U.S. NUCLEAR REGULATORY COMMISSION

REGION III

Report No. 50-156/OL-88-01

Docket No. 50-156 License No. R-74

Licensee: University of Wisconsin

Facility Name: University of Wisconsin Nuclear Reactor

Examination Administered At: Madison, Wisconsin

Examination Conducted: May 24-25, 1988

Examiner: S. M. Hare 6/13/88 Date

Approved By: M. J. Jordan, Chief
Operator Licensing Section 1 6/13/88 Date

Examination Summary

Examination administered on May 24-25, 1988 Report No 50-156/OL-88-01
Examinations were administered to two operator candidates.
Results: Both candidates passed the examination.

REPORT DETAILS

1. Examiner

   S. M. Hare

2. Exit Meeting

   At the conclusion of the examination, the examiner held an exit meeting. The following facility personnel attended this meeting:

   R. J. Cashwell, Reactor Director

   The following observations were discussed:

   During the oral examinations, the examiner noted two areas of candidate weaknesses.

   a. The candidates exhibited poor contamination control while working with the whale tube and pneumatic tubes systems.

   b. The candidates failed to refer to emergency procedures when asked questions regarding emergency situations and the candidate's expected actions.

   Also, during the grading of the written examination, the examiner noted weaknesses in the Radiation Control and Safety Section for both candidates.

3. Examination Review

   An examination review was held on May 26, 1988, to discuss the written examination and the facility comments. Specific comments concerning written examination questions, followed by NRC responses are contained in Attachment 1.

Attachment 1

Facility Comments and NRC Responses

Facility Comment:

Question B.01 b. The answer given allows mention only of neutron fluxes and requires mention of both fast and thermal. Gamma ray fluxes should be permitted as an answer in addition to neutron fluxes, since gamma radiation is present in abundance in beams extracted from the beam ports. Trainees are instructed that gamma rays will always be present where neutrons are present at the facility, and that gamma radiation levels must be measured for personnel protection. Although facility descriptions usually indicate only thermal neutron fluxes for experimental facilities (Reference: UWNR 130, Irradiation Positions and General Description of the University of Wisconsin Nuclear Reactor, Page 3), operators must be aware that gamma ray exposure is also likely.

NRC Response: Concur - answer key revised to award partial credit for gamma flux.

Facility Comment:

Question C.01 c. The answer given is correct, but not responsive to the question asked. The answer refers to why there is a temperature coefficient, not why it is not a constant value. The reason for the variable temperature coefficient is beyond the scope of the knowledge required for operating personnel. If the question were changed to "Explain why the reactivity of a FLIP fuel core changes with changes in power level or fuel temperature" the answer would be responsive.

NRC Response: Concur - this portion of question deleted.

Facility Comment:

Question C.06. The question asks for "the three means by which primary water temperature is controlled." Although candidates may offer the answers given, they are trained that primary water temperature is controlled by bypassing the secondary flow to the heat exchanger. (Reference: Reactor Water Systems IV, Pages 2 and 6). The tower bypass control valve is installed to prevent freezing of the water in the tower during periods of low heat load. In actuality the cooling tower fan speed controls the temperature of the secondary water, which controls the primary water temperature only if the secondary water temperature goes too high for the primary temperature control to be able to respond. Due to this training, candidates should receive credit if they respond with "evaporation at pool surface and conduction into/through concrete shield" as alternates to the mention of the cooling toward fans and tower bypass valve.

NRC Response: Concur - answer key will be revised to allow full credit for the two referenced methods.

Facility Comment:

Question F.03. The question requires placing in proper sequence steps from the shutdown portion of UWNR 116, Primary-Secondary Cooling System Operating Procedure. The procedure steps that are to be arranged in order are from a non-safety system operating procedure that is a "posted" procedure. UWNR 001 states in Item 11.b. "Procedures which are frequently performed require occasional reference to copies posted in the area of use." Operators are not expected to memorize procedure steps for posted procedures. Further, the importance of the sequence of steps in this procedure is only that the primary pump be turned off before the secondary HX pump is secured (to assure secondary to primary DP is maintained should the interlock provided for that purpose fail) and that the rad monitor be observed after stopping the whale and diffuser pumps (since any samples that are in the whale tube will return to the surface when the whale pump is stopped). This question should be graded so that the only requirement for full credit is that Step 1 occur before Step 4 and that Step 6 come after Step 5.

NRC Response: Concur - answer key will be revised to reflect facility comment.

Facility Comment:

Question F.04, Part b. The answer sought occurs in UWNR 152 after Part 1.b. which states that "the remainder of this procedure will be carried out under the direct supervision of a Senior Reactor Operator." In addition, the table of isotopes likely to be observed is supplied to enable quick identification of radioisotopes without the need to consult other references. RO or SRO candidates should not be expected to memorize detailed data supplied in the Follow-up Actions section of a procedure.

NRC Response: Do not concur. The "table of isotopes likely to be observed" was provided in the question. Given this information, an operator should be able to identify whether they would appear as air particulate or in the pool water.

Facility Comment:

Question G.03. The answer given correctly states the upper limit indicated for swipe tests in "Radiation Safety for Laboratory Technicians," Chapter 5 (two or three times background). Official campus-wide guidance from "Radiation Safety Regulations," Section XII.A (copy attached) allows a further interpretation that contamination is defined as ten times background activity and that such contamination must be cleaned up or labeled. Despite the stated campus limits, policy at the reactor laboratory is that surveys or swipe tests must indicate minimum detectable levels. Although this policy is not stated in writing, all laboratory personnel are indoctrinated in the policy due to our desire to maintain a contamination free environment, due to frequent access by students and visitors. Full credit should be given for "minimum detectable," MDA, or similar statements indicating any contamination found must be cleaned to background levels.

NRC Response: Concur - answer key revised to reflect facility comment.

Facility Comments:

Question G.05. The question requests information on a part of "Radiation Safety For Laboratory Technicians" that is not applicable to the Reactor Laboratory. We do not use film badges or protective aprons. (We use TLD badges, and protective aprons are used by some x-ray and fluoroscopy personnel where thin layers of lead can afford protection from x-rays). Candidates are instructed that dosimetry be placed on front of the body between waist and neck. This question should be eliminated, or full credit should be given for "front of body between waist and neck."

NRC Response: Concur - answer key revised to reflect facility comment.

Facility Comments:

Question G.06. Regulatory Guide 8.13 does not state either whole body or extremity dose limits for pregnant females. It states that employees and supervisors should be made aware of NCRP recommendations to limit exposure of the fetus to 0.5 rem, but leaves it up to the female whether she will abide by the recommendation. It makes no statements about extremity dose. As worded, the question elicits a response of NRC dose limits that do not exist. At our facility females are informed of the recommendations of the RG, and sign a statement that they are aware of it. Candidates for licenses are placed in a difficult position by questions that seem to refer to regulations of which they have never heard. This question should be eliminated, or reworded to "What are the NRC recommended guidelines for radiation dose to pregnant females" and "What are the NRC dose limits for extremities of occupationally exposed personnel" without any intimation that there is any NRC limit specific to extremity dose for pregnant females.

NRC Response: Concur - the question has been deleted.

U. S. NUCLEAR REGULATORY COMMISSION
REACTOR OPERATOR LICENSE EXAMINATION

FACILITY: _UNIVERSITY_OF_WISCONSIN_

REACTOR TYPE: _TRIGA_MK_F_____________

DATE ADMINISTERED: _88/05/24______________

EXAMINER: _HARE_S.________________

CANDIDATE: ________________________

INSTRUCTIONS_TO_CANDIDATE:

Use separate paper for the answers. Write answers on one side only. Staple question sheet on top of the answer sheets. Points for each question are indicated in parentheses after the question. The passing grade requires at least 70% in each category. Examination papers will be picked up six (6) hours after the examination starts.

CATEGORY __VALUE__	% OF _TOTAL	CANDIDATE'S ___SCORE___	% OF CATEGORY _VALUE__	____________CATEGORY____________
_12.90__	_13.26	___________	________	A. PRINCIPLES OF REACTOR OPERATION
_14.50__	_14.91	___________	________	B. FEATURES OF FACILITY DESIGN
_14.00__	_14.40	___________	________	C. GENERAL OPERATING CHARACTERISTICS
_13.50__	_13.88	___________	________	D. INSTRUMENTS AND CONTROLS
_14.10__	_14.50	___________	________	E. SAFETY AND EMERGENCY SYSTEMS
_14.00__	_14.40	___________	________	F. STANDARD AND EMERGENCY OPERATING PROCEDURES
_14.25__	_14.65	___________	________	G. RADIATION CONTROL AND SAFETY
_97.25__		___________ Final Grade	________%	Totals

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

____
Candidate's Signature

MASTER COPY

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. 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.
3. Use black ink or dark pencil <u>only</u> to facilitate legible reproductions.
4. Print your name in the blank provided on the cover sheet of the examination.
5. Fill in the date on the cover sheet of the examination (if necessary).
6. Use only the paper provided for answers.
7. Print your name in the upper right-hand corner of the first page of <u>each</u> section of the answer sheet.
8. Consecutively number each answer sheet, write "End of Category __" as appropriate, start each category on a <u>new</u> page, write <u>only on one side</u> of the paper, and write "Last Page" on the last answer sheet.
9. Number each answer as to category and number, for example, 1.4, 6.3.
10. Skip at least <u>three</u> lines between each answer.
11. Separate answer sheets from pad and place finished answer sheets face down on your desk or table.
12. Use abbreviations only if they are commonly used in facility <u>literature</u>.
13. The point value for each question is indicated in parentheses after the question and can be used as a guide for the depth of answer required.
14. Show all calculations, methods, or assumptions used to obtain an answer to mathematical problems whether indicated in the question or not.
15. Partial credit may be given. Therefore, ANSWER ALL PARTS OF THE QUESTION AND DO NOT LEAVE ANY ANSWER BLANK.
16. If parts of the examination are not clear as to intent, ask questions of the <u>examiner</u> only.
17. You must sign the statement on the cover sheet that indicates that the work is your own and you have not received or been given assistance in completing the examination. This must be done after the examination has been completed.

18. When you complete your examination, you shall:

a. Assemble your examination as follows:

(1) Exam questions on top.

(2) Exam aids - figures, tables, etc.

(3) Answer pages including figures which are part of the answer.

b. Turn in your copy of the examination and all pages used to answer the examination questions.

c. Turn in all scrap paper and the balance of the paper that you did not use for answering the questions.

d. Leave the examination area, as defined by the examiner. If after leaving, you are found in this area while the examiration is still in progress, your license may be denied or revoked.

QUESTION A.01 (1.50)

a. Reactor Power is at 10 kilowatts and increasing on a 20 second period. How much time is required for the reactor to reach 100 kilowatts? (Show all work). (1.0)

b. How much time is required for (a) above, if a Startup Rate of 1 dpm (decades per minute) is used? (0.5)

QUESTION A.02 (2.00)

a. What would the reactor period be if doubling time was one minute? (Show all work). (1.0)

b. What is the Startup Rate (in Decades per Minute) for a 1 minute doubling time? (Show all work). (1.0)

QUESTION A.03 (1.50)

DESCRIBE how and why Xenon concentration changes initially if power at UWNR is decreased from 1000 watts to 500 watts.

QUESTION A.04 (2.50)

a) What are two (2) of the three (3) Safety Limits specified in Section 2.1 of the Technical Specifications? (1.25)

b) What are the two (2) Limiting Safety System Settings to assure these Safety Limits are not exceeded. (1.25)

QUESTION A.05 (1.00)

Which ONE of the following is NOT desirable for a material that is considered a good moderator?

a. Little tendency to capture neutrons

b. High scattering cross section

c. Low mass number

d. High absorption cross section

(***** CATEGORY A CONTINUED ON NEXT PAGE *****)

QUESTION A.06 (1.00)

A sample has a half-life of 6 minutes. Which ONE of the following answers indicates how long it will have to decay to reduce its activity to 0.001 times its original activity.

a. 30 minutes

b. 60 minutes

c. 90 minutes

d. 1?0 minutes

QUESTION A.07 (1.00)

Which ONE of the following provides the most energy when U-235 fissions?

a. Energy of fission neutrons

b. Instantaneous gamma energy

c. Kinetic energy of fission products

d. Neutrino energy

QUESTION A.08 (2.40)

The following terms sound similar but are very different. Explain the difference between:

a. Fast and prompt neutrons. (.8)

b. Slow and delayed neutrons. (.8)

c. Activity and Reactivity. (.8)

(***** END OF CATEGORY A *****)

QUESTION B.01 (2.00)

Answer the following questions concerning beam ports:

a. What provision is made for reducing exposure to radiation while loading and unloading experiments?

b. What types of fluxes are provided by the beam ports?

c. During normal operation, are beam port drain valves normally open, or normally closed?

QUESTION B.02 (1.50)

Answer the following questions concerning the Demineralizer:

a. Why are the following check valves installed? (0.75)

1. Demineralizer outlet line

2. Demineralizer inlet line

3. City water inlet line

b. LIST THREE (3) possible causes of low system DP. (0.75)

QUESTION B.03 (2.50

Refer to Figure B-1 and answer the following questions concerning the cooling system:

a. DESCRIBE the automatic operation of the valve labeled a. (1.0)

b. DESCRIBE the automatic operation of the valve labeled b. (1.0)

c. For the Heat Exchanger (labeled c), is the pressure higher on the PRIMARY or SECONDARY side? (0.5)

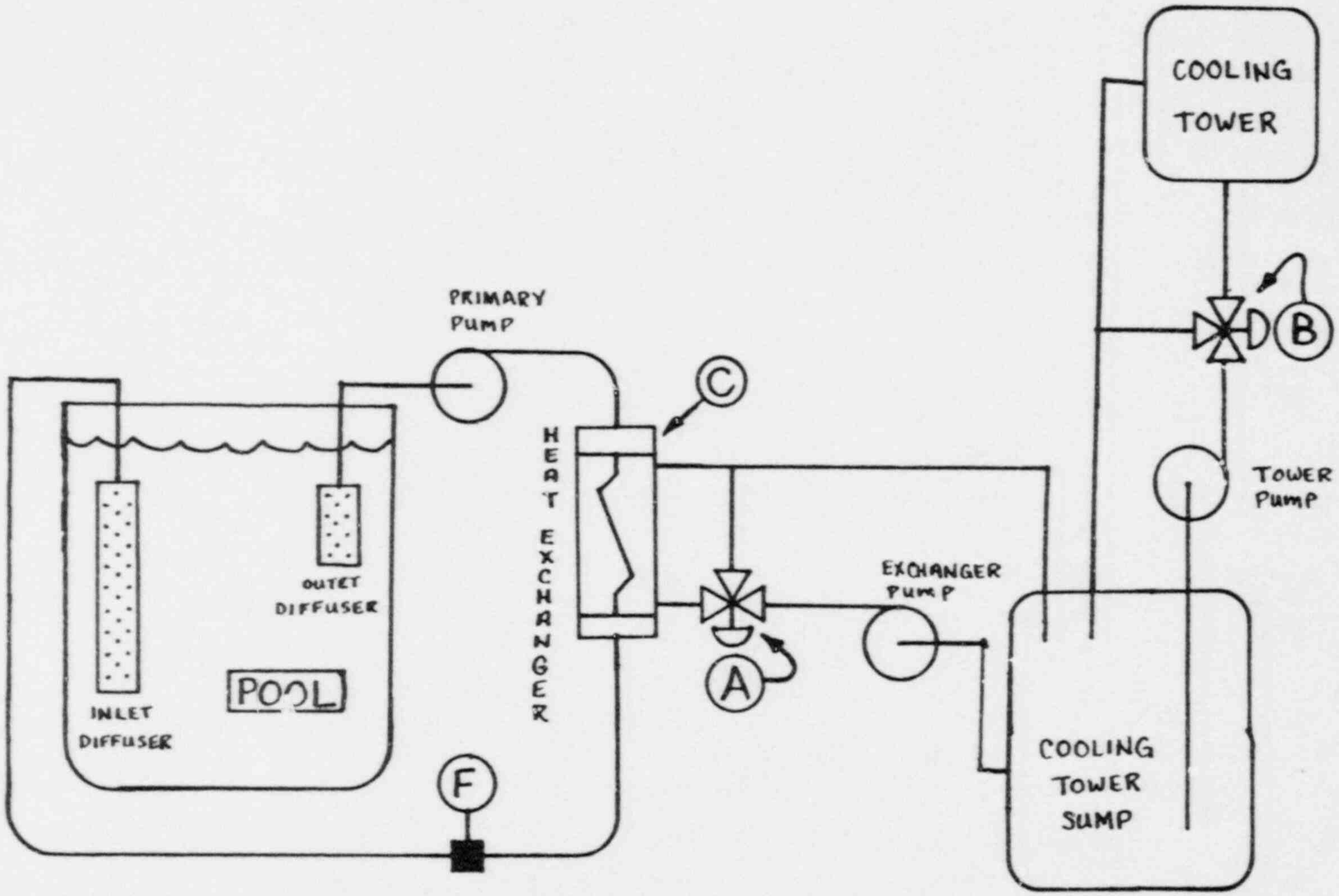
QUESTION B.04 (1.50)

What type of startup source is used at your facility and what is it's decay scheme?

(***** CATEGORY B CONTINUED ON NEXT PAGE *****)

FIGURE B-1

COOLING SYSTEM



QUESTION B.05 (1.00)

Which ONE of the following materials is the neutron absorbing material in a REGULATING blade?

a. Hafnium

b. Boral

c. Zirconium

d. Stainless Steel

QUESTION B.06 (1.50)

Answer the following questions concerning the thermal column:

a. Why does the thermal column have a ventilation system? (1.0)

b. How are personnel protected from gamma radiation? (0.5)

QUESTION B.07 (1.50)

If the pneumatic tube system developed a leak, HOW would draining of the pool be prevented?

QUESTION B.08 (1.00)

What are the two (2) purposes of the Barnstead Still?

QUESTION B.09 (2.00)

Correctly match the piping color codes (0.5 each)

a.	Contaminated water discharge	1.	Green
b.	Air line	2.	Black
c.	City Water	3.	Red
d.	Softened Water	4.	Blue

(***** END OF CATEGORY B *****)

QUESTION C.01 (1.50)

Answer the following regarding the use of FLIP fuel.

a. Why do calculations predict an increase in core reactivity for the first few years of operation for an all FLIP core? (0.75)

b. Why shouldn't the core be loaded with internal water gaps (other than transient rod guide tube and control blade shrouds)? (0.75)

c. Question deleted

QUESTION C.02 (2.25)

Technical Specifications require pool systems or components to be no more than 15 feet below the pool surface.

a. List two of these systems. (1.5)

b. Why do these limitations exist? (0.75)

QUESTION C.03 (1.00)

(Fill in the blank)
During Pulse operation, the reactor peak pulse power reaches approximately __________ Megawatts assuming the maximum allowed Technical Specification reactivity insertion.

a. 2000

b. 1800

c. 1000

d. 800

e. None of the above.

QUESTION C.04 (1.00)

(Fill in the blank)
Most irradiations of more than twenty minutes duration are performed in the ____________ .

(***** CATEGORY C CONTINUED ON NEXT PAGE *****)

QUESTION C.05 (1.00)

(Fill in the blank)
For steady state operation, the ___________ are slowly withdrawn to obtain the desired power level.

QUESTION C.06 (2.25)

Describe two means by which the primary water temperature is controlled. (1.125 each)

QUESTION C.07 (2.00)

State the Technical Specification maximum reactivity value for:

a. Nonsecured experiments. (1.0)

b. The worth of any single experiment. (1.0)

QUESTION C.08 (2.00)

a. Define moderator temperature coefficient. (1.0)

b. Why is it important to have a negative coefficient? (1.0)

QUESTION C.09 (1.00)

What are the normal steady state values shown on the Startup Checklist for:

a. Control blade magnet currents? (0.5)

b. Exhaust filter differential pressures? (0.5)

(***** END OF CATEGORY C *****)

QUESTION D.01 (1.00)

Describe how fuel temperature is measured?

QUESTION D.02 (1.00)

At what FOUR (4) points is PRIMARY temperature monitored?

QUESTION D.03 (1.00)

Which ONE (1) of the following rods can NOT be used for AUTOMATIC control?

a. No. 1 Safety Blade

b. Regulating Blade

c. No. 2 Shim Blade

d. Transient Rod

QUESTION D.04 (1.50)

Answer the following True-False questions concerning the Log Count Rate Channel (Startup Channel):

a. The fission counter drive automatically runs to the next lower position when the operator pushes the switch to "LOWER." (0.5)

b. Control elements may be withdrawn with care when the fission counter is moving. (0.5)

c. Placing the Interlock switch in DEFEAT causes a LOG COUNT RATE alarm. (0.5)

(***** CATEGORY D CONTINUED ON NEXT PAGE *****)

QUESTION D.05 (1.50)

Concerning the Safety Blade Drive Mechanism:

a. What is the speed of safety blade travel? (0.5)

b. How does the operator know if the limit switch at the top of stroke is reached? (2 indications) (1.0)

QUESTION D.06 (1.50)

Explain HOW gamma flux is compensated for in the LOG N CHANNEL?

QUESTION D.07 (1.00)

(Fill in the blank)
Instrumented fuel element(s) reside in a bundle with _______ (number) elements.

QUESTION D.08 (1.50)

Briefly describe the movement of the transient rod when it is ejected from the core to Pulse the reactor. (Your answer should cover the beginning of movement until the rod is back in place).

QUESTION D.09 (2.50)

Answer the following questions concerning the NIS Safety Channel.

a. Refer to Figure D-1. List the outputs of the Safety Channel shown (a-d).

b. Where are the detectors for the safety channels located?

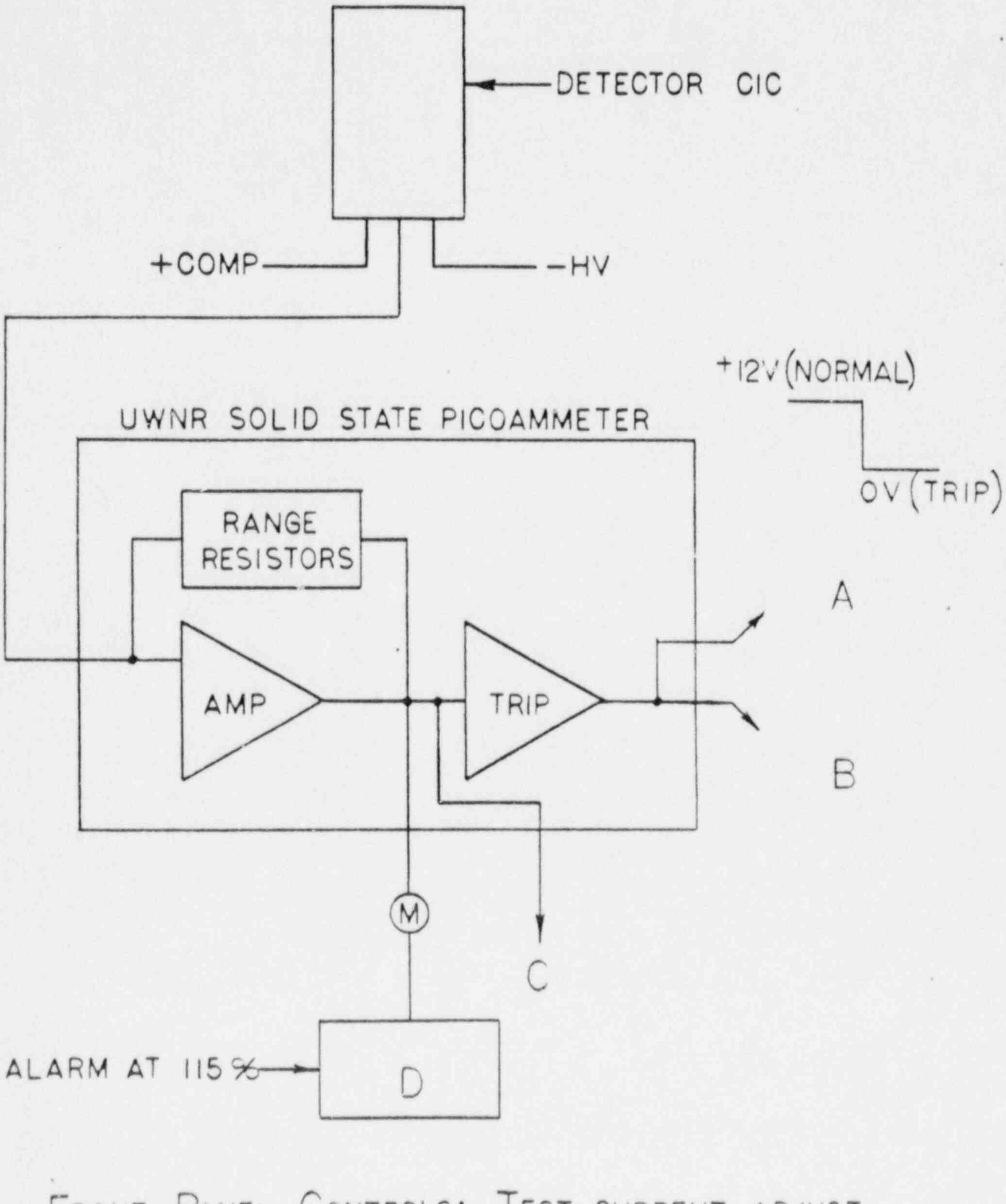
QUESTION D.10 (1.00)

UWNR is operating at power in the manual steady state mode. You desire to shift to automatic operation. WHAT happens when the MODE SWITCH is placed in AUTOMATIC? (Assume that the power schedule is set for 5 % above the desired power level.)

(***** END OF CATEGORY D *****)

FIGURE D-1

SAFETY CHANNELS



FRONT PANEL CONTROLS: TEST CURRENT ADJUST AND TEST SWITCH; TRIP SET ADJUST; TRIP RESET.

QUESTION E.01 (2.60)

Where are the four radiation area monitors located (1.6) and what are their set points? (1.0)

QUESTION E.02 (1.00)

a. By Technical Specification, when is the Reactor Laboratory ventilation system required to operate? (0.5)

b. How is its operation assured? (0.5)

QUESTION E.03 (2.50)

List the five safety system channels that are required by Technical Specifications to be operable before the reactor can be operated (1.25) and give the operating modes in which they are required. (1.25)

QUESTION E.04 (2.00)

LIST EIGHT (8) conditions that cause a relay scram.

QUESTION E.05 (1.00)

The reactivity to be inserted for pulse operation shall be determined and mechanically limited such that the reactivity insertion will not exceed _____________. (Choose the correct answer).

a. 1.0 % delta K/K

b. 1.1 % delta K/K

c. 1.14 % delta K/K

d. 1.40 % delta K/K

e. None of the above

(***** CATEGORY E CONTINUED ON NEXT PAGE *****)

QUESTION E.06 (1.00)

(True or False)
All Safety Blades will scram from any position during withdrawl and rundown even if one blade is being moved.

QUESTION E.07 (1.50)

List three conditions that result in an Electronic Scram.

QUESTION E.08 (1.50)

What are three of the four conditions which must be met prior to the safety blades being withdrawn?

QUESTION E.09 (1.00)

The scram time measured from the instant a Limiting Safety System Setting until the slowest scrammable element reaches it's fully inserted position shall not exceed _____ seconds (choose the correct answer.)

a. 2.0 seconds

b. 2.2 seconds

c. 1.0 seconds

d. 1.2 seconds

e. None of the above.

(***** END OF CATEGORY E *****)

QUESTION F.01 (1.00)

Under what condition(s) may a person other than the individual who signed a "Do Not Operate" tag approve the operation of the tagged equipment.

QUESTION F.02 (1.00)

For a member of the Nucleer Engineering Staff to insert materials into the reactor for the purpose of producing radioisotopes, direct supervision must be provided by a reactor operator or other member of the reactor staff.

QUESTION F.03 (2.00)

To shutdown the Primary-Secondary Cooling System, Place the following steps in order. You may refer to Figure B-1.

a. Stop the tower pump.

b. Monitor the bridge area monitor for possible alarm.

c. Stop the exchanger pump.

d. Stop the diffuser and whole pumps.

e. Stop the primary pump.

f. Stop the cooling tower fans.

QUESTION F.04 (2.00)

Answer the following questions concerning a SUSPECTED FISSION PRODUCT LEAK:

a. LIST the immediate actions for a FISSION PRODUCT LEAK. (1.0)

b. For the following isotopes, indicate whether they would be likely to be found in the POOL WATER or AIR PARTICULATE. (1.0)

   1. CS-139

   2. RB-89

   3. I-131

(***** CATEGORY F CONTINUED ON NEXT PAGE *****)

QUESTION F.05 (1.00)

During operation at power, the AIR ACTIVITY annunciator alarms. Under what condition(s) must you SHUT DOWN the reactor?

QUESTION F.06 (2.00)

Answer the following concerning the "Leak Resulting in Draining of Reactor Pool" procedure:

a. LIST four (4) indications of a leak (1.00).

b. One of the immediate actions says to attempt to maintain pool level by auxiliary fill means. For a LARGE leak, HOW is this accomplished (1.00)

QUESTION F.07 (2.00)

a. When must there be a licensed operator in the Control Room? (1.0)

b. How is the control room defined? (1.0)

QUESTION F.08 (2.00)

a. What are the immediate actions for a SCRAM? (1.0)

b. To continue operation after a SCRAM, what must be done? (1.0)

QUESTION F.09 (1.00)

What are your actions as Reactor Operator if a Spill of Radioactive Material occurs?

(***** END OF CATEGORY F *****)

QUESTION G.01 (1.00)

Before using a survey meter, it should be checked to see if it is working. How should the meter be checked.

QUESTION G.02 (2.00)

(True or False)

a. People working with tritium must wear a Film Badge.

b. Tritium cannot be detected with a portable survey meter.

QUESTION G.03 (1.00)

(Fill in the blank)
Cleanup of a spill is complete when the survey meter or wipe test shows that radiation levels are less than ______________________.

QUESTION G.04 (1.00)

(True or False)
An ion chamber is less sensitive than a Gm tube.

QUESTION G.05 (1.00)

(Fill in the blank)
When a protection apron is worn, the film badge should be worn (location) ______________________.

QUESTION G.06 (.00)

Question deleted

(***** CATEGORY G CONTINUED ON NEXT PAGE *****)

QUESTION G.07 (2.25)

With the core operating at a steady state 1000 KW, there are two sources of radiation at the pools surface.

a. Of the two sources, which one is the most significant source of radiation? (0.75).

b. How does the operator monitor access to the pool area from the:

   1. North Stairway (0.75)

   2. South Stairway (0.75)

QUESTION G.08 (3.00)

The radiation monitors are arranged into three systems; the primary area monitors, beam port monitors and air activity monitor.

a. Of the four primary area monitors, which three are connected to the Reactor Laboratory evacuation alarm (1.5).

b. Explain how the air monitor measures both particulate (0.75) and gaseous activity of air discharged from the stack (0.75).

QUESTION G.09 (1.50)

Calculate the dose rate at 5 meters from a 10 mCi point source given that the dose at 30 cm. is 150 mR/hr. (show calculations)

QUESTION G.10 (1.50)

University of Wisconsin uses four methods for the disposal of radioactive wastes. List 3 of these methods.

(***** END OF CATEGORY G *****)

(************* END OF EXAMINATION ***************)

ANSWER A.01 (1.50)

a. P = P(0) * e^(t/T)
100 = 10 * e^(t/20) (0.5)
In 10 = t/20
20 In 10 = t = 46 sec (0.5)

b. 1 minute (0.5)

REFERENCE
UWNR Operator Training Manual, Math and Physics, p. 1,2

ANSWER A.02 (2.00)

a. Doubling time = Period x 0.693 (0.5)
Period = 60 sec/0.693
= 86.6 sec (0.5)

b. SUR = 26/Period (0.5)
= 26/86.6
= .300 (0.5)
(Alternate calculation)
P = P0 * 10^SUR
SUR = LOG P/P0 (0.5)
= LOG 2
= 0.301 (0.5)

REFERENCE
UWNR Operator Training Manual, Math and Physics, p. 1, 2.

ANSWER A.03 (1.50)

Initially, removal by absorption of neutrons decreases (0.5) and production by decay of I-135 continues (0.5). Hence, the concentration of Xenon increases (0.5).

REFERENCE
UWNR Operator Training Manual, Math and Physics, p. 6.

ANSWER A.04 (2.50)

a) * The temperature in a Triga-Flip fuel element shall not exceed 1150 C.
* The temperature of a standard Triga fuel element shall not exceed 1000 C.
* The reactor power level shall not exceed 1500 kw under any condition of operation.
(any two at .625 each)

b) * Limiting fuel temperature to 400 C. (0.625)
* Limiting reactor power to 1.25 MW. (0.625)

REFERENCE
Facility Technical Specifications 2.1 and 2.2.

ANSWER A.05 (1.00)

d.

REFERENCE
UWNR Operator Training Manual, Math and Physics, p. 2.

ANSWER A.06 (1.00)

b.

REFERENCE
UWNR Operator Training Manual, Math and Physics Exam

ANSWER A.07 (1.00)

c.

REFERENCE
UWNR Operator Training Manual, Math and Physics, p. 2.

ANSWER A.08 (2.40)

a. Fast neutrons refer to those at high energy levels (1MeV) (0.4); while prompt neutrons are those released at the time of fission (0.4).

b. Slow neutrons are neutrons at low energy levels (1eV) (0.4); while delayed neutrons are those that are emitted from fission fragments after the fission event (0.4).

c. Activity is the rate of the radioactivity decay (0.4); while reactivity is the amount of deviation of a reactor from the just critical condition (0.4).

REFERENCE
UWNR Operator Training Manual, Math and Physics.

ANSWER B.01 (2.00)

a. A shutter assembly is closed to provide additional shielding. (also accept shut the reactor down) (0.75)

b. Both thermal and fast (0.25) neutron flux (0.5) (also accept gamma flux for 0.125).

c. Closed. (0.5)

REFERENCE
UWNR Operator Training Manual, Math and Physics, p. 2-36, 37.

ANSWER B.02 (1.50)

a. (0.25 pts each)
   1. Prevents draining of the Pool.

   2. Prevents filling of the Pool from city water supply.

   3. Prevents reactor water entering city water supply.

b. (any 3 at 0.25 pts each)
   1. Resin channeling

   2. Plugged inlet filter

   3. Air in pump

   4. Wear of pump components

   5. Pump not running

REFERENCE
UWNR Operator Training Manual, Reactor Water Systems IV, p. 1.

ANSWER B.03 (2.50)

a. The valve regulates flow through the heat exchanger (0.5) to maintain primary coolant temperature at the desired point (0.5).

b. The valve regulates sump temperature (0.5) by diverting full flow to the Cooling Towers (0.25) or bypassing the Cooling Towers completely (0.25).

c. Secondary (0.5).

REFERENCE
UWNR SAR, p. 2-27 through 29.

ANSWER B.04 (1.50)

Radium-Beryllium (0.75), Ra (alpha, neutron) Be (0.75)

REFERENCE
UWNR Operator Training Manual, SAR, p. 2-18.

ANSWER B.05 (1.00)

d.

REFERENCE
UWNR SAR, p. 2-9.

ANSWER B.06 (1.50)

a. Maintain a low pressure within the thermal column (0.5) to prevent (Ar-41) activity from diffusing into the Reactor Laboratory (0.5).

b. Concrete door (at the biological shield) (0.5)

REFERENCE
UWNR SAR, p. 2-34.

ANSWER B.07 (1.50)

To drain the pool more than eight (8) feet requires siphon action (0.5). A solenoid valve controlled siphon breaker prevents siphon action (0.5) by allowing air to enter the system if siphon action starts (0.5).

REFERENCE
UWNR SAR, p. 2-41.

ANSWER B.08 (1.00)

1. Distills softened water or supplies reactor makeup water

2. Removes Na ions

REFERENCE
UWNR Operator Training Manual, Reactor Water Systems I, p. 1.

ANSWER B.09 (2.00)

a. 3(Red)

b. 2(Black)

c. 1(Green)

d. 4(Blue)

REFERENCE
UWNR Operator Training Manual.

Joe Girbel

QUESTION C.01 (2.75)

Answer the following regarding the use of FLIP fuel.

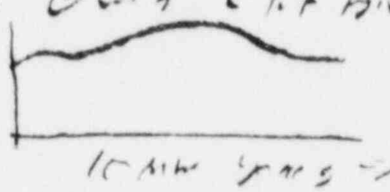
a. Why do calculations predict an increase in core reactivity for the first few years of operation for an all FLIP core? (0.75)

b. Why shouldn't the core be loaded with internal water gaps (other than transient rod guide tube and control blade shrouds)? (0.75)

c. Explain why the temperature coefficient of reactivity in FLIP full is not constant with changing temperature? (1.25)

a) For first few years some of burnable poison will burn out (Erbium) that exists in the fuel. ✓

ρ



b) In Flip Fuel nuetron mean free path is shorter so intensive power peaking in water gaps occurs with a flip fuel core. ✓

c) As temp increases nuetron spectrum is harder. Shifts to a higher energy level. This causes the resonance peaks of Erbium to shift to broader peak so more nuetrons are absorbed in these peaks causing more reactivity to be stolen as temperature increases. So the resonance escape probability increases. Also leakage increases with temp. giving more of a neg reactivity with temp.

(***** CATEGORY C CONTINUED ON NEXT PAGE *****)

All in all as Temp ↑ more nuetrons are escaping being absorbed but causing fissions so ρ goes down.

question delete

ANSWER C.05 (1.00)

Control Elements

REFERENCE
SAR p 2-44

ANSWER C.06 (2.25)

1. By primary water temperature control of the secondary water flow to the heat exchanger. (1.125

2. By changing the cooling tower fan speed. (.1.125)

REFERENCE
Facility SAR 2.3.2

ANSWER C.07 (2.00)

a. 0.7% delta k/k. (1.0)

b. 1.4% delta k/k. (1.0)

REFERENCE
Facility Technical Specifications 3.6

ANSWER C.08 (2.00)

a. Ratio of change in reactivity to change in moderator temperature. (1.0)

b. An increase in temperature from a transient leads to a decrease in reactivity (0.5) with a decrease in power. (0.5)

REFERENCE
OTM Reactor Physics

ANSWERS -- UNIVERSITY OF WISCONSIN -88/05/24-HARE S.

ANSWER C.09 (1.00)

a. 0.6 to 0.7 amps

b. 0.25 to 2.5 inches

REFERENCE
Facility SOI 111

ANSWER D.01 (1.00)

By thermocouples (0.5) placed in the fuel material (0.5).

REFERENCE
UWNR SAR

ANSWER D.02 (1.00)

(0.25 pts each)
1. Core Inlet

2. Heat Exchanger Inlet

3. Heat Exchanger Outlet

4. Demineralizer Inlet

REFERENCE
UWNR SAR

ANSWER D.03 (1.00)

a.

REFERENCE
UWNR Operator Training Manual, C & I III, p. 1.

ANSWER D.04 (1.50)

a. False (0.5)

b. False (0.5)

c. True (0.5)

REFERENCE
UWNR Operator Training Manual, Nuclear Instrumentation, p. 1, 2.

ANSWER D.05 (1.50)

a. 14.5 in/min +/- 1.0 (0.5)

b. (0.5 pts each)
1. Indicating light

2. Drive motor shuts off (or rod stops moving)

REFERENCE
UWNR SAR, p. 2-19.

ANSWER D.06 (1.50)

The Log N Channel is built with two (concentric) detectors (0.5). One detector is sensitive to gamma radiation only while the other detector is sensitive to neutron and gamma radiation (0.5). By using opposite supply voltages, the resultant gamma current multiple each other (0.5).

REFERENCE
UWNR Operator Training Manual, Nuclear Instrumentation, p. 4.

ANSWER D.07 (1.00)

3 or 4 elements

REFERENCE
UWNR SAR, p. 2-6.

ANSWER D.08 (1.50)

Compressed air is admitted to drive a piston (connected to the transient rod) upward, moving the rod out (0.5). At the end of the stroke, the piston strikes a shock absorber (that limits the amount of rod vibration at the upper limit) (0.5). Air is vented from the cylinder and the rod drops (by gravity) into the core (0.5).

REFERENCE
UWNR SAR, p. 2-23.

ANSWER D.09 (2.50)

a. (0.5 pts each)
   1. Electronic Scram (Note: a and b are interchangeable)
   2. Relay Scram
   3. Auto Control (Servo)
   4. (2-pen) recorder

b. Thermal column (0.5)

REFERENCE
UWNR Operator Training Manual, Nuclear Instrumentation, p. 8.

ANSWER D.10 (1.00)

The Servo system attains the schedules power level on a preset period (0.5) and maintains the power at the scheduled level (0.5).

REFERENCE
UWNR SAR, p. 5-8, 9.

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ANSWER E.01 (2.60)

1. Reactor Bridge (0.4). Just above 100% power or 50 mr/hr. (0.25)

2. Demineralizer (0.4). Just above 100% power or 90 mr/hr. (0.25)

3. Thermal Column Door (0.4). Just above 100% power or 10 mr/hr. (0.25)

4. At pneumatic sampler send-receive station (0.4). 10 mr/hr or per UWNR-130 (0.25).

REFERENCE
Facility SAR 2.5.9 and SOI 110 and 131.

ANSWER E.02 (1.00)

a. When the reactor is operating (0.5) (except for 2 days for repairs)

b. By daily Prestartup Checks (0.4) and weekly operation verification (0.1)

REFERENCE
Technical Specification 3.5 and 4.2.4 and SOI 110.

ANSWER E.03 (2.50)

Fuel element temperature (0.25) - All modes (0.5)
Log power level (0.25) - Steady state (0.15) and square wave (0.1)
Two Linear power level (Picoammeters) (0.25) - Steady state (0.15) and square wave (0.1)
Startup count rate (0.25) - During startup (0.25)
Gamma chamber (0.25) - Pulse mode (0.25)

REFERENCE
Facility Technical Specification 3.3.2.

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ANSWER E.04 (2.00)

(any 8 @ .25 pts each)

1. Fast Period
2. Manual scram
3. H.V. failure in control console
4. Core coolant entrance temp. _ 130 degrees-F
5. Power level _ 1.25 P max
6. Loss of control power or loss of A/C
7. Log N - period amp cal sw. not in INPUT position
8. Timed transient control rod scram in pulse mode
9. Pool water level low
10. Fuel temperature above LSSS.

REFERENCE
UWNR SAR, p. 2-49, 50.

ANSWER E.05 (1.00)

d.

REFERENCE
Technical Specification 3.2.

ANSWER E.06 (1.00)

True

REFERENCE
SAR 2-48

ANSWER E.07 (1.50)

1. Power level exceeding 1.25 Pmax

2. Period shorter than 3.5 seconds

3. Loss of signal from picoammeters

4. Loss of picoammeter signal to logic element

5. Loss of period signal to logic element

REFERENCE
SAR 2-50

ANSWER E.08 (1.50)

1. No scram conditions present and scram relays reset.

2. Count rate on Startup channel greater than 2 counts per second.

3. Fission counter not in motion.

4. Console key switch set to "on" position.

5. SRO signature on UWNR -112

6. Rundown switch not in rundown

7. Mode switch not in pulse mode
(any three at 0.5 each)

REFERENCE
SAR 2-48

ANSWER E.09 (1.00)

a.

REFERENCE
Technical Specification 3.3.

ANSWER F.01 (1.00)

When the tags are used to insure Senior Operator cognizance of equipment operation.

REFERENCE
Procedure UWNR 001, p. 3.4.

ANSWER F.02 (1.00)

True.

REFERENCE
Procedure UWNR 131, p. 1.

ANSWER F.03 (2.00)

Step e before step c. (1.0)

Step d before step b. (1.0)

REFERENCE
Procedure UWNR 116, p. 1.

ANSWER F.04 (2.00)

a. (0.33 pts each)
   1. Shutdown the reactor
   2. Initiate evacuation if air activity alarm exists
   3. Notify SRO

b. (0.33 pts each)
   1. Air Particulate
   2. Air Particulate
   3. Pool Water

REFERENCE
Procedure UWNR 152, p. 1, 2.

ANSWER F.05 (1.00)

If either recorder indicates a value higher than the alarm point.

REFERENCE
Procedure UWNR 155, p. 1.

ANSWER F.06 (2.00)

a. (any four at 0.25 pts each)
   1. Pool level annunciator
   2. Area radiation annunciator
   3. Tank level annunciator
   4. Loss of Pump running indicators
   5. Observation of leak (water on the floor)
   6. High pool makeup rate
   7. Pool overflow
   8. Poor pool water quality (or high radioactivity in pool water

b. Use of Emergency Pool Fill System (open double valves located above West basement door to laboratory).

REFERENCE
Procedure UWNR 151, p. 1, 2.
Procedure UWNR 106C, p.2.

ANSWER F.07 (2.00)

a. Any time when a key is in the console key switch (1.0)

b. All of the ground level of the Laboratory (0.5) except east of the console (0.5).

REFERENCE
Procedure UWNR 001, p. 1.

ANSWER F.08 (2.00)

a. Assure that safety blades (0.5) and transient rod have dropped (0.5).

b. A Senior Operator must grant permission (by signing the SCRAM form) (1.0).

REFERENCE
Procedure UWNR 115
Procedure UWNR 115, p. 8.

ANSWER F.09 (1.00)

(0.5 pts each)
1. Scram the reactor.

2. Remove the key from the key switch. (also accept immediate actions of UWNR-150)

REFERENCE
Procedure UWNR 157, p. 1.

ANSWERS -- UNIVERSITY OF WISCONSIN -88/05/24-HARE S.

ANSWER G.01 (1.00)

Battery check.
Current calibration.
Check for physical damage.
Tested by exposing it to a known source of radiation.

REFERENCE
Radiation Safety For Laboratory Technician, p. 10.

ANSWER G.02 (2.00)

a. False.

b. True.

REFERENCE
Radiation Safety for Laboratory Technician, p. 10, 14.

ANSWER G.03 (1.00)

Three times background or MDA

REFERENCE
Radiation Safety For Laboratory Technician, Chapter 5.

ANSWER G.04 (1.00)

True

REFERENCE
Radiation Safety For Laboratory Technician, Chapter 2.

ANSWER G.05 (1.00)

On the collar. or between waist and neck.

REFERENCE
Radiation Safety For Laboratory Technician, Chapter 2.

ANSWER G.06 (.00)

Answer deleted

REFERENCE
Regulatory Guide 8.13, Appendix, p. 8.13-4.

ANSWER G.07 [2.25]

a. N-16 [0.75]

b. 1. Chain and Switch arrangement which sounds an alarm [0.75].

2. Access is gained only through the console area and is well monitored [0.75].

REFERENCE
Safety Analysis Report, p. 2-56.

ANSWER G.08 [3.00]

a. * Demineralizer area [0.5];
* On the reactor bridge (about one foot above the water surface) [0.5];
* Beside the thermal column door [0.5].

b. Gaseous activity is measured with a large Kanne ionization chamber. [0.75]

Particulate activity is collected on a filter tape and counted with a thin end-window GM tube and count-rate meter. [0.75]

Alternate wording is acceptable.

REFERENCE
Safety Analysis Report, Section 2.5.9, p. 2-53.54.

ANSWER G.09 (1.50)

(D1/D2)^2 * DR1 = DR2

(30/500)^2 * 150 = DR2 (0.75)

DR2 = 0.54 mR/hr (0.75)

REFERENCE
Radiation Safety for Laboratory Technicians, p. 27.

ANSWER G.10 (1.50)

Any 3 of 4 @ 0.5 each.
1. Natural Decay.

2. Collection by Health Physics Staff.

3. Disposal into Atmosphere.

4. Disposal through Sanitary Sewer.

REFERENCE
Radiation Safety For Laboratory Technician, p. 27.

DATA SHEET

REACTOR THEORY FORMULAS

$$P = P_0 e^{t/\tau}$$

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

$$P = \frac{\Sigma \Phi_{th} V}{3.12 \times 10^{10} \text{ fissions/sec}}$$

$$SUR = 26.06/\tau$$

$$P_{th} = \frac{1}{1 + (B^2 L_{th}^2)} = e^{-(B^2 L_{th}^2)}$$

$$\rho = \frac{l^*}{\tau} + \frac{\overline{\beta}_{eff}}{1 + \lambda\tau}$$

$$P_f = e^{-(B^2 L_f^2)}$$

$$\rho = \frac{K - 1}{K}$$

$$p = e^{-[N][I_{eff}]/\xi\Sigma_s}$$

$$\Delta\rho = \ln \frac{K_{final}}{K_{initial}}$$

$$C_1 (1-K_{eff1}) = C_2 (1-K_{eff2})$$

$$\tau = \frac{\overline{\beta}_{eff} - \rho}{\lambda\rho}$$

$$m = \frac{1}{1-K} = \frac{C_{final}}{C_{initial}}$$

$$\tau = \frac{l^*}{\rho}$$

$$\alpha_T = \frac{1}{f}\frac{\Delta f}{\Delta t} + \frac{1}{p}\frac{\Delta p}{\Delta t} - B^2 \left(\frac{\Delta L_f^2}{\Delta t} + \frac{\Delta L_{th}^2}{\Delta t}\right)$$

$$K_{eff} = \epsilon P_f \, p \, P_{th} \, f \, \eta$$

$$P_1 = P_0 \frac{\overline{\beta}_{eff} - \rho_0}{\overline{\beta}_{eff} - \rho_1}$$

DATA SHEET

THERMODYNAMICS AND FLUID MECHANICS FORMULAS:

$$\dot{Q} = \dot{m} \Delta h$$

$$\dot{Q} = \frac{2 \pi L \Delta T}{\frac{1}{K} + \frac{\ln R_2/R_1}{K_2} + \frac{\ln R_3/R_2}{K_3}}$$

$$\dot{Q} = U A (\Delta T_m)$$

$$\dot{Q} = \dot{m} c_p (\Delta T)$$

$$\dot{Q} = \alpha \delta A R^4$$

$$\eta = \frac{\dot{Q}_{in} - \dot{Q}_{out}}{\dot{Q}_{in}}$$

$$\eta = \frac{(h_{in} - h_{out})real}{(h_{in} - h_{out})ideal}$$

$$\eta_p = \frac{W_{actual}}{W_{supplied}}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\dot{m} = \rho A V$$

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

$$\dot{m} = KA \sqrt{\Delta P_x \rho}$$

$$\dot{m}_{nc} = KA_Q \sqrt[3]{\dot{Q}} = KA \Delta T \sqrt{\Delta T} = KA \Delta p \sqrt{\Delta P}$$

$$\Delta T_m = \frac{\Delta T (in) - \Delta T (out)}{\ln \left(\frac{\Delta T (in)}{\Delta T (out)}\right)}$$

$$G = \frac{\Sigma_f \phi_{th}}{8.8 \times 10^9}$$

$$T_{cl} - T_{ps} = \frac{Gr^2}{4k}$$

$$\dot{Q} = \frac{kA\Delta T}{\Delta x}$$

$$\dot{Q} = \frac{A \Delta T_{total}}{\frac{\Delta x_a}{K_a} + \frac{\Delta x_b}{K_b} + \ldots + \frac{\Delta x_n}{K_n}}$$

DATA SHEET

CENTRIFUGAL PUMP LAWS:

$\frac{N_1}{N_2} = \frac{\dot{m}_1}{\dot{m}_2}$ $\frac{(N_1)^2}{(N_2)^2} = \frac{H_1}{H_2}$ $\frac{(N_1)^3}{(N_2)^3} = \frac{P_1}{P_2}$

RADIATION AND CHEMISTRY FORMULAS:

$R/hr = 6CE/d^2$

$I_x = I_0\, e^{-mx}$

$C_1V_1 = C_2V_2$

$G = \frac{\text{Dilution Rate}}{\text{Volume}}$

$I = I_0 \left(\frac{1}{10}\right)^n$

$C = C_0\, e^{-Gt}$

$A = A_0\, e^{-\lambda t}$

$A = \lambda N$

CONVERSIONS:

$1\ gm/cm^3 = 62.4\ lbm/ft^3$

Density of water (20 C) = $62.4\ lbm/ft^3$

1 gal = 8.345 lbm

$1\ ft^3 = 7.48$ gal

Avogadro's Number = 6.023×10^{23}

1 gal = 3.78 liters

Heat of Vapor (H_2O) = 970 Btu/lbm

1 lbm = 454 grams

Heat of Fusion (ICE) = 144 Btu/lbm

e = 2.72

1 AMU = 1.66×10^{-24} grams

π = 3.14159

Mass of Neutron = 1.008665 AMU

1 KW = 738 ft-lbf/sec

Mass of Proton = 1.007277 AMU

1 KW = 3413 Btu/hr

Mass of Electron = 0.000549 AMU

1 HP = 550 ft-lbf/sec

One atmosphere = 14.7 psia = 29.92 in. Hg

1 HP = .746 KW

°F = 9/5 °C + 32

1 HP = 2545 Btu/hr

°C = 5/9 (°F − 32)

1 Btu = 778 ft-lbf

°R = °F + 460

1 MEV = 1.54×10^{-16} Btu

°K = °C + 273

h = 4.13×10^{-21} M-sec

1 W = 3.12×10^{10} fissions/sec

$g_c = 32.2\ lbm\text{-}ft/lbf\text{-}sec^2$

$c^2 = 931$ MEV/AMU

1 inch = 2.54 cm

C = 3×10^8 m/sec

$\sigma = 0.1714 \times 10^{-8}\ Btu/hr\ ft^2\ R^4$

DATA SHEET

AVERAGE THERMAL CONDUCTIVITY (K)

Material	K
Cork	0.025
Fiber Insulating Board	0.028
Maple or Oak Wood	0.096
Building Brick	0.4
Window Glass	0.45
Concrete	0.79
1% Carbon Steel	25.00
1% Chrome Steel	35.00
Aluminum	118.00
Copper	223.00
Silver	235.00
Water (20 psia, 200 degrees F)	0.392
Steam (1000 psia, 550 degrees F)	0.046
Uranium Dioxide	1.15
Helium	0.135
Zircaloy	10.0

MISCELLANEOUS INFORMATION:

$E = mc^2$

$KE = 1/2\ mv^2$

$PE = mgh$

$V_f = V_0 + at$

Geometric Object	Area	Volume
Triangle	$A = 1/2\ bh$	//////////////////
Square	$A = S^2$	//////////////////
Rectangle	$A = L \times W$	//////////////////
Circle	$A = \pi r^2$	//////////////////
Rectangular Solid	$A = 2(L\times W + L\times H + W\times H)$	$V = L \times W \times H$
Right Circular Cylinder	$A = (2\ \pi r^2)h + 2(\pi r^2)$	$V = \pi r^2 h$
Sphere	$A = 4\ \pi r^2$	$V = 4/3\ (\pi r^2)$
Cube	///////////////////////////////	$V = S^3$

DATA SHEET

MISCELLANEOUS INFORMATION (continued):

				10 CFR 20 Appendix B			
				Table I		Table II	
Material	Half-Life	Gamma Energy MEV per Disintegration		Col I Air uc/ml	Col II Water uc/ml	Col I Air uc/ml	Col II Water uc/ml
Ar-41	1.84 h	1.3	Sub	2×10^{-6}	-----	4×10^{-8}	------
Co-60	5.27 y	2.5	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	5×10^{-5}
I-131	8.04 d	0.36	S	9×10^{-9}	6×10^{-5}	1×10^{-10}	3×10^{-7}
Kr-85	10.72 y	0.04	Sub	1×10^{-5}	-----	3×10^{-7}	------
Ni-65	2.52 h	0.59	S	9×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
Pu-239	2.41×10^{4} y	0.008	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
Sr-90	29 y	-----	S	1×10^{-9}	1×10^{-5}	3×10^{-11}	3×10^{-7}
Xe-135	9.09 h	0.25	Sub	4×10^{-6}	-----	1×10^{-7}	------
Any single radionuclide with $T_{1/2}$ > 2 hr which does not decay by alpha or spontaneous fission				3×10^{-9}	9×10^{-5}	1×10^{-10}	3×10^{-6}

Neutron Energy (MEV)	Neutrons per cm^2 equivalent to 1 rem	Average flux to deliver 100 mrem in 40 hours
thermal	970×10^{6}	670 (neutrons / cm^2 x sec)
0.02	400×10^{6}	280
0.5	43×10^{6}	30
10	24×10^{6}	17

Linear Absorption Coefficients μ (cm^{-1})				
Energy (MEV)	Water	Concrete	Iron	Lead
0.5	0.090	0.21	0.63	1.7
1.0	0.067	0.15	0.44	0.77
1.5	0.057	0.13	0.40	0.57
2.0	0.048	0.11	0.33	0.51
2.5	0.042	0.097	0.31	0.49
3.0	0.038	0.088	0.30	0.47