September 3, 2010

Dr. Raymond J. Juzaitis
Nuclear Engineering Department Head
Texas A & M University
Zachry Bldg., Room 129
Mail Stop 3133
College Station, TX 77843

SUBJECT: INITIAL EXAMINATION REPORT NO. 50-059/OL/10-02, TEXAS A&M UNIVERSITY AGN-201M REACTOR

Dear Dr. Juzaitis:

During the week of August 16, 2010, the Nuclear Regulatory Commission (NRC) administered an operator licensing examination at your AGN-201M Reactor. The examination was conducted according to NUREG-1478, "Operator Licensing Examiner Standards for Research and Test Reactors," Revision 2. Examination questions and preliminary findings were discussed with those members of your staff identified in the enclosed report at the conclusion of the examination.

In accordance with Title 10 of the *Code of Federal Regulations* Section 2.390, a copy of this letter and the enclosures will be available electronically for public inspection in the NRC Public Document Room or from the Publicly Available Records (PARS) component of NRC's Agencywide Documents Access and Management System (ADAMS). ADAMS is accessible from the NRC Web site at http://www.nrc.gov/reading-rm/adams.html. The NRC is forwarding the individual grades to you in a separate letter which will not be released publicly. Should you have any questions concerning this examination, please contact Mr. Paul V. Doyle Jr, at (301) 415-1058 or via internet e-mail Paul.Doyle@nrc.gov.

Sincerely,

***/RA/***
Johnny H. Eads, Jr., Chief
Research and Test Reactors Oversight Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Docket No. 50-059

Enclosures: 1. Initial Examination Report No. 50-059/OL/10-02
2. Written examination with facility comments incorporated

cc: Christopher Crouch, Reactor Supervisor
cc without enclosures: Please see next page

September 3, 2010

Dr. Raymond J. Juzaitis
Department Head
Department of Nuclear Engineering
3133 TAMU
College Station, TX 77843-3133

SUBJECT: INITIAL EXAMINATION REPORT NO. 50-059/OL/10-02, TEXAS A&M UNIVERSITY AGN-201M REACTOR

Dear Dr. Juzaitis:

During the week of August 16, 2010, the Nuclear Regulatory Commission (NRC) administered an operator licensing examination at your AGN-201M Reactor. The examination was conducted according to NUREG-1478, "Operator Licensing Examiner Standards for Research and Test Reactors," Revision 2. Examination questions and preliminary findings were discussed with those members of your staff identified in the enclosed report at the conclusion of the examination.

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DISTRIBUTION w/ encls.:

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**ADAMS ACCESSION #: ML102371230** **TEMPLATE #:NRR-074**

| | | | | | | |
|---|---|---|---|---|---|---|
| OFFICE | PROB:CE | | IOLB:LA | E | PROB:SC | |
| NAME | PDoyle | | CRevelle | | JEads | |
| DATE | 08/31/2010 | | 09/02/2010 | | 09/03/2010 | |

OFFICIAL RECORD COPY

cc:

Mayor, City of College Station
P.O. Box Drawer 9960
College Station, TX 77840-3575

Governor's Budget and
Planning Office
P.O. Box 13561
Austin, TX 78711

Texas A&M University System
ATTN: Dr. Warren D. Reece, Director
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Technical Advisor
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Texas Commission on Environmental Quality
P.O. Box 13087, MS 122
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Test, Research, and Training
Reactor Newsletter
University of Florida
202 Nuclear Sciences Center
Gainesville, FL 32611

U. S. NUCLEAR REGULATORY COMMISSION
OPERATOR LICENSING INITIAL EXAMINATION REPORT

REPORT NO.: 50-059/OL/10-02

FACILITY DOCKET NO.: 50-059

FACILITY LICENSE NO.: R-23

FACILITY: TEXAS A&M UNIVERSITY AGN-201M Reactor

EXAMINATION DATES: August 17- 19, 2010

SUBMITTED BY: ______________________________ __________
Paul V. Doyle Jr., Chief Examiner Date

SUMMARY:

The NRC administered an operator licensing examination to two Senior Reactor Operator (Instant) (SRO-I) candidates and two Reactor Operator (RO) candidates. One RO candidate failed one section (B) of the written examination. All other candidates passed all portions of their respective examinations.

## REPORT DETAILS

1. Examiner:
   Paul V. Doyle Jr., Chief Examiner, NRC

2. Results:

| | RO PASS/FAIL | SRO PASS/FAIL | TOTAL PASS/FAIL |
|---|---|---|---|
| Written | 1/1 | 2/0 | 3/1 |
| Operating Tests | 2/0 | 2/0 | 4/0 |
| Overall | 1/1 | 2/0 | 3/1 |

3. Exit Meeting:
   Paul V. Doyle Jr., NRC, Examiner
   Christopher Crouch, Reactor Supervisor, Texas A&M University
   W. Dan Reece, Senior Reactor Operator, Texas A&M University

The chief examiner met with the facility staff to discuss the overall administration of the examination. The examiner did not note any serious weaknesses on the part of the candidates.

ENCLOSURE 1

# OPERATOR LICENSING EXAMINATION

## With Answer Key

UNITED STATES NUCLEAR REGULATORY COMMISSION

# TEXAS A&M UNIVERSITY AGN-201M

## Week of August 09, 2010

**ENCLOSURE 2**

## QUESTION A.01 [1.0 point]
Which ***ONE*** of the following is the definition of a cross section?

a. The probability that a neutron will be captured by the nucleus.

b. The most likely energy at which a charged particle will be captured.

c. The length a charged particle travels past the nucleus before being captured.

d. The area of the nucleus including the electron cloud.

## QUESTION A.02 [1.0 point]
Which of the following power manipulations would take the longest to complete assuming the same period is maintained?

a. 100 mW to 400 mW

b. 400 mW to 500 mW

c. 1 W to 3.5 W

d. 3.5 W to 4.5 W

## QUESTION A.03 [1.0 point]
**Inelastic scattering** is the process whereby a neutron collides with a nucleus and:

a. recoils with the same kinetic energy it had prior to the collision.

b. recoils with a lower kinetic energy, with the nucleus emitting a gamma ray.

c. is absorbed by the nucleus, with the nucleus emitting a gamma ray.

d. recoils with a higher kinetic energy, with the nucleus emitting a gamma ray.

## QUESTION A.04 [1.0 point]
At the beginning of a reactor startup, $K_{eff}$ is 0.90 with a count rate of 30 CPS. Power is increased to a new, steady value of 60 CPS. The new $K_{eff}$ is:

a. 0.91

b. 0.925

c. 0.95

d. 0.975

## QUESTION A.05 [1.0 point]

Of the approximately 200 Mev of energy released per fission event, the largest amount appears in the form of:

a. Beta and gamma radiation

b. Prompt and delayed neutrons

c. Kinetic energy of the fission fragments

d. Fast Neutron radiation

## QUESTION A.06 [1.0 point]

The reactor is critical at some power level. A heat source is turned on in the reactor room resulting in the reactor water tank increasing in temperature. In order to maintain a steady power level you must …

a. insert control rod(s) to compensate for the positive reactivity added by the temperature increase.

b. insert control rod(s) to compensate for the negative reactivity added by the temperature increase.

c. withdraw control rod(s) to compensate for the positive reactivity added by the temperature increase.

d. withdraw control rod(s) to compensate for the negative reactivity added by the temperature increase.

## QUESTION A.07 [2.0 points, ½ each]

Reactor period has just stabilized at -80 seconds following a reactor shutdown. If safety channel #1 reads $1 \times 10^4$ counts/minute, what do you expect the channel to read in three minutes?

a. $3 \times 10^3$ counts/minute

b. $1 \times 10^3$ counts/minute

c. $3 \times 10^2$ counts/minute

d. $1\times 10^2$ counts/minute

## QUESTION A.08 [1.0 point]

The reactor is at 5 watts, when someone inserts an experiment which causes a 10 second positive period. If the scram delay time is **1 second** and the lowest scram setpoint is **9.7 watts**, which ONE of the following is the **MAXIMUM** power the reactor will reach prior to scramming?

a. 9.1 watts

b. 10.7 watts

c. 15.5 watts

d. 25 watts

## QUESTION A.09 [1.0 point, ¼ each]

Identify whether each of the following isotopes is either fissile (FIS) or fertile (FER).

a. $Th^{232}$

b. $U^{233}$

c. $U^{235}$

d. $U^{238}$

## QUESTION A.10 [1.0 point]

Most references list the delayed neutron fraction for $U^{235}$ (β) as 0.0065. The SAR lists β for the core as 0.0074. The β in the SAR is more commonly referred to as $\beta_{effective}$. Which ONE of the following is the reason that $\beta_{effective}$ is larger than β?

a. Delayed neutrons are born at higher energies than prompt neutrons resulting in a greater worth for the neutrons.

b. Delayed neutrons are born at lower energies than prompt neutrons resulting in less leakage during slowdown to thermal energies.

c. The fuel also includes $U^{238}$ which has a relatively large β for fast fission.

d. The $U^{238}$ in the core becomes $Pu^{239}$ (by neutron absorption), which has a higher β for fission.

**QUESTION B.01 [1.0 point]**
Identify which ONE of the following correctly describes the relative penetrating power of the listed types of radiation from least penetrating to most penetrating. (Alpha (α), Beta (β), Gamma (γ), and Neutron (n).)

a. α, β, γ, n

b. n, α, β, γ

c. α, β, n, γ

d. β, α, γ, n

**QUESTION B.02 [1.0 point]**
Which ONE of the following is the definition for Measuring Channel?

a. A combination of sensor, lines, amplifiers and output devices which are connected for the purpose of measuring or responding to the value of a process variable.

b. Any apparatus devices or material that is a normal part of the reactor assembly.

c. A combination of safety channels and associated circuitry which forms an automatic protective system for the reactor, or provides information which requires manual protective be initiated.

d. A measuring channel in the reactor safety system.

**QUESTION B.03 [1.0 point, ¼ each]**
Match the Area radiation levels in column A with the corresponding area type (as defined by 10 CFR 20) from column B.

| | Column A | | Column B |
|---|---|---|---|
| a. | 2 mr/hr | 1. | Unrestricted |
| b. | 5 mr/hr | 2. | Radiation Area |
| c. | 10 mr/hr | 3. | High Radiation Area |
| d. | 100 mr/hr | 4. | Very High Radiation Area |

**QUESTION B.04 [1.0 point]**
Which ONE of the following reactor personnel positions is the MINIMUM level responsible for supervising maintenance or modification on all equipment which could affect the reactivity of the reactor?

a. Licensed Reactor Operator

b. Licensed Senior Reactor Operator

c. Reactor Supervisor

d. Head of Nuclear Engineering Department

**QUESTION B.05 [1.0 point]**
The shutdown margin, required by Technical Specifications, with the most reactive safety or control rod fully inserted shall be at least:

a. 0.55 % Δk/k

b. 0.65 % Δk/k

c. 0.80 % Δk/k

d. 1.00 % Δk/k

**QUESTION B.06 [1.0 point]**
Per Technical Specification 6.6, “Temporary procedures which do not change the intent of previously approved procedures and which do not involve any unreviewed safety question may be employed on approval by the ...”

a. Senior Reactor Operator on Shift.

b. Reactor Supervisor.

c. Head of the Nuclear Engineering Department.

d. Dean of the School of Engineering.

**QUESTION B.07 [1.0 point]**
Which **ONE** of the following watch standing combinations is NOT allowed? Note: WB stands for ‘warm body’ an individual certified by the Reactor Supervisor as qualified to activate manual scram and initiate emergency procedures.

a. SRO on panel, WB in Nuclear Engineering Office.

b. SRO on panel, RO in Control Room

c. RO on panel, SRO on Call, WB in Reactor room.

d. WB on panel, RO directing, SRO on call.

**QUESTION B.08 [1.0 point, ¼ each]**
A reactor sample has a disintegration rate of $2 \times 10^{12}$ disintegrations per second and emits a 0.6 MeV γ. The expected dose rate from this sample at a distance of 10 feet would be approximately: (Assume a point source)

a. 200 mR/hr

b. 325 mR/hr

c. 2 R/hr

d. 7.5 R/hr

**QUESTION B.09 [1.0 point]**
Per 10CFR20, your Total Effective Dose Equivalent (TEDE) limit is …

a. 0.1 REM

b. 0.5 REM

c. 1 REM

d. 5 REM

**QUESTION B.10 [1.0 point]**
Which ONE of the following scrams on the alarm panel **IS** required by the current Technical Specifications?

a. Count Rate Low

b. Skirt Door Open

c. Accelerator Door Open

d. High Pressure Core Tank

**QUESTION C.01 [1.0 point]**
Which one of the following detectors is used for Nuclear Instrumentation Channel #2 (Log)?

a. $BF_3$ filled Proportional Counter

b. $BF_3$ filled Ionization Chamber

c. $BF_3$ filled Geiger-Muller tube

d. $U^{235}$ lined Fission Chamber

**QUESTION C.02 [1.0 point, ¼ each]**
Match the Energy dampening device used to absorb the shock of a reactor scram in column b with its respective rod in column a. Items may be used more than once or not at all.

| | Column A | | Column B |
|---|---|---|---|
| a. | Safety #1 | 1. | Dash pot |
| b. | Safety #2 | 2. | Spring |
| c. | Coarse Control Rod | 3. | None |
| d. | Fine Control Rod | | |

**QUESTION C.03 [1.0 point]**
Which one of the following is the diameter of the experiment access ports?

a. ½ inch

b. 1 inch

c. 2 inches

d. 4 inches

**QUESTION C.04 [1.0 point]**
The reactor is critical, with the Fine Control Rod (FCR) fully inserted. If you wish to reposition the FCR to the mid-plane of its travel, how far and in what direction must you move the Coarse Control Rod (CCR), maintaining critical conditions?

a. 25% out of core

b. 12.5% into core

c. 12.5% out of core

d. 25% into core

**QUESTION C.05 [1.0 point]**
Which ONE of the following signals will result in opening the interlock bus?

a. Manual scram switch

b. Period trip

c. Earthquake sensor

d. Channel #2 high (95% full scale)

**QUESTION C.06 [1.0 point]**
Which ONE of the following is ***NOT*** a characteristic associated with using fueled control rods vice poison control rods?

a. Smaller reactor size.

b. Less than critical mass when shutdown.

c. More symmetrical flux distribution when operating.

d. More difficult calculations for a homogeneous reactor.

**QUESTION C.07 [1.0 point]**
Which ONE of the following is the approximate value for how much the reactor will be shut down by if the safety fuse were to melt?

A. 0.005 $\Delta k/k$

B. 0.01 $\Delta k/k$

C. 0.05 $\Delta k/k$

D. 0.1 $\Delta k/k$

**QUESTION C.08 [1.0 point]**
The shield tank water temperature interlock prevents reactor operation:

a. in the event of a high temperature condition.

b. during a condition that will produce high radiation levels.

c. during periods of high thermal stress.

d. from a reactivity addition due to a temperature decrease.

**QUESTION C.09 [1.0 point]**
The shield tank is designed to provide shielding from:

a. high energy β radiation.

b. high energy γ radiation.

c. fast neutron radiation.

d. the thermal column area.

**QUESTION C.10 [1.0 point]**
In the event the reactor fails to scram, the TWO design features that serve to prevent exceeding core temperature limits are the:

a. thermal fuse and large temperature coefficient.

b. Glory Hole Cadmium plug and thermal fuse.

c. large temperature coefficient and volume of water shield.

d. Glory Hole Cadmium plug and volume of water shield.

A.01 a
REF: (Reference 1), Volume 1, Module 2, page 7.

A.02 a $P = P_0 e^{T/\tau}$.
REF: (Reference 1), Volume 2, Module 3, page 11.

A.03 b
REF: (Reference 1), Volume 1, Module 1, page 45.

A.04 c
REF: (Reference 1), Volume 2, Module 4, pages 1 through 9.

A.05 c
REF: (Reference 1), Volume 1, Module 1, page 61.

A.06 b
REF: (Reference 1), Volume 2, Module 4, page 28.

A.07 b, $P = P_0 e^{t/\tau} = 1 \times 10^4 \times e^{-80/180} = 1 \times 10^4 \times e^{-2.25} = 1 \times 10^4 \times 0.1054 = 1.054 \times 10^3$
REF: (Reference 1), Volume 1, Module 2, page 7.

A.08 b, $P = P_0 e^{t/\tau} = 9.7 \times e^{1/10} = 9.7 \times 1.1052 = 10.72$
REF: (Reference 1), Volume 1, Module 2, page 7.

A.09 a, FER; b, FIS; c, FIS; d, FER
REF: (Reference 1), Volume 1, Module 1, pages 50 & 52.

A.10 b
REF: (Reference 1), Volume 2, Module 4, page 12.

Reference 1 = DOE Handbook Nuclear Physics and Reactor Theory, Volumes I and II.

B.01 c
REF:

B.02 a
REF: TAMU AGN-201m Technical Specifications 1.7, 1.12, 1.14, and 1.17

B.03 a, 1; b, 2; c, 2; d, 3
REF: 10 CFR 20 § 20.1003 *Definitions*

B.04 b
REF: TAMU AGN-201m Technical Specifications 6.1.9.b

B.05 d
Ref: TAMU AGN-201m Technical Specifications 3.1.b

B.06 b
REF: T.S. 6.6, last paragraph.

B.07 a
Ref: TAMU AGN-201m Technical Specifications, 6.1.9.a (1-3)

B.08 c, DR = 6CE/f*2 R/hr, =6(2 X 10*12/3.7X10*10)(0.6)/10*2, =1.9459 R/hr
Ref: ~~ISU Test Bank; Glasstone & Sesonke, Sect 9.41, p 525.~~

B.09 d
REF: 10CFR20.1201

B.10 a
REF: Facility supplied photograph DSCF2569.JPG and TAMU AGN-201m Technical Specifications 3.2.

C.01 b
REF: TAMU AGN-201m Safety Analysis Report § 7.2.3, 2nd ¶ under heading *Channel #2,* page 7-x.

C.02 a, 1; b, 1; c, 1; d, 3
REF: TAMU AGN-201m Safety Analysis Report § 4.2.2, 2nd ¶, on page 4-14.

C.03 d
REF: TAMU AGN-201m Safety Analysis Report § 4.1, 1st ¶ on page 4-2.

C.04 b
REF: TAMU AGN-201m Safety Analysis Report § 4.2.2, 2nd ¶, page 4-5.

C.05 c
REF: TAMU AGN-201m Safety Analysis Report § 7.2, Figure 7.2.1-1 on page 7-3.

C.06 d
REF: TAMU AGN-201m Safety Analysis Report § 7.2.3, 2nd ¶, page 4-5.

C.07 c
REF: TAMU AGN-201m Technical Specifications 2.2.b

C.08 d
Ref: TAMU AGN-201m Technical Specifications, Basis for specification 3.2.f.

C.09 c
Ref: TAMU AGN-201m Technical Specifications, Basis for specification 3.2.e.

C.10 a
Ref: TAMU AGN-201m Technical Specifications, Basis for specification 2.2.b

# U. S. NUCLEAR REGULATORY COMMISSION
## RESEARCH AND TEST REACTOR
## OPERATOR LICENSE EXAMINATION

FACILITY: Texas A&M University

REACTOR TYPE: AGN-201M

DATE ADMINISTERED: 08/ /2010

CANDIDATE:

INSTRUCTIONS TO CANDIDATE:
Answers are to be written on the answer sheet provided. Attach the answer sheets to the examination. Points for each question are indicated in brackets for each question. A 70% in each section is required to pass the examination. Examinations will be picked up three (3) hours after the examination starts.

| % of Category Value | % of Total | Candidates Score | Category Value | | Category |
|---|---|---|---|---|---|
| 10.00 | 33.3 | ______ | ______ | A. | Reactor Theory, Thermodynamics and Facility Operating Characteristics |
| 10.00 | 33.3 | ______ | ______ | B. | Normal, Emergency and Radiological Controls Procedures |
| 10.00 | 33.3 | ______ | ______ | C. | Facility and Radiation Monitoring Systems |
| 30.00 | | ______ | ______% FINAL GRADE | | TOTALS |

All work done on this examination is my own. I have neither given nor received aid.

______________________________
Candidate's Signature

# NRC RULES AND GUIDELINES FOR LICENSE EXAMINATIONS

During the administration of this examination the following rules apply:

1. Cheating on the examination means an automatic denial of your application and could result in more severe penalties.

2. After the examination has been completed, you must sign the statement on the cover sheet indicating that the work is your own and you have neither received nor given assistance in completing the examination. This must be done after you complete the examination.

3. Restroom trips are to be limited and only one candidate at a time may leave. You must avoid all contacts with anyone outside the examination room to avoid even the appearance or possibility of cheating.

4. Use black ink or dark pencil <u>only</u> to facilitate legible reproductions.

5. Print your name in the blank provided in the upper right-hand corner of the examination cover sheet and each answer sheet.

6. Mark your answers on the answer sheet provided. USE ONLY THE PAPER PROVIDED AND DO NOT WRITE ON THE BACK SIDE OF THE PAGE.

7. The point value for each question is indicated in [brackets] after the question.

8. If the intent of a question is unclear, ask questions of the examiner only.

9. When turning in your examination, assemble the completed examination with examination questions, examination aids and answer sheets. In addition turn in all scrap paper.

10. Ensure all information you wish to have evaluated as part of your answer is on your answer sheet. Scrap paper will be disposed of immediately following the examination.

11. To pass the examination you must achieve a grade of 70 percent or greater in each category.

12. There is a time limit of three (3) hours for completion of the examination.

13. When you have completed and turned in you examination, leave the examination area. If you are observed in this area while the examination is still in progress, your license may be denied or revoked.

A.01 a b c d ___

A.02 a b c d ___

A.03 a b c d ___

A.04 a b c d ___

A.05 a b c d ___

A.06 a b c d ___

A.07 a b c d ___

A.08 a b c d ___

A.09a FIS FER ___

A.09b FIS FER ___

A.09c FIS FER ___

A.09d FIS FER ___

A.10 a b c d ___

B.01 a b c d ___

B.02 a b c d ___

B.03a 1 2 3 4 ___

B.03b 1 2 3 4 ___

B.03c 1 2 3 4 ___

B.03d 1 2 3 4 ___

B.04 a b c d ___

B.05 a b c d ___

B.06 a b c d ___

B.07 a b c d ___

B.08 a b c d ___

B.09 a b c d ___

B.10 a b c d ___

C.01 a b c d ___

C.02a 1 2 3 ___

C.02b 1 2 3 ___

C.02c 1 2 3 ___

C.02d 1 2 3 ___

C.03 a b c d ___

C.04 a b c d ___

C.05 a b c d ___

C.06 a b c d ___

C.07 a b c d ___

C.08 a b c d ___

C.09 a b c d ___

C.10 a b c d ___

EQUATION SHEET

$$\dot{Q} = \dot{m} c_P \Delta T = \dot{m} \Delta H = UA\Delta T$$

$$P_{max} = \frac{(\beta - \rho)^2}{(2\alpha \ell)}$$

$$\lambda_{eff} = 0.1 \sec^{-1}$$

$$P = P_0 \; e^{t/\mathrm{T}}$$

$$SCR = \frac{S}{-\rho} \cong \frac{S}{1 - K_{eff}}$$

$$\ell^* = 1 \times 10^{-4} \sec$$

$$SUR = 26.06 \left[ \frac{\lambda_{eff} \rho + \dot{\rho}}{\overline{\beta} - \rho} \right]$$

$$CR_1 (1 - K_{eff_1}) = CR_2 (1 - K_{eff_2})$$

$$CR_1 (-\rho_1) = CR_2 (-\rho_2)$$

$$P = \frac{\beta (1 - \rho)}{\beta - \rho} P_0$$

$$M = \frac{1}{1 - K_{eff}} = \frac{CR_2}{CR_1}$$

$$P = P_0 \; 10^{SUR(t)}$$

$$M = \frac{1 - K_{eff_1}}{1 - K_{eff\,2}}$$

$$SDM = \frac{1 - K_{eff}}{K_{eff}}$$

$$\mathrm{T} = \frac{\ell^*}{\rho - \overline{\beta}}$$

$$\mathrm{T} = \frac{\ell^*}{\rho} + \left[ \frac{\overline{\beta} - \rho}{\lambda_{eff} \rho + \dot{\rho}} \right]$$

$$T_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

$$\Delta\rho = \frac{K_{eff_2} - K_{eff_1}}{K_{eff_1} K_{eff_2}}$$

$$\rho = \frac{K_{eff} - 1}{K_{eff}}$$

$$DR = DR_0 \, e^{-\lambda t}$$

$$DR_1 \, d_1^{\,2} = DR_2 d_2^{\,2}$$

$$DR = \frac{6 \, Ci \, E(n)}{R^2}$$

$$\frac{(\rho_2 - \beta)^2}{Peak_2} = \frac{(\rho_1 - \beta)^2}{Peak_1}$$

DR – Rem, Ci – curies, E – Mev, R – feet

$$^{135}_{52}Te \xrightarrow{(19\sec)} {}^{135}_{53}I \xrightarrow{(6.6hr)} {}^{135}_{54}Xe \xrightarrow{(9.1hr)} {}^{135}_{55}Cs \xrightarrow{(2.3\times10^6\, yr)} {}^{135}_{56}Ba$$

---

**1 Curie = 3.7 x $10^{10}$ dis/sec**

**1 kg = 2.21 lbm**

**1 Horsepower = 2.54 x $10^3$ BTU/hr**

**1 Mw = 3.41 x $10^6$ BTU/hr**

**1 BTU = 778 ft-lbf**

**°F = 9/5 °C + 32**

**1 gal ($H_2O$) ≈ 8 lbm**

**°C = 5/9 (°F - 32)**

**$c_P$ = 1.0 BTU/hr/lbm/°F**

**$c_p$ = 1 cal/sec/gm/°C**