Fetal Dosimetry

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Learning Objectives

- Describe the models used for fetal dosimetry
- Identify potential fetal effects from maternal intakes
- Analyze several case studies

Dose Limits/Guidance

- 10 CFR 20.1208:
  - The dose to an embyo/fetus of a declared pregnant women shall not exceed 500 mrem
  - Dose is sum of deep dose equivalent to woman and dose equivalent from radionuclides in the woman and embryo/fetus
- Regulatory Guide 8.36 (1992)
- NUREG/CR-5631 (Rev. 2) (1996)

Pregnancy Dating (Gestational)

- Gestational age calculated from beginning of last menstrual period (LMP).
- Average length of pregnancy 280 days or 40 weeks (95% CL 2 weeks); 3 trimesters.
- During the first 2 weeks following ovulation, successive phases are:
  - Ovulation
  - Fertilization of the ovum
  - Formation of the free blastocyst
  - Implantation of the blastocyst
- Embryo: 0 - 10 weeks; fetus: 10 - 40 weeks.

Fetal Dose Considerations

- Assume DDE is same as recorded for woman
- Photon irradiation by radioactive materials in the woman's body (assume no particulate radiation reaches fetus)
- Photon irradiation by radioactive materials in fetus itself
- Particulate irradiation by radioactive materials in fetus itself

Fetal Dose Definition

- The “fetal dose” from intakes of radionuclides by the mother is the dose equivalent calculated for the duration of the pregnancy
- Committed dose (equivalent) in terms of integration over 50 years is not used
- Effective dose equivalent is not used

Fetal Dose Models

- Fetal dose is based on uptake to mother's transfer compartment (bloodstream)
- A simplified model of dose to the uterus may be used (App. A to Reg. Guide 8.36) or
- A gestation-time dependent model including fetal biokinetics may be used (App. C to Reg. Guide 8.36)

Calculating Maternal Uptake

- Ingestion: intake x f_1
- Inhalation: use Task Group Lung Model
  - Class D: intake x (0.48 + 0.15 f_1)
  - Class W: intake x (0.12 + 0.51 f_1)
  - Class Y: intake x (0.05 + 0.58 f_1)
- Injection: uptake = intake
  - can also be used for wounds, or use NCRP 156 model

Example 1--Reg. Guide 8.36

- Declared pregnant woman ingests 22 μCi ^{58}Co
- Uptake = f_1 x 22 = 0.3 x 22 = 6.6 μCi
- Simplified dose coefficient from App. A:
  - DE = 9.17E-03 x uptake
  - DE = 9.17E-03 rem/ μCi x 6.6 μCi
    = 61 mrem

Example 1, con't

- Dose coefficients given in App. C of Reg. Guide 8.36 give dose to fetus as a function of fetal gestational age at time of maternal intake.
- Dose factor for maternal ^{58}Co intake in first month is 8.79E-03 rad/ μCi
- Dose = 8.79E-03 rad/ μCi x 6.6 μCi
  = 58 mrad = 58 mrem

Example 2

- Pregnant worker has inhalation of 100 μCi ^{131}I in third month of gestation
- Uptake for Class D = 0.48 + 0.15 f_1
- Uptake = 100 μCi x (0.48 + 0.15 x 1.0)
  = 100 μCi x 0.63 = 63 μCi
- Simplified model dose factor = 3.64E-03
- DE = 63 μCi x 3.64E-03 rem/ μCi
  = 229 mrem

Example 2, con't

- The time-specific dose factor from App. C is 9.94E-05 rad/ μCi for I-131 in third month
- DE = 63 μCi x 9.94E-05 rad/ μCi
  = 6 mrad = 6 mrem
- Difference is due to inclusion of fetal biokinetics in this model--no thyroid uptake until 2nd trimester

Pre-existing Body Burden

- If the woman has a pre-existing body burden at the time of conception, ASSUME the entire body burden will become systemic
- If body burden determined from whole-body counting, use result directly
- If body burden determined from excreta analysis, use IRF to get intake, then retention model to get body burden

Chronic Intakes

- Chronic intakes are treated as a series of discrete individual intakes
- May use simplified model, which will normally be an over-estimate
- May use time-specific factors in App. C, adding all intakes over a month

Specific Windows of Opportunity for Radiation Damage in Fetal Development

- Cataracts: 0-6 days (gestational)
- Exencephaly: 0-37 days
- Embyronic death: 4-11 days
- Anencephaly or microcephaly: 9-90 days
- Anophthalmia: 16-32 days
- Cleft palate: 20-37 days
- Skeletal dyscrasias: 25-85 days
- Growth retardation: 50+ days

Deterministic Effects on the Embryo / Fetus

- Preconception - No statistically significant effects noted
- Preimplantation - “All or none”
- Implantation - Transient IUGR; threshold 10-20 rads
- Organogenesis: 7-13 weeks
  - Embryo sensitive to lethal, teratogenic and growth-retarding effects because of the criticality of cellular activities and the high proportion of radiosensitive cells.
  - IUGR, gross congenital malformations, microcephaly and mental retardation are the predominant effects for doses > 50 rads
  - There is no report of external irradiation inducing morphologic malformation in humans unless the individual also had growth retardation or a CNS anomaly

Specific Radiation Effects on the Fetus

- Mental retardation
  - Highest risk during major neuronal migration (8-15 weeks). Incidence increases with dose. At 1 Gy (100 rads), 75% experience severe retardation
  - At 16-25 weeks, fetus shows no increase in mental retardation at doses < 0.5 Gy(50 rads)
- IQ
  - Risk factor associated with diminution of IQ is 21-33 points at 1 Gy given in the gestational period 8-15 weeks.
- Microcephaly: Hiroshima Data
  - 0 dose - 4%; 1-9 rads - 7%; 10-19 rads - 11%
  - 20-29 rads - 23%; 30-49 rads - 36%; 50-149 rads - 45%
  - > 150 rads - 35%

Considerations for Pregnancy Termination

- Normal rate of preclinical loss - > 30%.
- At 0.1 Gy (10 rad), this is increased by 0.1-1%.
- Consider the lifetime risk factor for induction of childhood tumors to be 1 in 2000 per rad. At 5 rad, maximal risk for childhood leukemia is 1 in 400. Conversely, probability of not having childhood cancer is > 99%.
- If the fetal absorbed dose > 50 rad in the 7-13 week window, there is a substantial risk of IUGR and CNS damage.
- In the range 25 - 50 rad at 7-13 weeks: parental decision with physician guidance.

Comparison of Risks during Pregnancy

- Maternal Rubella:
  - < 11 weeks: 80% will have fetus with congenital infection
  - 13-14 weeks: 54 % incidence of congenital infection
  - 24 weeks: 25% with congenital syndrome
- Maternal Alcohol Use
  - Moderate (2-3 drinks/day) - 10% incidence of fetal alcohol syndrome (FAS)
  - Heavy (> 5 drinks/day) - 30% incidence of FAS
- Maternal Smoking
  - Incidence of fetal growth retardation directly proportional to number of cigarettes smoked

Medical Fetal Exposure

- The possibility of pregnancy should always be considered when women of child-bearing age receive medical radiation
- For most diagnostic procedures, Mossman has indicated that pregnancy testing is not cost-effective
- However, for therapeutic procedures, significant fetal doses can be received, particularly in the case of radioiodines

Low-dose Cases

- 7-week pregnant female administered 0.1 GBq Tl-201 for cardiac stress test. Resulting dose to embryo was 11 mGy
- 6-week pregnant female administered 0.3 GBq Tc-99m sestamibi in rest phase plus 0.9 GBq Tc-99m sestamibi in stress phase. Resulting dose to embryo was 16 mGy
- No expected consequences except mental stress to the patient

Radioiodine Procedures

- All radioiodines easily cross the placenta and enter the fetal circulation
- The fetal thyroid becomes functional at about the eleventh week of gestation, and concentrates iodine from then onwards
- Due to the small mass of the fetal thyroid, absorbed doses can be large
- Watson has published a comprehensive fetal thyroid dosimetry model

Fetal Thyroid Dose Factors, mGy/MBq

Months	I-123	I-124	I-125	I-131
3	2.7	24	290	230
4	2.6	27	240	260
5	6.4	76	280	580
6	6.4	100	210	550
7	4.1	96	160	390
8	4.0	110	150	350
9	2.9	99	120	270

High Dose Case No.1 (Ohio)

- 32 y.o. amenorrheic female administered 0.3 GBq I-131 for hyperthyroidism, later discovered to have been 16 weeks pregnant
- Fetal whole body dose only 26 mGy
- Fetal thyroid dose was 88 Gy, producing complete ablation
- Supplemental thyroid hormone administered; fetus born 2 months prematurely, and at 9 months of age was in 6th percentile for weight and growth

High Dose Case No. 2 (Missouri)

- Patient administered 5.75 GBq of I-131 for treatment of metastatic disease later found to be 13.5 weeks pregnant with twins
- Fetal effective dose estimated to be 0.4 Sv
- Absorbed dose to fetal thyroids estimated to exceed 2 kGy
- Patient elected to terminate the pregnancy

High Dose Case No. 3 (Kansas)

- Patient administered 440 MBq I-131 for hyperthyroidism later found to be 18-20 weeks pregnant at time of procedure
- Dose equivalent to fetus estimated to be 30 mSv, fetal thyroid dose equivalent estimated to be 250 Sv
- Pregnancy continued to full term

High Dose Case No. 4 (W. Va.)

- Patient administered 340 MBq I-131 for hyperthyroidism later found to be 14 weeks pregnant at time of procedure
- Fetal dose equivalent estimated to be 23 mSv
- Fetal thyroid absorbed dose estimated to be 88 Gy
- Intra-amniotic thyroid hormone therapy; pregnancy continued to term

Root Causes

- In every case, patient denied any possibility of pregnancy
- In the Missouri case, results of pregnancy test ordered by referring physician not transmitted to nuclear medicine department
- Nuclear medicine facilities did not require pregnancy tests, contrary to guidance from American College of Radiology

Conclusions

- Pregnancy testing should be mandatory before radionuclide therapy procedures
- Pregnancy testing should be recommended before diagnostic radioiodine procedures
- Pregnancy testing may not be cost-effective before non-radioiodine diagnostic procedures