ENCLOSURE 1

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

REPORT NO.: 50-027/OL-92-01

FACILITY DOCKET NO.: 50-027

FACILITY LICENSE NO.: R-76

FACILITY: Washington State University

EXAMINATION DATES: January 7-9, 1992

EXAMINER: Paul V. Doyle, Jr., Chief Examiner

SUBMITTED BY: Paul V. Doyle 2-11-92
Paul V. Doyle, Jr., Chief Examiner Date

APPROVED BY: Warren J. Eccian for 2/12/92
James L. Caldwell, Chief Date
Non-Power Reactor Section
Operator Licensing Branch
Division of Licensee Performance
and Quality Evaluation, NRR

SUMMARY:

The NRC administered written and operating examinations to four reactor operator (RO) applicants. One RO applicant failed one section of the written examination. The other three applicants passed all portions of the examination and have been issued the appropriate licenses.

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REPORT DETAILS

1. Examiners:

   Paul V. Doyle, Jr., Chief Examiner

2. Results:

	RO (Pass/Fail)	SRO (Pass/Fail)	Total (Pass/Fail)
NRC Grading:	3/1	N/A	3/1

3. Written Examination:

   The written was administered to four RO candidates on January 9, 1992. Three RO candidates passed the examination and one candidate failed one section.

4. Operating Examinations:

   Operating examinations were administered on January 7-8, 1992 to four RO candidates. All four RO candidates passed this portion of the examination.

5. Exit Meeting:

   Personnel attending:

   Gerald Tripard, Director, Washington State University Facility
   Gerald Neidinger, Supervisor, Washington State University Facility
   Paul Doyle, Chief Examiner

   No generic program weaknesses were noted during the walkthrough examination process.

ENCLOSURE 2

FACILITY COMMENTS AND NRC RESOLUTION OF COMMENTS

SECTION B

1. Which ONE of the following statements describes the condition of the reactor when it is shutdown?

   a. The console key is in the "OFF" position and the key is removed from the console

   b. All control rods are fully inserted into the core and there is no refueling or maintenance in progress.

   c. The reactor is sub-critical by at least $1.00 of reactivity and there is no refueling or maintenance in progress.

   d. The reactor is sub-critical and the fuel and bulk water temperatures are less than 40°F.

Facility Comment:
The second half of answer part C is not part of the definition according to our tech specs. We prefer, however to leave the question stand. If the question is ever used again, it should reflect the tech specs.

Resolution:
No change to exam grading.

4. Which ONE of the following is statements describe the Technical Specifications for the minimum number and type of personnel required when the reactor is critical or approaching criticality?

   a. A licensed reactor operator at the control console, another licensed reactor operator within the reactor laboratory and a licensed senior reactor operator on call.

   b. A licensed reactor operator at the control console and a licensed senior reactor operator within the reactor laboratory.

   c. A licensed reactor operator at the console, another responsible person within the reactor laboratory and a licensed senior reactor operator on call.

   d. A licensed reactor operator at the control console, and another responsible person within the reactor laboratory.

Facility Comment:
These [questions 4 and 15] were very similar and required a minute distinction between tech specs and SOP 4 which is slightly more conservative. Is it really your intention to use an SOP standard as a distractor for a question about Tech Specs? After all, the operator is expected to follow and have burned into his memory the SOP he actually executes. I would think that non-SOP distractors would serve a better function. Per telecon clarification Choice B is the requirement per SOP # 4 Sect. A.3. This answer is more conservative than the Tech. Spec answer and as such should be allowed as a correct answer.

Resolution:
Agree. The answer key has been modified to recognize either b or c as correct.

SECTION B (continued)

5. Which ONE of the following radioactive gases poses the most significant hazard to personnel?

   a. Argon-41

   b. Nitrogen-16

   c. Oxygen-18

   d. Hydrogen-3

Facility Comment:
This question was vague because it didn't specify location of personnel although it was orally clarified somewhat during the exam.

Resolution:
Agree. This question was orally corrected to say ... significant hazard to the environment? No change to the answer key.

11. A special experiment involving the production of radioisotopes, has been proposed for irradiation in the reactor. Which one of the following choices describes the review(s), evaluations(s) approval(s) and designation(s) required to perform the experiment?

   a. The experiment must be evaluated by the Reactor Supervisor, reviewed by the Reactor Safety Committee, approved by the Health and Safety Committee and designated Class I.

   b. The experiment must be evaluated by the Radiological Health and Safety Committee, approved by the Reactor Safety Committee and designated Class I.

   c. The experiment must be evaluated by the Radiological Health and Safety Committee, approved by the Reactor Supervisor and designated Class II.

   d. The experiment must be evaluated by the Reactor Supervisor, approved by the Reactor Safety Committee and the Radiological Health and Safety Committee and designated Class II.

Facility Comment:
Experiments at our [Washington State] facility are not designated by Class I or Class II. The answer given in the key gives reference to SAR section 9.3.5. Our SAR has no such section. This question does not apply to our facility [and] should be deleted.

Resolution:
Agree. The answer key has been modified to delete this question.

SECTION B (continued)

12. Which ONE of the following is the lowest level of approval for deviation from a Standard Operating Procedure to accomplish a task in the safest and most efficient manner?

    a. Licensed Senior Reactor Operator

    b. Laboratory management

    c. Reactor Safety Committee

    d. Radiation Safety Committee

Facility Comment:
The level of authority required for approval of a deviation from a Standard Operating Procedure is dependent on the time length and [illegible]nt of the deviation (See attached Administrative Procedure #2). The lowest [illegible]l is a licensed Senior Operator.

Resolution:
Agree with comment. After further review the examiner decided this question should be deleted due to the fact that it is too vague in intent.

15. What are the minimum personnel requirements for performing a Prestart Checklist?

    a. A licensed operator must perform the Checklist, but a licensed SRO must be present while performing steps which require control rod movement or magnet activation.

    b. Any authorized laboratory personnel may conduct the checklist, but a licensed SRO must be present while performing steps which require control rod movement or magnet activation.

    c. A licensed operator (RO or SRO) must perform the checklist, but only a licensed SRO may perform the steps which require control rod movement or magnet activation.

    d. Any authorized laboratory personnel may conduct the checklist, but a licensed SRO must be present while performing steps which require rod movement or magnet activation.

Facility Comment:
These [questions 4 and 15] were very similar and required a minute distinction between tech specs and SOP 4 which is slightly more conservative. Is it really your intention to use an SOP standard as a distractor for a question about Tech Specs? After all, the operator is expected to follow and have burned into his memory the SOP he actually executes. I would think that non-SOP distractors would serve a better function. Per SOP # 4 choice A is the correct answer to this question. SOP # 4 is more limiting than the Tech Spec requirement as listed in choices B and D.

SECTION B (continued)

Resolution:
Agree. Due to the fact that the question did not specify whether the limit was from Tech Specs or from procedures three answers could be considered correct for this question. Therefore this question has been deleted from the answer key.

SECTION C

3. Make-up water to the pool is provided through:

   a. a manual valve opened by the operator when necessary to restore pool level.

   b. a solenoid valve which opens in response to a float switch in the pool.

   c. a mixed-bed ion exchanger.

   d. a culligan deionizer and recirculation pump.

Facility Comment:
This really has three correct answers; b, c and d. Makeup water must pass through all the devices mentioned in b, c, and d. When I answered the question I felt reasonably sure that you were expecting b, but I thought that one should be able to devise a better question on the subject.

Resolution:
Agree. The answer key for this question will not be changed due to the fact that all four candidates chose the correct answer.

14. The quick disconnect pin of a control rod has been inadvertently removed and not replaced. When the operator attempts to raise the rod out of the core, the "blade in" light will:

   a. go out, and the position indication will not function normally.

   b. go out, and the position indication will function normally.

   c. stay on, and the position indication will not function normally.

   d. stay on, and the position indication will function normally.

Facility Comment:
The "BLADE IN" light microswitch is on the control element drive mechanism (See attached diagram). If the control element drive functions normally, the Blade In/Out lights will functions normally. The correct answer is the "BLADE IN" light will,

   b. go out and the position indication will function normally.

Resolution:
Agree. The answer key has been modified to show "B" as the correct answer.

SECTION C (continued)

16. The Argon-41 Monitor has two types of detectors. They are:

a. proportional counter and scintillation detector

b. proportional counter and GM detector

c. scintillation detector and GM detector

d. fission chamber and proportional counter

Facility Comment:
The Argon-41 detector has only one detector; a scintillation detector. Section A of Standard Operating Procedure #18 outlines the Absolute Calibration of the Argon-41 Monitoring system which is done only after initial setup or when there is a detector or geometry change. The system is assembled, calibrated and then the proportional counter removed and system setup as per diagram B. Subsequent annual calibrations are per Section C of S.O.P. #18. Question 016 has no correct answer.

Resolution:
Agree. The answer key has been modified to delete this question.

In addition to the changes made to the answer key based on the facility comments an NRC internal review of the examination resulted in the following changes:

Questions B.6, and B.7 were modified to accept two correct answers.

B.6 Accept either "B" or "C"

B.7 Accept either "C" or "D"

B.13 Accept either "B" or "D"

U. S. NUCLEAR REGULATORY COMMISSION
NON-POWER REACTOR LICENSE EXAMINATION

FACILITY: Washington State Univ.

REACTOR TYPE: WSTR

DATE ADMINISTERED: 92/01/~~09~~06

REGION: 5

CANDIDATE: _____

LICENSE APPLIED FOR: _____

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 parentheses 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.

CATEGORY VALUE	% OF TOTAL	CANDIDATE'S SCORE	% OF CATEGORY VALUE		CATEGORY
20.00	33.90	_____	_____	A.	REACTOR THEORY, THERMODYNAMICS AND FACILITY OPERATING CHARACTERISTICS
19.00	32.20	_____	_____	B.	NORMAL AND EMERGENCY OPERATING PROCEDURES AND RADIOLOGICAL CONTROLS
20.00	33.90	_____	_____	C.	PLANT AND RADIATION MONITORING SYSTEMS
59.00		_____ 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 not received or 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 only to facilitate legible reproductions.

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

6. Fill in the date on the cover sheet of the examination (if necessary).

7. The point value for each question is indicated in parentheses after the question. The amount of blank space on an examination question page is NOT an indication of the depth of answer required.

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. To pass the examination, you must achieve at least 70% in each category.

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

12. When you are done and have turned in your examination, leave the examination area as defined by the examiner. If you are found in this area while the examination is still in progress, your license may be denied or revoked.

ANSWER SHEET

Multiple Choice (Circle or X your choice)

If you change your answer, write your selection in the blank.

MULTIPLE CHOICE

001	a	b	c	d	___
002	a	b	c	d	___
003	a	b	c	d	___
004	a	b	c	d	___
005	a	b	c	d	___
006	a	b	c	d	___
007	a	b	c	d	___
008	a	b	c	d	___
009	a	b	c	d	___
010	a	b	c	d	___
011	a	b	c	d	___
012	a	b	c	d	___
013	a	b	c	d	___
014	a	b	c	d	___
015	a	b	c	d	___
016	a	b	c	d	___
017	a	b	c	d	___
018	a	b	c	d	___
019	a	b	c	d	___
020	a	b	c	d	___

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

ANSWER SHEET

Multiple Choice (Circle or X your choice)

If you change your answer, write your selection in the blank.

001	a	b	c	d		___
002	a	b	c	d		___
003	a	b	c	d		___
004	a	b	c	d		___
005	a	b	c	d		___
006	a	b	c	d		___
007	a	b	c	d		___
008	a	b	c	d		___
009	a	b	c	d		___
010	a	b	c	d		___
011	a	b	c	d		___
012	a	b	c	d		___
013	a	b	c	d		___
014	a	b	c	d		___
015	a	b	c	d		___
016	a	1	2	5	10	___
	b	1	2	5	10	___
	c	1	2	5	10	___
	d	1	2	5	10	___
017	a	b	c	d		___
018	a	b	c	d		___

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

ANSWER SHEET

Multiple Choice (Circle or X your choice)

If you change your answer, write your selection in the blank.

001 a b c d ___

002 a b c d ___

003 a b c d ___

004 F1 On / Off ___ F3 On / Off ___ F4 On / Off ___

D1 Open / Closed ___ D2 Open / Closed ___

D3 Open / Closed ___ D4 Open / Closed ___

005 A 1 2 3 4 5 6 7 8 9 ___ B 1 2 3 4 5 6 7 8 9 ___

C 1 2 3 4 5 6 7 8 9 ___ D 1 2 3 4 5 6 7 8 9 ___

E 1 2 3 4 5 6 7 8 9 ___ F 1 2 3 4 5 6 7 8 9 ___

006 a b c d ___

007 a b c d ___

008 a b c d ___

009 a b c d ___

010 A 1 2 3 ___ B 1 2 3 ___ C 1 2 3 ___

D 1 2 3 ___ E 1 2 3 ___

011 a b c d ___

012 a b c d ___

013 a b c d ___

014 a b c d ___

015 a b c d ___

016 a b c d ___

017 a b c d ___

018 a b c d ___

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

QUESTION: 001 (1.00)

In a reactor at full power, the thermal neutron flux is 2.5 E12 neutrons per square centimeter per second and the macroscopic fission cross-section is 0.1 per centimeter. The fission reaction rate is:

a. 2.5 E11 fissions/sec

b. 2.5 E13 fissions/sec

c. 2.5 E11 fissions/cubic cm/sec

d. 2.5 E13 fissions/cubic cm/sec

QUESTION: 002 (1.00)

Which condition below describes a reactor which is exactly critical?

a. k = 1; delta k/k = 1

b. k = 1; delta k/k = 0

c. k = 0; delta k/k = 1

d. k = 0; delta k/k = 0

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

QUESTION: 003 (1.00)

A 1/M plot is used to predict criticality during fuel bundle loading. From the data below and the graph provided, criticality will occur after which fuel bundle is loaded?

a. 20th bundle

b. 22nd bundle

c. 24th bundle

d. 26th bundle

Count Rate	# of bundles
842	2
936	4
1123	7
1684	12
2807	16

QUESTION: 004 (1.00)

Thermalization of neutrons is accomplished most efficiently when the moderator has:

a. LOW atomic mass number and HIGH scattering cross-section

b. HIGH atomic mass number and HIGH scattering cross-section

c. LOW neutron absorption cross-section and LOW scattering cross-section

d. LOW neutron absorption cross-section and HIGH atomic mass number

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

QUESTION: 005 (1.00)

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. Alpha radiation

QUESTION: 006 (1.00)

A factor in the six-factor formula which is most affected by control rod position is:

a. Resonance escape probability

b. Fast fission factor

c. Neutron reproduction factor

d. Thermal utilization factor

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

QUESTION: 007 (1.00)

Which ONE of the following is the reason for the -80 second period following a reactor scram?

a. the ability of U-235 to fission with source neutrons

b. the half-life of the longest-lived group of delayed neutron precursors is 55 seconds

c. the amount of negative reactivity added on a scram is greater than the Shutdown Margin

d. the doppler effect, which adds positive reactivity due to the temperature decrease following a scram

QUESTION: 008 (1.00)

Which ONE of the following is true concerning the differences between prompt and delayed neutrons?

a. Prompt neutrons account for less than one percent of the neutron population while delayed neutrons account for approximately ninety-nine percent of the neutron population

b. Prompt neutrons are released during fast fissions while delayed neutrons are released during thermal fissions

c. Prompt neutrons are released during the fission process while delayed neutrons are released during the decay process

d. Prompt neutrons are the dominating factor in determining the reactor period while delayed neutrons have little effect on the reactor period

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

QUESTION: 009 (1.00)

Which ONE of the following correctly describes the relationship between Differential Rod Worth (DRW) and Integral Rod Worth (IRW)?

a. DRW is the area under the IRW curve.

b. IRW is the slope of the DRW curve at a given location.

c. DRW is the value of the IRW at a given location.

d. IRW is the area under the DRW curve.

QUESTION: 010 (1.00)

A thermal neutron is:

a. a neutron possessing thermal rather than kinetic energy.

b. a neutron that was produced in a significant time (on the order of seconds) after its initiating fission took place.

c. a neutron that was produced by fast fission.

d. a neutron that experiences no net change in energy after several collisions with atoms of the moderator.

QUESTION: 011 (1.00)

What is the stable reactor period which produces a power rise from 15 watts to 50 kilowatts in 243 seconds?

a. 10 seconds

b. 30 seconds

c. 40 seconds

d. 60 seconds

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

QUESTION: 012 (1.00)

With the reactor on a constant period, which transient requires the LONGEST time to occur?

A reactor power change of:

a. 5% power -- going from 1% to 6% power

b. 10% power -- going from 10% to 20% power

c. 15% power -- going from 20% to 35% power

d. 20% power -- going from 40% to 60% power

QUESTION: 013 (1.00)

The bath temperature coefficient of reactivity is 1.0E-4 delta K/K/deg.C. When the water temperature decreases by 10 deg C, a regulating blade with a Differential Rod Worth of 0.05 % delta K/K/inch must be:

a. inserted 2 inches

b. withdrawn 2 inches

c. inserted 0.5 inches

d. withdrawn 0.5 inches

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

QUESTION: 014 (1.00)

When a neutron is absorbed by U-235, the probability that a fission event will occur is:

a. 0.14

b. 0.35

c. 0.50

d. 0.85

QUESTION: 015 (1.00)

In the Washington State University reactor, a reactivity insertion of 20 cents corresponds approximately to:

a. 0.0010 delta k/k

b. 0.0014 delta k/k

c. 0.0070 delta k/k

d. 0.0020 delta k/k

QUESTION: 016 (1.00)

Which ONE of the following is the time period in which the maximum amount of Xenon-135 will be present in the core?

a. 8 to 10 hours after a startup to 100% power.

b. 4 to 6 hours after a power increase from 50% to 100% power.

c. 4 to 6 hours after a power decrease from 100% to 50% power.

d. 8 to 10 hours after a scram from 100% power.

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

QUESTION: 017 (1.00)

Which ONE of the statements below describes why installed neutron sources are used in reactor cores?

a. To increase the count rate by an amount equal to the source contribution.

b. To increase the count rate by 1/M (M= Subcritical Multiplication Factor).

c. To provide neutrons to initiate the chain reaction.

d. To provide a neutron level high enough to be monitored by instrumentation.

QUESTION: 018 (1.00)

The following facility parameters are given:

Primary coolant flow rate	350 gpm
Secondary system flow rate	700 gpm
Primary coolant temperature change	20 degrees F
Secondary coolant inlet temperature	73 degrees F

Which ONE of the following is the secondary coolant outlet temperature?

a. 78 degrees F

b. 83 degrees F

c. 88 degrees F

d. 93 degrees F

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

QUESTION: 019 (1.00)

Which ONE of the following explains the response of a subcritical reactor to equal insertions of positive reactivity as the reactor approaches critical?

a. Each reactivity insertion causes a SMALLER increase in the neutron flux, resulting in a LONGER time to stabilize

b. Each reactivity insertion causes a LARGER increase in the neutron flux, resulting in a LONGER time to stabilize

c. Each reactivity insertion causes a SMALLER increase in the neutron flux, resulting in a SHORTER time to stabilize

d. Each reactivity insertion causes a LARGER increase in the neutron flux, resulting in a SHORTER time to stabilize

QUESTION: 020 (1.00)

Which ONE of the following is the reason for operating with thermal neutrons instead of fast neutrons?

a. Neutron efficiency is increased since thermal neutrons are less likely to leak out of the core

b. Neutron absorption in non-fuel material increases exponentially as neutron energy increases

c. The fission cross section of the fuel is much higher for thermal energy neutrons

d. Doppler and moderator temperature coefficients become positive as neutron energy increases

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

QUESTION: 001 (1.00)

Which ONE of the following statements describes the condition of the reactor when it is SHUTDOWN?

a. The Console key switch is in the "OFF" position and the key is removed from the console.

b. All control rods are fully inserted into the core and there is no refueling or maintenance in progress.

c. The reactor is sub-critical by at least $1.00 of reactivity and there is no refueling or maintenance in progress.

d. The reactor is sub-critical and the fuel and bulk water temperatures are less than 40°C.

QUESTION: 002 (1.00)

What is the Technical Specification limit (Reactivity) for the storage of material in the reactor pool fuel storage racks?

a. Keff must be less than 0.95 for all conditions of moderation.

b. Keff must be less than 0.90 for all conditions of moderation.

c. Keff must be less than 0.85 for all conditions of moderation.

d. Keff must be less than 0.80 for all conditions of moderation.

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

QUESTION: 003 (1.00)

Which ONE of the following is the fuel element failure prevented by limiting the maximum temperature of the fuel element?

a. Ductile failure of the fuel element cladding due to cladding creep and thermal stresses at elevated temperatures.

b. Fuel Element cladding failure due to the pressure buildup in the fuel element from fission gases and fuel moderator disassociation.

c. Fuel element centerline fuel melting due to exceeding the melting point of the fuel hydride.

d. Cladding "hot spot perforations" due to the fuel to cladding interaction caused by excessive fuel swelling.

QUESTION: 004 (1.00)

Which ONE of the following statements describe the Technical Specification for the minimum number and type of personnel required when the reactor is critical or approaching criticality?

a. A licensed reactor operator at the control conscle, another licensed reactor operator within the reactor laboratory and a licensed senior reactor operator on call.

b. A licensed reactor operator at the control console and a licensed senior reactor operator within the reactor laboratory.

c. A licensed reactor operator at the control console, another responsible person within the reactor laboratory and a licensed senior reactor operator on call.

d. A licensed reactor operator at the control console, and another responsible person within the reactor laboratory.

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

QUESTION: 005 (1.00)

Which ONE of the following radioactive gases poses the most significant hazard to personnel?

a. Argon-41

b. Nitrogen-16

c. Oxygen-18

d. Hydrogen-3 (Tritium)

QUESTION: 006 (1.00)

Which of the following is the MAXIMUM permissible QUARTERLY exposure to radiation allowed at the Washington State University reactor facility?

a. 300 millirem

b. 1250 millirem

c. 3000 millirem

d. 5000 millirem

QUESTION: 007 (1.00)

A person is working 4 feet from a gamma point source emitting 8R/hr at one foot. Which of the following is the length of time that the person can work without exceeding the whole body QUARTERLY 10 CFR 20 dose limit. Assume no previous exposure for the quarter.

a. 37 minutes

b. 1.25 hours

c. 2.5 hours

d. 6.0 hours

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

QUESTION: 008 (1.00)

A container of radioactive materials is to be transferred to an off-campus user. The container has a RADIOACTIVE-YELLOW III label attached to it. Which one of the following is the expected radiation level at the surface of the container?

a. At least 0.5 mr/hr but less than 50 mr/hr

b. At least 50 mr/hr but less than 100 mr/hr

c. At least 100 mr/hr but less than 200 mr/hr

d. At least 200 mr/hr

QUESTION: 009 (1.00)

A cobalt-60 source has been dropped in the reactor laboratory. Thirty (30) feet from the source a beta-gamma detector reads 100 mr/hr. What is the curie content of the source? (Assume a 1.2 and a 1.3 Mev gamma emission.)

a. 90 curies

b. 30 curies

c. 6 curies

d. 2.5 curies

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

QUESTION: 010 (1.00)

An experiment has been removed from the reactor. A radiation reading of 1 R/hr was recorded at 3 feet when the experiment was removed. Fifteen minutes later a reading of 750 mr/hr was recorded at the same distance (3 feet). What is the approximate length of time required (measured from the time of removal) for the radiation level to decrease to 10 mrem/hr at 1 foot?

a. 3 hours

b. 6 hours

c. 9 hours

d. 12 hours

QUESTION: 011 (1.00)

A special experiment involving the production of radioisotopes, has been proposed for irradiation in the reactor. Which one of the following choices describes the review(s), evaluation(s) approval(s) and designation(s) required to perform the experiment?

a. The experiment must be evaluated by the Reactor Supervisor, reviewed by the Reactor Safety Comittee, approved by the Health and Safety Committee and designated as Class I.

b. The experiment must be evaluated by the Radiological Health and Safety Committee, approved by the Reactor Safety committee and designated as Class I.

c. The experiment must be reviewed by the Radiological Health and Safety Committee, approved by the Reactor Supervisor and designated as Class II.

d. The experiment must be evaluated by the Reactor Supervisor, approved by the Reactor Safety Committee and the Radiological Health and Safety Committee and designated Class II.

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

QUESTION: 012 (1.00)

Which ONE of the following is the lowest level of approval for deviation from a Standard Operating Procedure to accomplish a task in the safest and most efficient manner?

a. Licensed Senior Reactor Operator

b. Laboratory management

c. Reactor Safety Committee

d. Radiation Safety Committee

QUESTION: 013 (1.00)

What is the the dosimetry requirement for visitors being escorted while the reactor is SHUTDOWN?

a. Each visitor is required to carry a pocket dosimeter if the visitor is not wearing a badge.

b. One person in the group of visitors must wear a pocket dosimeter, in addition to the dosimetry worn by the escort.

c. Each visitor is required to wear both a badge and a pocket dosimeter.

d. One person in the group of visitors is designated to wear dosimetry, but the escort's dosimetry may fulfill this requirement.

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

QUESTION: 014 (1.00)

Which of the following statements describe the requirements for the retention of WSU Reactor Facility Records?

a. Both Procedure logs and Fuel logs need only be retained for five (5) years.

b. Procedure logs need only be retained for five (5) years, but fuel logs must be retained indefinitely.

c. Fuel logs need only be retained for five (5) years, but Procedure logs must be retained indefinitely.

d. Both Procedure logs and Fuel logs must be retained indefinitely.

QUESTION: 015 (1.00)

What are the minimum personnel requirements for performing a Prestart Checklist?

a. A licensed operator (RO or SRO) must perform the Checklist, but a licensed SRO must be present while performing steps which require control rod movement or magnet activation.

b. Any authorized laboratory personnel may conduct the Checklist, but a licensed SRO must be present while performing steps which require control rod movement or magnet activiation.

c. A licensed operator (RO or SRO) must perform the Checklist, but only a licensed SRO may perform the steps which require control rod movement or magnet activation.

d. Any authorized laboratory personnel may conduct the Checklist, but a licensed SRO must be present while performing steps which require rod movement or magnet activation.

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

QUESTION: 016 (2.00)

Per the WSU RO training manual "Quality Factors" are used to convert a meter reading of r or RADS to REM for different types of radiation. Match the "Quality Factors in Column B with the detected radiation in Column A.

COLUMN A	COLUMN B
A. X-ray or Gamma	1
B. Alpha	2
C. Thermal Neutron	5
D. Fast Neutron	10
	20

QUESTION: 017 (1.00)

Which ONE of the following situations would be classified as an UNUSUAL EVENT in accordance with the Emergeny Plan?

a. Sample Spill

b. Bomb Threat (Over telephone)

c. Personal injury with radiological contamination

d. Severe fuel clad leak approaching MCA size, with pool nearly empty and ventilation system inoperative.

QUESTION: 018 (1.00)

In order to maintain an 'active' RO or SRO license, how many hours per quarter must you perform the functions of an RO or SRO?

a. 2

b. 4

c. 8

d. 12

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

QUESTION: 001 (1.00)

If the compensation voltage for a CIC is lost when the reactor is at low power, indicated power will be:

a. unchanged.
b. higher than actual.
c. lower than actual.
d. higher or lower, depending on the exact power level.

QUESTION: 002 (1.00)

When operating in the Pulse mode, four scrams must be available. They are:

a. High Fuel Temperature, Seismic Detection, Short Period, High Flux

b. Short Period, Manual, High Flux, High Fuel Temperature

c. Loss of High Voltage, Manual, High Flux, Transient Rod scram after pulse

d. High Fuel Temperature, Loss of High Voltage, Manual, Transient Rod scram after pulse

QUESTION: 003 (1.00)

Make-up water to the pool is provided through:

a. a manual valve opened by the operator when necessary to restore pool level.

b. a solenoid valve which opens in response to a float switch in the pool.

c. a mixed-bed ion exchanger.

d. a Culligan deionizer and recirculation pump.

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

QUESTION: 004 (2.00)

Refer to Figure 1. When the Ventilation System is operating in the AUTO mode, fill in the correct status of the fans (On, Off) and the dampers (Open, Closed)

Fan Status	Damper Status
F1_____	D1_____
F3_____	D2_____
F4_____	D3_____
	D4_____

QUESTION: 005 (2.00)

Refer to Figure 2. Match the core component in column 2 to the core location in column 1. There is only one component for each location. No component is used more than once, but not all components are used.

Core Location	Core Component
a._____	1. Neutron Source
b._____	2. Log-N Fission Chamber
c _____	3. No. 1 CIC
d._____	4. No. 2 CIC
e._____	5. Blade No. 1
f._____	6. Blade No. 4
	7. Standard Bundle
	8. FLIP Bundle
	9. Rotator Tube

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

QUESTION: 006 (1.00)

The purpose of the Nitrogen-16 diffuser system is to:

a. Increase the heat transfer from the core to the pool at high powers.

b. Decrease the activation rate of Oxygen-16 to Nitrogen-16.

c. Increase the transport time of Nitrogen-16 to the pool surface.

d. Break up gas bubbles of Oxygen-16 to reduce Nitrogen-16 formation.

QUESTION: 007 (1.00)

With reference to the transient control rod, de-energizing the solenoid valve located between the accumulator tank and cylinder will result in the transient rod:

a. dropping into the core.

b. moving to the fully withdrawn position.

c. remaining in its present position (as is).

d. moving to the fully withdrawn position, and then dropping into the core.

QUESTION: 008 (1.00)

The instrumented fuel rods are:

a. located in the peripheral fuel bundles.

b. standard-type rods.

c. three-rod bundles.

d. FLIP-type rods.

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

QUESTION: 009 (1.00)

The equations which describe the operation of the neutron source are:

a. Sb-124 --> Sb-124 + gamma
   gamma + Be-9 --> Be-8 + neutron
b. Pu-239 --> U-235 + alpha
   alpha + Be-9 --> C-12 + neutron
c. Sb-124 --> Sb-124 + beta
   beta + Be-9 --> Li-8 + neutron
d. Pu-239 --> U-235 + beta
   beta + B-10 --> Be-9 + neutron

QUESTION: 010 (1.00)

Match the detector type to the nuclear instrumentation channel. Detector types may be used more than once.

NI Channel	Detector type
a. Safety Channel #1	1. Fission Chamber
b. Linear Channel	2. Compensated Ion Chamber
c. Pulse Power Channel	3. Gamma Chamber
d. Log Power Channel	
e. Safety Channel #2	

QUESTION: 011 (1.00)

The purpose of the "Delay" switch in the rabbit control system is to insert a 10-second delay between the time that:

a. the sample leaves the core and counting begins.

b. irradiation ends and counting begins.

c. irradiation ends and the sample reaches the receiver.

d. the sample is fired out and the receiver ball valve opens.

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

QUESTION: 012 (1.00)

The two inhibits associated with the Wide Range Channel are to prevent:

a. initiation of a pulse above 1 kw, and control rod withdrawal when less than 2 cps.

b. initiation of a pulse above 1 kw, and control rod withdrawal when the period is less than 10 seconds.

c. control rod withdrawal when less than 2 cps, and control rod withdrawal when the period is less than 10 seconds.

d. initiation of a pulse above 2KW, and control rod withdrawal when less than 2 cps.

QUESTION: 013 (1.00)

Prior to discharge to the sanitary sewer, the hot drains are:

a. collected in a sampling tank and then pumped to a retention tank.

b. diluted with potable water and then pumped to a sampling tank.

c. collected in a retention tank and then pumped to a sampling tank.

d. diluted with potable water and then pumped to a retention tank.

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

QUESTION: 014 (1.00)

The quick disconnect pin of a control rod has been inadvertently removed and not replaced. When the operator attempts to raise the rod out of the core, the "blade in" light will:

a. go out, and the position indication will not function normally.

b. go out, and the position indication will function normally.

c. stay on, and the position indication will not function normally.

d. stay on, and the position indication will function normally.

QUESTION: 015 (1.00)

The alarm setpoints for the Reactor Bridge, Sample and Cave Monitors are (respectively):

a. 100, 50, 200 mR/hr

b. 100, 200, 50 mR/hr

c. 200, 50, 100 mR/hr

d. 200, 100, 50 mR/hr

QUESTION: 016 (1.00)

The Argon-41 Monitor has two types of detectors. They are:

a. proportional counter and scintillation detector

b. proportional counter and GM detector

c. scintillation detector and GM detector

d. fission chamber and proportional counter

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

QUESTION: 017 (1.00)

FLIP fuel rods contain:

a. 20% enriched uranium and no burnable poison.

b. 20% enriched uranium and erbium as a burnable poison.

c. 70% enriched uranium and no burnable poison.

d. 70% enriched uranium and erbium as a burnable poison.

QUESTION: 018 (1.00)

Which ONE of the following describes the difference between a moderator and reflector?

a. Reflectors slow down neutrons while moderators decrease core leakage.

b. Reflectors shield against neutrons while moderators decrease core leakage.

c. Reflectors shield against neutrons while moderators slow down neutrons.

d. Reflectors decrease core leakage while moderators slow down neutrons.

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

ANSWER: 001 (1.00)

C. Fission reaction rate = (flux)(macroscopic cross-section)

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 83

ANSWER: 002 (1.00)

B.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Pages 81-83

ANSWER: 003 (1.00)

B.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 137

ANSWER: 004 (1.00)

A.

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

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 74

ANSWER: 005 (1.00)

C.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 7

ANSWER: 006 (1.00)

D.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 123

ANSWER: 007 (1.00)

B.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 6, Page 6-18

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

ANSWER: 008 (1.00)

C.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 30

ANSWER: 009 (1.00)

D.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 124

ANSWER: 010 (1.00)

D.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 37

ANSWER: 011 (1.00)

B.

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

REFERENCE:

WSU Reactor Operator Training Manual, Unit 6, Page 6-15

ANSWER: 012 (1.00)

A.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 6, Page 6-15

ANSWER: 013 (1.00)

B.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 7, Page 6-29

ANSWER: 014 (1.00)

D.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 43

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

ANSWER: 015 (1.00)

B.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 6, Page 6-14

ANSWER: 016 (1.00)

D.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 154

ANSWER: 017 (1.00)

D.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 6, Page 6-21

ANSWER: 018 (1.00)

B.

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

REFERENCE:

WSU Reactor Operator Training Manual, Unit 11

ANSWER: 019 (1.00)

B.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 133

ANSWER: 020 (1.00)

C.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 5, Page 52

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

ANSWFR: 001 (1.00)

C

REFERENCE:

WSU Tech Spe;cs, 1.0 Definitions Sect. 1.1 Reactor Operating Conditions p. 2

ANSWER: 002 (1.00)

D

REFERENCE:

WSU Tech Spec. 5.5, Fuel Storage. p. 26

ANSWER: 003 (1.00)

B

REFERENCE:

WSU Tech Spec 2.1 Fuel Element Temperature p.6

ANSWER: 004 (1.00)

C

REFERENCE:

WSU Technical Specifications 6.2

ANSWER: 005 (1.00)

A

REFERENCE:

SAR

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

ANSWER: 006 (1.00)

B or C

REFERENCE:

10 CFR 20

ANSWER: 007 (1.00)

C or D

REFERENCE:

10 CFR 20.101

ANSWER: 008 (1.00)

D

REFERENCE:

SOP # 33, APPENDIX pp. 4 & 5

ANSWER: 009 (1.00)

C

REFERENCE:

Equation Sheet

ANSWER: 010 (1.00)

B

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

REFERENCE:

Equation Sheet

ANSWER: 011 (1.00)

~~D~~ Deleted

REFERENCE:

SAR Section 9.3.5

ANSWER: 012 (1.00)

~~B~~ Deleted

REFERENCE:

ANSWER: 013 (1.00)

D or E

REFERENCE:

Standard Operating Procedures

ANSWER: 014 (1.00)

B

REFERENCE:

WSU Admin Procedures Section 8

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

ANSWER: 015 (1.00)

D Deleted

REFERENCE:

WSU SOP #4

ANSWER: 016 (2.00)

A,1; B,20; C,5; D,10

REFERENCE:

WSU RO Training Manual Unit 10.

ANSWER: 017 (1.00)

B

REFERENCE:

WSU NRC Emergeny Plan & Implementing Procedures Sect 4.3 p. 19

ANSWER: 018 (1.00)

B

REFERENCE:

10 CFR 55.53

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

ANSWER: 001 (1.00)

B.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 8

ANSWER: 002 (1.00)

D.

REFERENCE:

WSU SAR, Page 4-25

ANSWER: 003 (1.00)

B.

REFERENCE:

WSU SAR, Page 4-30

ANSWER: 004 (2.00)

F1,ON; F3,OFF; F4,ON; D1,OPEN; D2,CLOSED; D3,CLOSED; D4,OPEN

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

REFERENCE:

WSU Reactor Operator Training Manual, Unit 11

ANSWER: 005 (2.00)

A,6; B,2; C,5; D,3; E,4; F,1

REFERENCE:

WSU Reactor Operator Training Manual, Unit 11

ANSWER: 006 (1.00)

C.

REFERENCE:

WSU SAR, Page 4-35

ANSWER: 007 (1.00)

A.

REFERENCE:

WSU SAR, Page 4-19

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

ANSWER: 008 (1 JO)

D.

REFERENCE:

WSU Reactor Operator Training Manual, Unit 11

ANSWER: 009 (1.00)

A.

REFERENCE:

WSU Operator Training Training Manual, Unit 11

ANSWER: 010 (1.00)

A,1; B,2; C,3; D,1; E,2

REFERENCE:

WSU SAR, Pages 4-26 to 4-29

ANSWER: 011 (1.00)

A.

REFERENCE:

WSU Standard Procedure 2

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

ANSWER: 012 (1.00)

A.

REFERENCE:

WSU SAR, Page 4-29

ANSWER: 013 (1.00)

C.

REFERENCE:

WSU SAR, Page 3-9

ANSWER: 014 (1.00)

B C

REFERENCE:

WSU Reactor Operator Training Manual, Unit 11

ANSWER: 015 (1.00)

D.

REFERENCE:

WSU Special Procedure 17

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

ANSWER: 016 (1.00)

~~A.~~ Deleted

REFERENCE:

WSU Special Procedure 18

ANSWER: 017 (1.00)

D.

REFERENCE:

WSU Safety Analysis for Conversion to FLIP Fuel

ANSWER: 018 (1.00)

D.

REFERENCE:

WSU Reactor Operator Training Manual, Glossary

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

ANSWER KEY

001 C
002 B
003 B
004 A
005 C
006 D
007 B
008 C
009 D
010 D
011 B
012 A
013 B
014 D
015 B
016 D
017 D
018 B
019 B
020 C

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

ANSWER KEY

MULTIPLE CHOICE

001 C

002 D

003 B

004 C

005 A

006 B or C

007 C or D

008 D

009 C

010 B

011 ~~B~~ DELETED

012 ~~B~~ DELETED

013 D or B

014 B

015 ~~D or B~~ DELETED

016 A,1 B,20 C,5 D,10 (0.5 each)

017 B

018 B

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

ANSWER KEY

001	B					
002	D					
003	B					
004	F1-ON	F3-OFF	F4-ON (0.33 each)			
	D1-Open	D2-Closed	D3-Closed	D4-Open (0.25 each)		
005	A,6	B,2	C,5	D,3	E,4	F,1 (0.333 each)
006	C					
007	A					
008	D					
009	A					
010	A,1	B,2	C,3	D,1	E,2 (0.2 each)	
011	A					
012	A					
013	C					
014	~~B~~ B					
015	D					
016	~~A~~ DELETED					
017	D					
018	D					

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

EQUATION SHEET

$\dot{Q} = \dot{m}\, c_p\, \Delta T$

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

$\dot{Q} = UA\, \Delta T$

$$SUR = \frac{26.06\ (\lambda_{eff}\rho)}{(\beta - \rho)}$$

$SUR = 26.06/\tau$

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

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

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

$\tau = (\ell^*/\rho) + [(\bar{\beta}-\rho)/\lambda_{eff}\rho]$

$\rho = (Keff-1)/Keff$

$\rho = \Delta Keff/Keff$

$\bar{\beta} = 0.0077$

$DR_1D_1^2 = DR_2D_2^2$

$$DR = \frac{6\ Ci\ E}{R^2}$$

$$\text{Cycle Efficiency} = \frac{\text{Net Work (out)}}{\text{Energy (in)}}$$

$SCR = S/(1-Keff)$

$CR_1\ (1-Keff)_1 = CR_2\ (1-Keff)_2$

$$M = \frac{(1-Keff)_0}{(1-Keff)_1}$$

$M = 1/(1-Keff) = CR_1/CR_0$

$SDM = (1-Keff)/Keff$

$Pwr = W_f\, \dot{m}$

$\ell^* = 1 \times 10^{-5}$ seconds

$\tau = \ell^*/(\rho-\bar{\beta})$

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

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

$DR = DR_oe^{-\lambda t}$

---

1 Curie = 3.7×10^{10} dps

1 hp = 2.54×10^3 BTU/hr

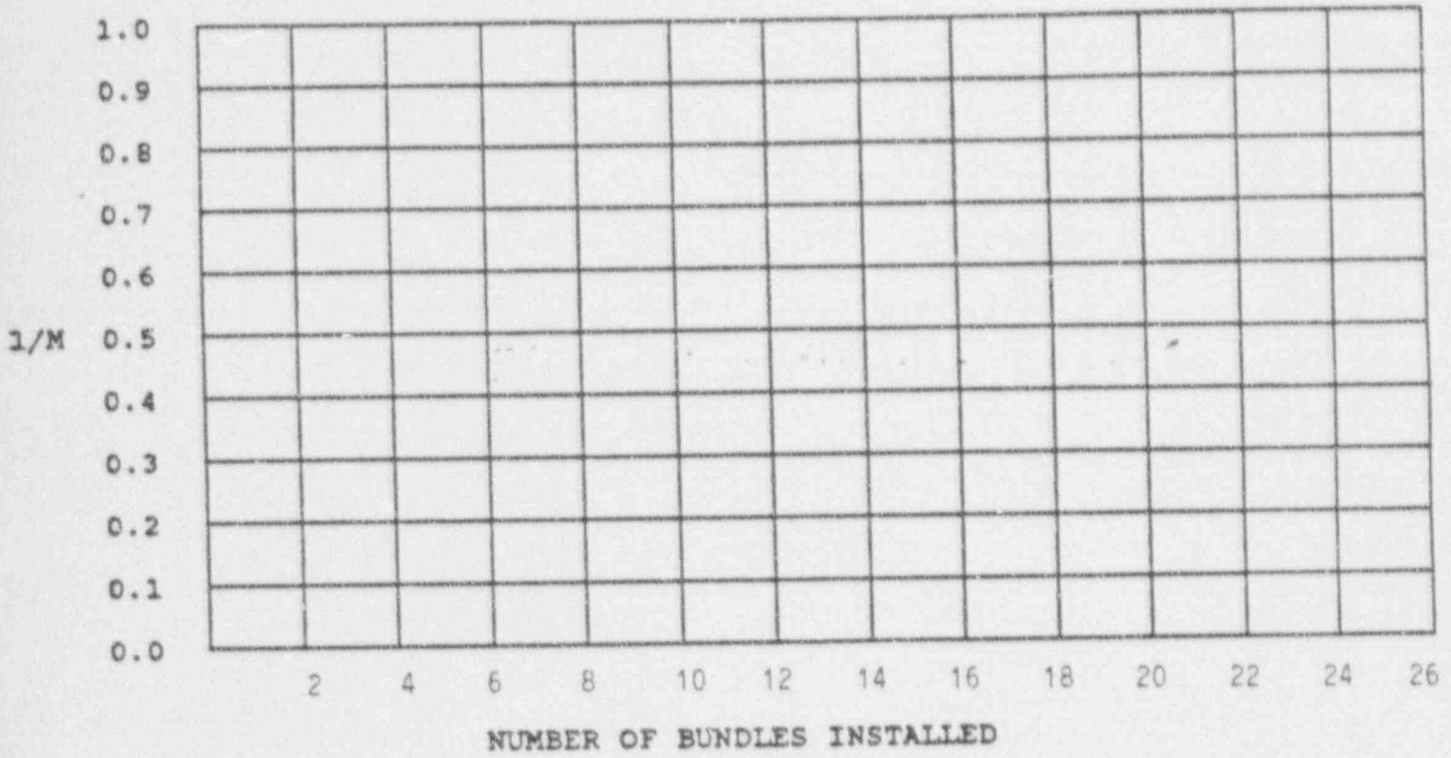
1 BTU = 778 ft-lbf

1 kg = 2.21 lbm

1 Mw = 3.41×10^6 BTU/hr

°F = 9/5°C + 32

°C = 5/9 (°F - 32)


1.0
0.9
0.8
0.7
0.6
1/M 0.5
0.4
0.3
0.2
0.1
0.0
2 4 6 8 10 12 14 16 18 20 22 24 26
NUMBER OF BUNDLES INSTALLED

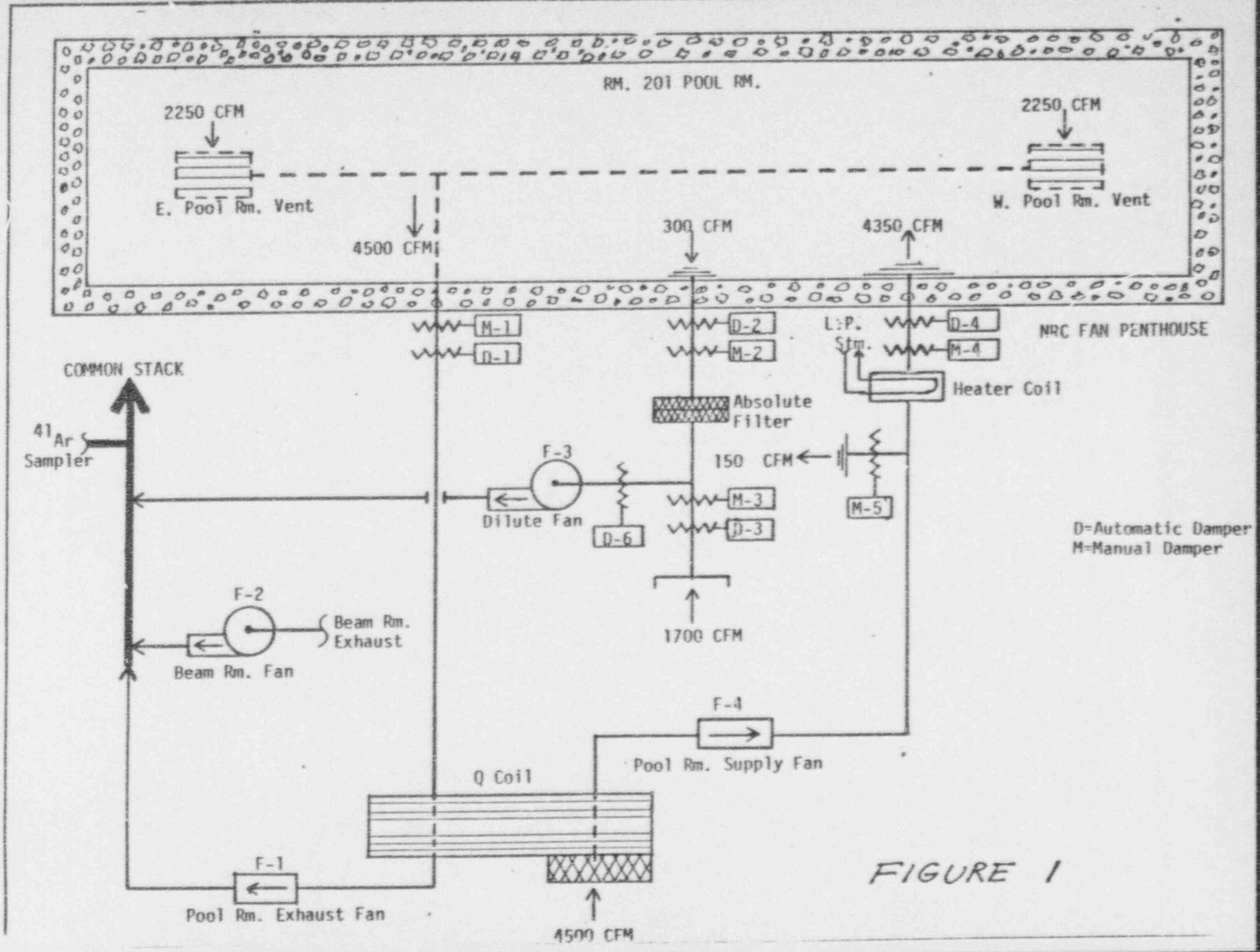

RM. 201 POOL RM.
2250 CFM
E. Pool Rm. Vent
2250 CFM
W. Pool Rm. Vent
4500 CFM
300 CFM
4350 CFM
M-1
D-1
D-2
M-2
L.P. Stm.
D-4
M-4
NRC FAN PENTHOUSE
Heater Coil
COMMON STACK
41Ar Sampler
Absolute Filter
F-3
150 CFM
M-5
Dilute Fan
D-6
M-3
D-3
D=Automatic Damper
M=Manual Damper
1700 CFM
F-2
Beam Rm. Exhaust
Beam Rm. Fan
F-4
Pool Rm. Supply Fan
Q Coil
F-1
Pool Rm. Exhaust Fan
4500 CFM

FIGURE 1

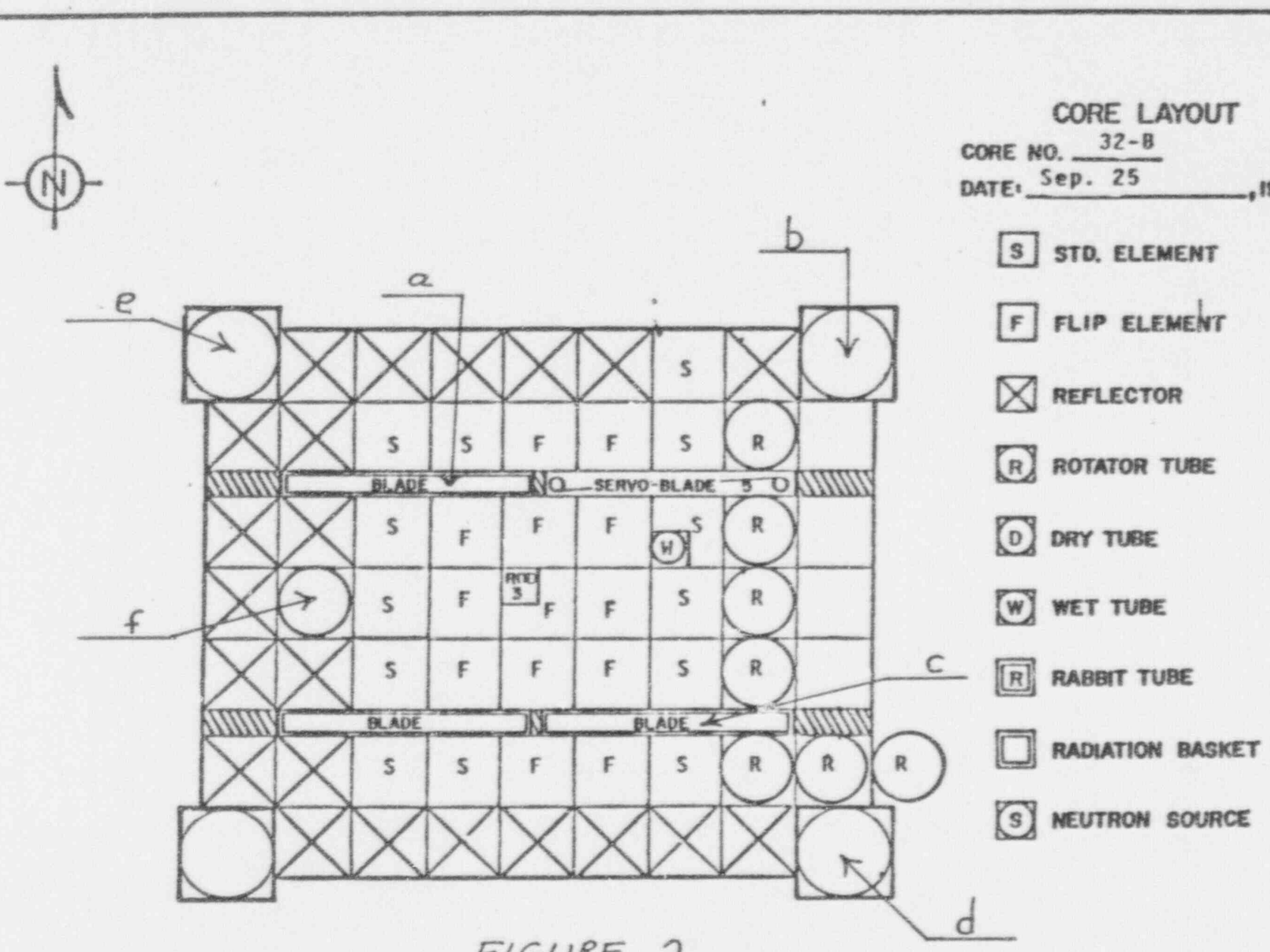

CORE LAYOUT
CORE NO. 32-B
DATE: Sep. 25 ,19 91
S STD. ELEMENT
F FLIP ELEMENT
REFLECTOR
R ROTATOR TUBE
D DRY TUBE
W WET TUBE
R RABBIT TUBE
RADIATION BASKET
S NEUTRON SOURCE
a
b
c
d
e
f
BLADE
SERVO-BLADE 3
BLADE
BLADE
N

FIGURE 2

EQUATION SHEET

$\dot{Q} = \dot{m}\, c_p\, \Delta T$

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

$\dot{Q} = UA\, \Delta T$

$SUR = 26.06/\tau$

$SUR = \dfrac{26.06\,(\lambda_{eff}\,\rho)}{(\beta - \rho)}$

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

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

$\tau = (\ell^*/\rho) + [(\bar{\beta} - \rho)/\lambda_{eff}\rho]$

$\rho = (K_{eff} - 1)/K_{eff}$

$\rho = \Delta K_{eff}/K_{eff}$

Cycle Efficiency $= \dfrac{\text{Net Work (out)}}{\text{Energy (in)}}$

$SCR = S/(1 - K_{eff})$

$CR_1\,(1 - K_{eff})_1 = CR_2\,(1 - K_{eff})_2$

$M = 1/(1 - K_{eff}) = CR_1/CR_0$

$M = \dfrac{(1 - K_{eff})_0}{(1 - K_{eff})_1}$

$SDM = (1 - K_{eff})/K_{eff}$

$Pwr = W_f\, \dot{m}$

$\tau = \ell^*/(\rho - \bar{\beta})$

$\ell^* = 1 \times 10^{-5}$ seconds

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

$$\nu(P_e - P_i) + 1/2\,(v_e^2 - v_i^2) + g(z_e - z_i) = 0$$

---

1 Curie $= 3.7 \times 10^{10}$ dps
1 hp $= 2.54 \times 10^3$ BTU/hr
1 BTU $= 778$ ft-lbf
°C $= 5/9$ (°F - 32)

1 kg $= 2.21$ lbm
1 Mw $= 3.41 \times 10^6$ BTU/hr
°F $= 9/5$ °C + 32