST

Radiobiology and Radiation Protection

ANSWERS

ITEM 1: Hormesis

ANSWER **C**

The effects on humans of large radiation doses delivered at high dose-rates are relatively well known, i.e., the shape of the dose–response curve is well-defined. In contrast, the effects that might result from exposure to small doses of radiation in a protracted, low dose-rate pattern are not known with any degree of certainty. This lack of certainty regarding the effects of radiation at low doses and low dose-rates is largely due to the fact that the effects are likely to be identical to those caused by any number of other agents, such as toxic chemicals and chronic tobacco use. If a radiation effect is to be observed, it must occur with sufficient frequency in the irradiated population that this frequency of occurrence can be distinguished from the normal "background" incidence of the effect. In the absence of large-scale epidemiologic studies involving hundreds of thousands or even millions of individuals exposed to small doses of radiation above the background level, the derivation of a dose–response curve in the low-dose region requires extrapolation from the dose–response curve derived from high dose data. It is this extrapolation that introduces the uncertainty and controversy.

Radiation protection regulations must be written in a conservative manner, such that exposure to the doses permitted in the regulations does not lead to significant excess risk to the exposed person. Because the few data points that exist between the high-dose region of the dose–response curve and the zero-dose axis are scattered and do not have an exact geometrical relationship to each other, a mathematical model must be assumed and employed to complete the dose–response curve in this region. The model currently enjoying favor among national and international scientific advisory bodies is the linear–quadratic model, in which the lowest-dose region behaves according to a linear model of shallow slope and the remainder of the low-dose region behaves according to a quadratic model. This model agrees reasonably well with the sparse experimental and epidemiologic data and with the increased body of radiobiologic data that shows that the ability of a living system to repair low-dose damage may be greater than previously thought. The linear model is preferred by regulatory agencies, such as the U.S. Nuclear Regulatory Commission. This model connects a straight line from the bottom end of the high-dose response curve to the zero-dose/zero-effect intercept of the curve. It is considered to be suitably conservative by the regulatory community and by the overwhelming majority of the scientific community. A minority of scientists insists that a supralinear model fits the data just as well as the other two models. The supralinear model postulates that the effects of radiation per rem at low doses are more severe than at high doses, so that the dose–response curve is elevated above the

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Books Received

Technical Manual. *Richard H. Walker, ed, American Association of Blood Banks, Arlington, VA, 1990, 665 pp, $33.00*

Envisioning Information. *Edward R. Tufte, Graphics Press, Cheshire, CT, 1990, 126 pp, $48.00*

From the Watching of Shadows: The Origins of Radiological Tomography. *Steve Webb, Adam Hilger Publishing, Bristol, England or New York, NY, 1990, 347 pp, $59.00*

Radiation Protection: A Guide for Scientists and Physicians (Third Edition). *Jacob Shapiro, Harvard University Press, Cambridge, MA, 1990, 494 pp, $35.00*

Obsessive-Compulsive Disorders: Theory and Management (Second Edition). *Michael A. Jenike, Lee Baer, and William E. Minichiello, Mosby Yearbook Medical Publishers, Chicago, IL, 1990, 436 pp. $45.00*

Disorders of the Patellofemoral Joint, (Second Edition) *John P. Fulkerson and David S. Hungerford, Williams & Wilkins York, PA, 1990, 294 pp, $65.00*

Clinical Application of Radiolabelled Platelets. *Ch. Kessler, M.R. Hardeman, H. Henningsen and J-N. Petrovici, Kluwer Academic Publishers Group, Dordrecht, The Netherlands, 1990, 295 pp, $89.00*

Handbooks in Radiology: Head and Neck Imaging. *H. Ric Harnsberger, Mosby-Year Book, St. Louis, MO, 547 pp, $29.95*

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linear and linear–quadratic models throughout the low-dose region. A hyperbolic model has not been postulated.

Yet another controversial model for the low-dose region of the dose–response curve is the hormesis model. It has been known for many years that small amounts of chemicals or pathogens that are dangerous in large concentrations can be beneficial; e.g., a vaccination is the administration of a dangerous pathogen in a low concentration so that the body will develop an immunity. This property of being dangerous at high levels and beneficial at low levels is called hormesis. There is an increasing body of literature that supports the hormesis hypothesis for radiation. For example, animals reared inside shielded rooms and exposed to less natural background radiation than comparably handled control animals were less healthy and lived shorter lives. It has been hypothesized that natural background radiation sterilizes precancerous or cancerous cells, and that it is only with the general decrease of health as we grow older that this protective mechanism breaks down. If hormesis were assumed as a mathematical model, the dose–response curve would be "J" shaped, and at low doses would dip below the effect axis at zero dose. At low levels of radiation, beneficial effects predominate, but as dose increases the detrimental effects eventually overcome the beneficial effects. The curve shown in the figure represents one example of a hormesis model.

[Test figure in Question 1 is reprinted with permission from Hickey RJ, Bowers EJ, Clelland RC. Radiation hormesis, public health, and public policy: A commentary. *Health Phys* 1983;44:207–219.]

ITEM 2: Diagnostic Radiation Exposure in Pregnancy
ANSWER **A**

Based on the best knowledge available today, the risk of congenital malformation is negligible for doses of 5 rads or less, and is significantly increased above control levels only at doses above 15 rads. Thus, the risk of a radiation-induced congenital abnormality from a dose of 6.2 rads would be negligible. The possibility of such abnormalities is further reduced because the total dose of 6.2 rads was delivered in two parts separated by a radiation-free interval of 3 weeks. Because the first dose of 3.1 rads was delivered at the end of the second week of pregnancy (at the end of the preimplantation period), the greatest risk is for embryonic death, not malformation. The second 3.2-rad dose was delivered in the period of organogenesis, but the dose would be well below the practical threshold for any significant risk of induced abnormality (the risk becomes significant only for doses above 15 rads). The risk of skeletal abnormalities would also be negligible. Although mental retardation was observed after high-dose rate, in utero exposure from the A-bomb, it was confined mainly to the 8–15 weeks after conception, with none observed in those exposed 0–7 weeks after conception. In any case, even if the two 3.1-rad doses had been given on the same day, this would not be sufficient indication for a therapeutic abortion.

References

1. Mole RH. Irradiation of the embryo and fetus. *Br J Radiol* 1987;60:17–31.
2. NCRP Report 54: *Medical radiation exposure of pregnant and potentially pregnant women.* Washington, D.C.: National Commission on Radiation Protection and Measurements, 1977.

ITEM 3: Reduction of Medical Radiation Exposure
ANSWER **D**

Current radiation protection guidelines are based on the intentionally conservative assumption that small increments of additional radiation dose can lead to increased risk of stochastic effects. Therefore, it is desirable to lower the radiation dose of every individual, in keeping with the ALARA principle. It also is desirable to minimize possible genetic effects. All of these factors contribute to a philosophy of reducing and maintaining both individual and collective doses as low as reasonably achievable.

Nonstochastic effects occur only after exposure to rather large amounts of radiation, well above the levels of exposure for individuals exposed to diagnostic radiation. The internal deposition of long-lived radioactive materials can be of concern if the activity of the materials is sufficiently high. Fortunately, most of the radionuclides used in nuclear medicine have short half-lives and are administered in sufficiently low activities that they pose very little long-term concern.

The Atomic Energy Act of 1954 established the Atomic Energy Commission and authorized the distribution of by-product materials to properly trained individuals. The Act did not address the lowering of medical radiation doses.