ORNL-TM-2034 (Rev.

Vol. V

REACTOR OPERATOR STUDY HANDBOOK

(Programmed Instruction Version)

VOLUME V

INSTRUMENTATION AND CONTROLS

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

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Operations Division

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(Programmed Instruction Version)

VOLUME V - INSTRUMENTATION AND CONTROLS

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FOREWORD

This programmed text is recommended as an aid in the study of reactor technology. It is not the intent of the authors and editors that the text be considered a finished product. While field testing of both the subject matter and the continuity of thought has been limited, the need for study material in programmed form was a basic consideration in the decision to publish the text. Revisions may be made at any time to correct errors, to expand the subject matter coverage, or to update the reactor technology. If the text is used with these reservations, and in conjunction with other study helps, it can be the basis for very rewarding individual study on the part of the student.

CONTENTS

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INTRODUCTION

As a part of the reactor operator training program of Operations Division, Oak Ridge National Laboratory, five areas of instruction have been programmed for individual study. They are:

- Volume I - Elementary Mathematics Review
- Volume II - Radiation Safety and Control
- Volume III - Reactor Physics
- Volume IV - Heat Theory and Fluid Flow
- Volume V - Instrumentation and Controls

These programmed studies are a part of a course in reactor operation that includes classwork, lectures, and on-the-job training. At the end of the course, the operator trainee is tested for competence in all areas of reactor operations before being certified to operate a particular reactor.

It is suggested that the programs be studied in the sequence given above; however, sequential dependence has been minimized so that they may be studied either individually or as an integrated group.

This version of Volume V of the programmed version of the Operations Division's reactor operator study handbook is based upon the original version authored by R. A. Costner, Jr., E. N. Cramer, and R. L. Scott, Jr., and retains much of the original material.

INSTRUCTIONS

The material contained in this manual has been prepared using a technique called "programmed instruction". This technique of instruction consists of:

1. Presenting ideas of information in small, easily digestible steps called "frames".
2. Allowing you to set your own pace.
3. Encouraging response in an active way so that you have a strong impression of the idea presented.
4. Letting you know immediately if your answer is correct, thus reinforcing your impression.
5. Presenting many clues at first to help you arrive at the correct answer. (As you progress, the number of clues is reduced.)

A few sample frames are found on the next page. These will be used to illustrate the proper use of "programmed instruction". Most frames will require you to respond by filling in a blank, or blanks, to complete a sentence. Other frames will give you a choice of several responses. Some frames are for informational purposes only and require no response. The correct response to a given frame is always found on the right side of the page adjacent to the following frame. When reading a frame, a sheet (or strip) of paper should be used to cover the area below the dotted line which follows the frame. After completely reading a frame, you should write your response on a piece of paper. Next, move the paper down the page until you reach the next dotted line or turn the page. This will uncover the next frame and the correct response for the frame you have just completed. Compare your response with the correct response. If they do not match, read that frame again before moving on to the next one; <u>do not proceed</u> until you understand the information in the frame you are reading. If the responses do match, proceed to the frame you have just uncovered.

At the end of each section, there are self-test questions for review. If you miss one of the self-test questions, repeat the pertinent frames. It is not enough to respond correctly as you proceed through the material; you must remember correctly at the end of the program and even later. You should attempt to complete each section once you have started.

Sample Frames

i. Programmed instruction is a method of presenting information in short paragraphs called "frames". These _____ usually contain only one or two concepts for the student to grasp.

- - - - - - -

ii. By requiring you to think of the appropriate response and to write that _____ on a piece of paper, you take an active part in the program, and thereby reinforce your learning.

frames

- - - - - - -

iii. This method of instruction, called _____ _____, allows you to proceed with the material at a rate which you determine for yourself.

response

- - - - - - -

iv. Programmed instruction provides the appropriate response immediately and thus should reinforce the student's _____.

programmed instruction

- - - - - - -

learning

SECTION V

V-1. PRINCIPLES OF ELECTRICITY

The purpose of this section is to present principles of electricity and electrical circuits which are basic to all instrument and control circuits. Most people would agree that very little knowledge of electricity is necessary in order to use it, just as very little knowledge of the machinery of a car is necessary in order to drive it. However, we believe that most of you will agree that some knowledge of the machinery of an automobile can help you to understand what a car can and cannot do under various conditions, making you a better driver. And since electrical instruments, motors, controls, etc., are so important to the safe operation of a reactor, we believe that some knowledge of electricity can help make the difference between a person's being a reactor "operator" and being just a "button pusher".

- - - - - - -

Electricity is a form of energy. This means it has the capacity to exert a force and cause something to move. This capacity to exert a force and cause motion has been defined as work.

- - - - - - -

1. Electricity, as a form of energy, has the capacity to do _____.

- - - - - - -

2. When work is done, a force has been exerted on some matter; and as a result of that force, the matter is made to _____. work

- - - - - - -

1.1. Fundamentals

1.1a. Current, Potential, and Resistance

3. The electrical charges of elementary particles are of two kinds. We call them negative and positive for convenience. The commonly known particles of which all matter is made are protons (charged positively), electrons (charged negatively), and neutrons which have no charge. — move

\- - - - - - -

4. Protons are particles which are charged _____ and electrons are _____ charged particles.

\- - - - - - -

5. The electrical energy from the motion of the small particles which we call electrons causes lamps to light, motors to turn, ranges to produce heat, and TV sets to operate. — positively, negatively

\- - - - - - -

6. The motion or movement of electrons produces _____ energy.

\- - - - - - -

7. Metals have relatively large numbers of "free" electrons which are in continuous random motion. The protons, on the other hand, are not free to move since they are part of the tightly bound-together nuclei of the atoms. What is meant when speaking of electric currents in conductors is the drift of the free _____ one way or the other along the conductor. — electrical

\- - - - - - -

8. That material along which the free electrons drift is called a _____. — electrons

- - - - - - -

9. The movement of many free _____ along a wire is called an electric current. This is analogous to many drops of water flowing in a pipe, which we call a _____ of water. — conductor

- - - - - - -

10. In one typical research reactor the coolant flow through the reactor vessel is 18,000 gal/min. Water is moving past a point at the rate of 18,000 gal/min. This is a measure of the coolant _____. — electrons, current

- - - - - - -

11. Electron flow is measured in a similar way. When 6.25×10^{18} electrons move past a point each second, by definition there is one ampere of current flowing past that point. This quantity of electrons is given a name for convenience. The name "coulomb", like that of many units of electrical measurements, was given to honor one of the pioneers in the field. "Ampere" was the name of another of these pioneers. When a coulomb of electricity or charge moves past a point in a conductor each second, there is an _____ of current flowing. — current or flow

- - - - - - -

12. The unit commonly used for measuring electric current is the _____. — ampere

- - - - - - -

13. If only half of a _____ of charge moves past a point in one second, the current is only half an ampere. The ampere is commonly abbreviated amp or a. So, in the above case, we would write the answer 0.5 amp. When written on an electrical diagram, it probably would be written 0.5 a.

ampere

\- - - - - - -

14. The ampere is a convenient unit for measuring the electric currents required to operate household appliances but is, however, much too large for measuring the currents found frequently in reactor and other instrumentation or in such things as the familiar transistor radio receivers. For these cases the ampere is divided by 1000 to give a unit called a milliampere (ma) or by 1,000,000 to give a microampere (μa). The symbol "μ" is a Greek letter pronounced Mu and here signifies one one-millionth or $1/10^6$ or 10^{-6}.

coulomb

\- - - - - - -

15. If the current in your transistor radio is only 0.065 ampere, you would call it a current of 65 _____.

\- - - - - - -

16. A current of 0.000015 ampere would commonly be written 15 μa and would be read 15 _____.

milliamperes or ma

\- - - - - - -

17. Until now we have discussed only the movement of charges and have called the movement electric _____. We have also said that the unit used to measure electric current is the _____.

microamperes

\- - - - - - -

18. Early studies of electricity began with the study of charged bodies. It was called "static" electricity because when certain things like amber or glass rods were "electrified" (charged) by rubbing them with another material the charges remained pretty well in one place. They were static.

current, ampere

\- - - - - - -

19. Early experimenters found that the materials which were good insulators were the materials which could be charged. A material which has few "free" electrons (is not a conductor) may be _____ by rubbing with a suitable material.

\- - - - - - -

20. When a hard rubber rod is rubbed with wool, one charge is produced on the rubber and the opposite charge is produced on the wool. Free _____ are rubbed off one material and accumulate on the other. Thus, if the rubber gains electrons, it is said to have a negative charge.

charged

\- - - - - - -

21. The piece of wool which is used to rub the rubber rod loses some electrons and is said to have a _____ charge.

electrons

\- - - - - - -

22. Since in an _____ it is very difficult for charges to move, the charge on the rubber rod remains for some time and is called a static charge.

positive

\- - - - - - -

23. The charge that is built up on a comb when you comb your hair is called a _____ charge because it remains on the comb for some time. — insulator

- - - - - - -

24. A gain of electrons produces a _____ charge. A loss of electrons produces a _____ charge. — static

- - - - - - -

25. There is a device in which electric charges may be stored. It is called a capacitor or a condenser. — negative, positive

- - - - - - -

> The term condenser originated from the erroneous idea that electricity was a fluid which could be stored in a suitable container. An early capacitor was the Leyden jar which consists of a glass jar coated part way up the inside and outside with metal foil. Charging the jar was done by connecting an "electric machine" (charge generator) across the two foils. Electrons were displaced from one foil or "plate" of the capacitor to the other.

- - - - - - -

26. The charging of a capacitor results in a static charge of one type on one plate and the opposite type on the other plate. The charge on a capacitor is stationary or _____ until a discharge path is arranged between the plates.

- - - - - - -

27. If a conductor is connected between the plates of a charged capacitor, a current will flow in it. The current is due to the "difference in potential" between the capacitor's plates due to the static charge thereon. The difference in potential is measured in "volts" (v), a name given to honor the pioneer Italian physicist Alessandro Volta. static

\- - - - - - -

28. "Difference in potential" or simply "potential difference" is a measure of the difference in the number of free electrons in two locations. This potential difference is measured in _____.

\- - - - - - -

29. Lightning often results when very strong electrical charges build up on clouds, producing a potential difference (voltage) between the clouds or between the earth and clouds of thousands of volts. This static condition remains just like that of the rubber rod and wool until something happens to "ionize" (see Section 1.1h) the air. Then there is a strong current between the clouds or the cloud and the earth that we call a lightning flash. As soon as the cloud-to-cloud or cloud-to-earth potential difference becomes low enough the current stops and the charge starts building up again. volts

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30. Early experiments in which capacitors were discharged were man's first experiences with what we now call current electricity.

\- - - - - - -

In this text, only electron current will be considered. In early work with electricity, it was arbitrarily decided that "current" flowed from the positive pole to the negative pole; and then an arbitrary naming of the positive and negative poles was done. Later it was proved that the choice of poles was wrong and that the electron current flows from the negative to the positive pole. Students have had to learn to say that current flows from positive to negative, although they know that it does not. Since electron flow must be considered in developing an understanding of electrical phenomena in radiation, only electron flow will be taught. Hopefully, this approach will assist the student in gaining a quicker analytical understanding of ionization chambers and their currents. We shall use the terms "electron current" and "electric current" interchangeably, but the student should remember that we always mean electron current.

- - - - - - -

31. When chemical cells and batteries of such cells were developed, the study of current electricity grew in importance. The current produced by batteries is called direct current because the charge movement or electron current is always in one direction.

- - - - - - -

32. An electric current that flows in only one direction through a conductor (not back and forth) is called _____ current.

- - - - - - -

33. By the way, perhaps we should explain the terms cell and battery. When two conductors made of different materials are immersed in the same electrolyte (a certain class of chemical solution), chemical action will build up a supply of electrons on one conductor and create a deficiency of electrons on the other. Thus, a difference of potential is produced between the two conductors.   direct

\- - - - - - -

This is the sort of system that produces electrolytic corrosion.

\- - - - - - -

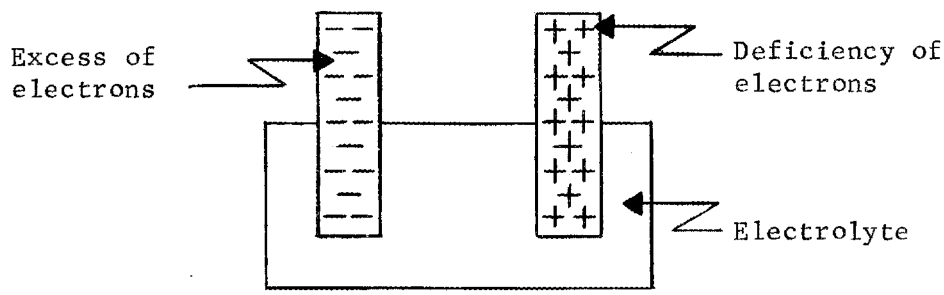

Fig. V-1. An Electrical Cell

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34. The system made up of the two different conductors and the electrolyte is called an electrical cell. In an ordinary flashlight cell, one conductor is carbon, the other is zinc, and the electrolyte is ammonium chloride. The chemical action produces excess electrons on the zinc so it becomes the _____ pole of the cell.

\- - - - - - -

35. At this point we might introduce the word electrode. We have been discussing poles of a cell, and for cells the word "pole" is accepted. However, a more universally accepted word is "electrode", which means either terminal of an electric source or either conductor by which a current enters or leaves an electrolyte. — negative

\- - - - - - -

36. Although we shall continue to use the word pole when we discuss cells or batteries, remember that a terminal through which current is introduced into another system is often called an _____.

\- - - - - - -

37. The chemical action in a cell also produces a deficiency of electrons on the carbon center rod, and it becomes the _____ pole (also called an _____) of the cell. — electrode

\- - - - - - -

38. When the term "cell is used correctly, it means one chemical system consisting of two different conductors and an electrolyte. Each _____ of your car battery is made up of lead plates, lead dioxide plates, and dilute sulfuric acid for the electrolyte. — positive, electrode

\- - - - - - -

39. A battery is a group of cells connected either in "series" (positive pole of one cell to negative pole of next cell) or in "parallel" (all positive poles together and all negative poles together). — cell

\- - - - - - -

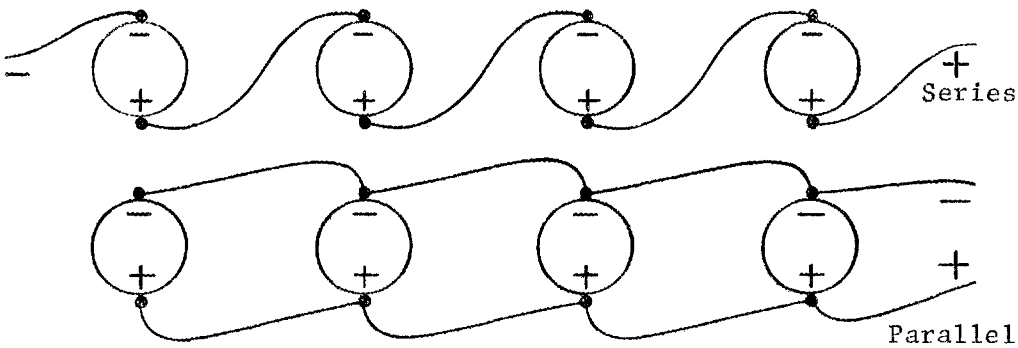

Fig. V-2. Cells Wired in "Series" and in "Parallel"

- - - - - - -

40. For example, if you have a two-cell flashlight, you place two cells end to end such that the center pin (positive pole) of one cell contacts the smooth end (negative pole) of the next cell. Thus, you have two cells "wired" in ______, making a two-cell _____.

- - - - - - -

41. When cells are wired in series, the total voltage is the sum of voltages of the cells. If your car uses a 12-volt electrical system, six 2-volt cells are wired in series to make a 12-volt _____ for the system. — series, battery

- - - - - - -

42. The total voltage of cells wired in parallel remains the same as the voltage of one cell; but the total current available is more because, in effect, you have both a larger positive electrode and a larger negative electrode. The total effect is to make a low-voltage battery that will last a longer time. — battery

- - - - - - -

43. When a conductor is connected between the terminals (electrodes) of a battery, as in Figure V-3, electrons are repelled from the negative pole and are attracted to the _____ pole. Since this electron movement is always in one direction, it is called _____ current. The ammeter (Figure V-3) is a current-measuring instrument.

— — — — — — —

44. Figure V-3 illustrates a simple electrical "circuit", the path along which electrons flow from the negative pole of an electrical source to the positive. In a practical system, the circuit must generally contain more components to limit the amount of current and to convert the energy to useful work.

positive, direct

— — — — — — —

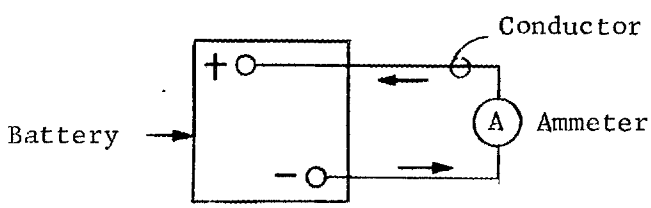

Fig. V-3. Direction of Electron Flow in a Battery-Powered Circuit

— — — — — — —

45. If the conductor is disconnected from either battery terminal, the current stops flowing through the _____ because for all practical purposes there are no _____ _____ in air to carry the current as there are in the conductor.

— — — — — — —

46.	An instrument which measures an electric current is called an _____. One which measures potential difference or voltage is called a voltmeter.	circuit, free electrons

- - - - - - -

47.	An electron current in a wire is the movement of electrons from the more _____ end of the wire to the more _____ end of the wire. This movement is caused by the _____ _____ between the ends of the wire.	ammeter

- - - - - - -

48.	We have described the driving force on electrical charges and said that it is the result of a difference in potential between two points. This potential difference is measured in _____.	negative, positive, potential difference

- - - - - - -

49.	We have also described electron or electric current, which we measure in terms of a unit called the _____.	volts

- - - - - - -

50.	We said, too, that a current of 0.0005 ampere could also be written 0.5 ma and read 0.5 _____ or written 500 μa and read 500 _____.	ampere

- - - - - - -

51.	Even the best commonly used conductors are not perfect; as electrons move through a wire, they encounter an opposition that is called resistance. The unit used in measuring this resistance is the ohm.	milliampere, microamperes

- - - - - - -

52. On electrical diagrams the Greek letter omega, Ω, is used as a symbol for the ohm. A resistance may be labeled 500 Ω and is read 500 _____.

- - - - - - -

53. Electrical resistance is influenced by a number of ohms
things. The resistance of a wire varies with length, temperature, diameter, and the material of which it is made.

- - - - - - -

54. Since the resistance of materials varies widely, we quite often separate all matter into two groups: good conductors (meaning they have low resistance) and poor conductors (meaning they have high resistance).

- - - - - - -

55. A good conductor is a material which offers little opposition to electric current. Thus it has (low, high) resistance.

- - - - - - -

56. Thus, while 1000 ft of No. 10 iron wire has a low
resistance of about 6 ohms, it would take about six times that length of No. 10 copper wire to have the same resistance. The resistance of 1000 ft of No. 10 copper wire is about _____ ohm.

- - - - - - -

57. A poor conductor is one which allows very little electrical current to flow through it. Such a material could be used as a resistor, a device placed in a current path to (increase, retard) the movement of electrons. — one

- - - - - - -

58. Copper is a good conductor and nichrome is, comparatively, a poor conductor. Nichrome wire would be (good, poor) to use as a resistor, and it would be (good, poor) to use to wire a house. — retard

- - - - - - -

59. Some materials conduct so little electricity that they cannot be used as conductors at all. These offer more opposition to electric current than most resistors, and we call them insulators. — good, poor

- - - - - - -

60. Materials like rubber, ceramics, glass, air, and dry wood are extremely poor conductors so they are good _____.

- - - - - - -

61. Most metals are relatively good conductors. Of these, silver is the best conductor, copper next, then gold, and then aluminum. Since silver and gold are much more expensive than copper or aluminum, these last two are most commonly used as _____. — insulators

- - - - - - -

62. Water which has only traces of dissolved solids is a poor conductor. Sea water, which has large amounts of dissolved solids, is a good conductor. Potable water is normally a relatively poor conductor. Demineralized water, then would probably be a very poor (conductor, insulator). — conductors

- - - - - - -

63. If demineralized water is a good insulating material, a resistance measurement of this water should show a (high, low) reading. A meter that would measure its ability to conduct electricity would show a _____ reading. — conductor

- - - - - - -

64. At some demineralizer installations, the water's current-conducting capacity is read with a meter that reads low numbers if the water resistance is high. The meter actually measures the ability of the water to _____ electricity. If the ability to conduct an electric current is low, the water resistance is _____. — high, low

- - - - - - -

65. So, a material that conducts electricity easily is a (good, poor) resistor, while pure water, which conducts very little electric current, would have (high, low) resistance. — conduct, high

- - - - - - -

1.1b. Power in DC Circuits

66. The unit of electric power is the "watt". It is a unit of measure of the amount of power supplied to an electric circuit. (A kilowatt is 1,000 watts.) Mathematically, the watts of power consumed in an electric circuit are equal to the product of the current in the circuit in amperes and the potential difference across the circuit in volts; W = I x E. — poor, high

\- - - - - - -

Voltage is sometimes called "electromotive force" since it is the force which drives an electric current. The symbol for electromotive force is "E". You will find that in mathematical formulae V and E may be used interchangeably to mean "volts" or "electromotive force". Also, "electromotive force" is written "emf".

\- - - - - - -

67. Electrical energy used divided by the time during which it is expended equals electrical power which may be measured in _____.

\- - - - - - -

68. A motor that draws or passes 5 amps when connected to a 120-v line is a 600-watt motor. If the motor is run for 10 seconds, it uses 6000 watt·sec of electrical energy. — watts

\- - - - - - -

69. Power = energy/time or, written another way, power x time = _____.

\- - - - - - -

70. So: watts x seconds = energy used, and kilowatts x hours = _____ used. If a 100-watt light bulb burns for 10 hours, you pay for 100 x 10 = 1000 watt hours or 1 kwh of electrical _____. — energy

- - - - - - -

71. The rate at which energy is used is a measure of power. Electrical power is usually measured in _____. — energy, energy

- - - - - - -

1.1c. Ohm's Law

72. In an electric circuit there is a fixed relationship between the current and resistance in the circuit and the potential difference across it. This relationship is called Ohm's law. The law may be stated thus: One ampere of current flows whenever there is one volt of potential difference across one ohm of resistance. Ohm's law may be expressed in equation form as $I = V/R$. — watts

- - - - - - -

73. In the above equation, I is the intensity or amount of current, measured in _____; V is potential difference, measured in _____; and R is resistance, measured in _____.

- - - - - - -

74. We can calculate the amperes of current in a circuit if we know the volts across the circuit and the _____ of the circuit. — amperes, volts, ohms

- - - - - - -

75. Figure V-4 shows a number of common symbols used in drawing electrical circuit diagrams. In the following frames, these symbols will be used in drawings to represent the components of circuits discussed. resistance

\- - - - - - -

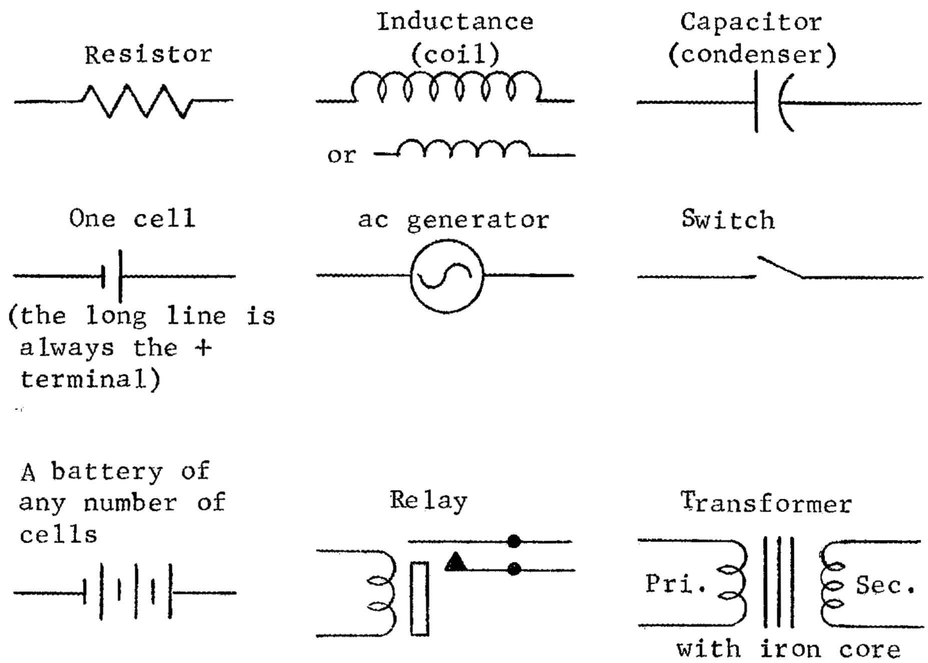

Fig. V-4. Common Electrical Symbols

\- - - - - - -

76. As was pointed out earlier, the term "circuit" is used to identify the path along which electric charges move from one pole to another of a battery, generator, or utility outlet, as shown below.

\- - - - - - -

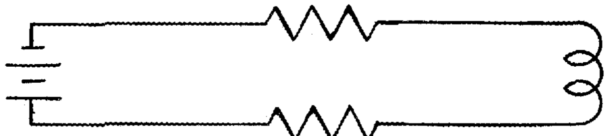

Fig. V-5. A Simple Electric Circuit

- - - - - - -

77. In the above-illustrated circuit, the two resistors and coil are commonly called the "load". This load, with the battery and connecting wires, is an electric _____. The load may make some practical use of the electron flow and it also limits the electron flow rate so that the battery and the conductors are not damaged.

- - - - - - -

78. A circuit may have a load which is only one item such as a lamp, motor, heater, coil resistor, etc.; or the load may consist of several items. — circuit

- - - - - - -

79. Regardless of how many components make up the load, the electron path from one pole of the voltage source through the load to the other pole of the voltage source is called the electric _____.

- - - - - - -

80. If an electric toaster is used on a 120-volt electric line and has a resistance of 20 ohms, how many amperes of current will flow through it? Using Ohm's Law, I = 120/20 = _____. — circuit

- - - - - - -

81. The filament of a light bulb that allows 0.5 amp to flow when used on a 120-volt line has a resistance of 240 _____.

6 amperes

- - - - - - -

82. If we did not know the value of R, we could calculate it as follows:

I = 0.5 amp

V = 120 volts

Ohm's Law is: I = V/R; or, it can be written:

R = V/I

so that R = _____ volts ÷ _____ amp = _____ ohms.

ohms

- - - - - - -

83. There is a similar equation to relate watts, amperes, and volts: watts = amperes x volts

W = I x V

120, 0.5, 240

- - - - - - -

84. Watts are calculated as the product of _____ times _____. However, if you wanted to calculate amperes, the equation would become: amperes = watts/_____.

- - - - - - -

85. For example, the lamp mentioned in Frame 81 that allows a current of 0.5 a to flow when used on a 120-volt line would have a wattage rating of _____ watts.

amperes (or volts), volts (or amperes), volts

- - - - - - -

86. A lamp rated at 150 watts when used on a 120-volt line would have a current through it of _____ amps.

60 (0.5 a x 120 v = 60 w)

- - - - - - -

87. In Part a of Figure V-6, there is a potential difference between the poles that is measured in _____. We would call it an open circuit voltage. There is no current because the two poles are not connected by a suitable conductor. Air is a very (poor, good) conductor. In fact, air would be considered a good _____.

1.25
$\left(\frac{150 \text{ w}}{120 \text{ v}} = 1.25 \text{ a}\right)$

– – – – – – –

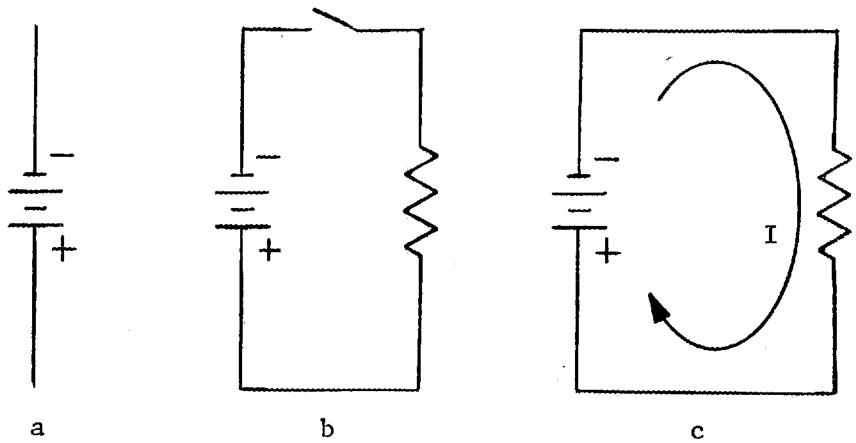

Fig. V-6. Open and Closed Circuits

– – – – – – –

88. In Part b of Figure V-6, there is still no current because the air gap in the open switch is a good _____.

volts,
poor,
insulator

– – – – – – –

89. However, when we close the switch, electrons begin to move from the _____ pole to the _____ pole through the conductor and resistance in the direction shown by the curved arrow in Part c of Figure V-6.

insulator

– – – – – – –

90. This movement of electrons constitutes a current. According to Ohm's Law, the amount of current depends on the potential difference, measured in _____, and the amount of opposition, measured in _____.

negative
positive

\- - - - - - -

91. If the battery supplies 20 volts of potential difference and the resistance is 10 ohms, the current can be calculated by _____ Law.

$I = V/R$

$I = 20\ V/10\ \Omega = 2$ _____

volts,
ohms

\- - - - - - -

92. Remove the 10-Ω resistance and replace it with a 5-Ω resistance. If the opposition becomes less and the voltage remains the same, the current will (increase, decrease, remain the same).

Ohm's,
amps

\- - - - - - -

93. By Ohm's Law $I = 20\ V/5\ \Omega = 4$ amps. When the resistance decreases by a factor of two (we used half the resistance), the current increases by a factor of _____.

increase

\- - - - - - -

94. In other words, as resistance increases, current _____.

two

\- - - - - - -

95. The reverse is also true; as resistance decreases, the amount of current _____.

decreases

\- - - - - - -

96. So, if the resistance as indicated in Part b of Figure V-6 (with the switch closed) becomes 2 ohms while the voltage remains 20, the current will be _____ amps. increases

- - - - - - -

97. Now let us replace the fixed resistor with a device called a "potentiometer". As indicated in Part c of Figure V-6, this device is a fixed resistor with an additional contact that can be moved along the resistor from end to end. (The volume control on a radio receiver is one form of potentiometer). 10

- - - - - - -

98. We have redrawn Part c of Figure V-6 for convenience (See Figure V-7). If we place a voltmeter (V_1) between x and y, it will read the same voltage as the battery. According to Ohm's Law, the voltage will be the product of the current through the resistor and the resistance of the resistor: V = IR.

- - - - - - -

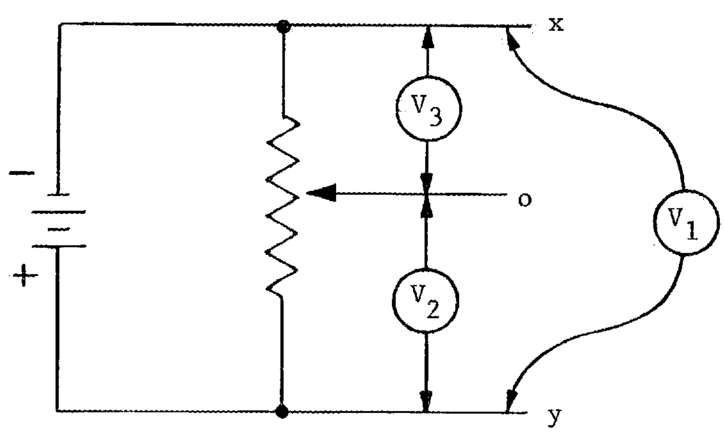

Fig. V-7. Electric Circuit with a Potentiometer

- - - - - - -

99. Voltmeter V_2 in Figure V-7 is connected across only part of the resistance of the potentiometer and will read a potential difference that is equal to the product of that part of the resistance (below the arrow) and the current through it. The current through the whole resistance of the potentiometer is (more than, less than, equal to) the current through the part of the resistance across which V_2 is connected. The voltage read by V_2 is (equal to, less than, more than) that read by V_1.

\- - - - - - -

100. As we move the sliding contact, o, toward y, the voltage measured by V_2 will become (greater, less). — equal to, less than

\- - - - - - -

101. As we move the sliding contact, o, along the resistor toward x, a greater amount of resistance is spanned by the probes of V_2; and the voltage is correspondingly (greater, less). — less

\- - - - - - -

102. Now, if we place another voltmeter (V_3) between x and o, we will find that the sum of the voltages measured by V_2 and V_3 will be equal to the voltage measured by V_1. — greater

\- - - - - - -

103. We could say, then, that the sliding contact divides the voltage across the whole resistance into two voltages. One voltage is from x to _____; and the other is from _____ to y. The sum of these voltages is equal to the voltage from _____ to _____.

\- - - - - - -

104. This voltage-dividing principle is the reason for calling the device a potentiometer. The word means potential metering, potential dividing, or potential measuring. The voltage from o to y may be (less than, more than, the same as) the voltage of the battery.

o,
o,
x,
y

- - - - - - -

105. The volume control (potentiometer) of your radio receiver allows you to decide how much of the total signal voltage you want to be amplified. If the sliding contact is close to y, the amount of voltage amplified is small and the final volume output is (small, large).

less than or the same as

- - - - - - -

106. If the sliding contact is close to x, the amount of voltage from o to y is _____ and the volume output of your radio is _____.

small

- - - - - - -

107. The sliding contact allows you to vary the o-to-y voltage from a very small amount to an amount equal to the _____ voltage when the contactor, o, is at x.

large or high,
large or loud

- - - - - - -

108. A potentiometer is a device which serves as a voltage _____.

battery or source or x to y or total

- - - - - - -

109. The device in Figure V-8, below, is an adjustable resistor or rheostat.

divider

- - - - - - -

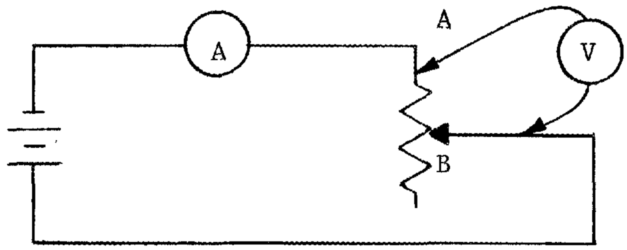

Fig. V-8. Electric Circuit with a Rheostat

Note that in this case, regardless of the position of B, all of the voltage is between A and B. Regardless of B's position on the resistor, a voltmeter from A to B is measuring the total voltage across the resistor, which is the source voltage.

- - - - - - -

110. As B moves down, the resistance in the circuit (becomes larger, becomes smaller, remains the same).

- - - - - - -

111. If the voltage does not change and the resistance from A to B becomes larger as B moves down, the current in the circuit must become _____.

becomes larger

- - - - - - -

112. As B moves toward A, the current in the circuit (increases, decreases, does not change) because the resistance becomes _____.

less or smaller

- - - - - - -

113. This type of variable resistor is called a rheostat. It is used to vary current while the potentiometer is used to vary or divide _____.

increases, smaller or less

- - - - - - -

1.1d. Capacitors in DC Circuits

114. Another important circuit component is the capacitor (or condenser). The capacitor is a storage device for an electrical charge. — voltage

\- - - - - - -

115. An electrical charge may be stored in a device called a _____.

\- - - - - - -

116. Two conducting plates separated by an insulator is called a capacitor, and this device has the capacity to store an _____ _____. — capacitor or condenser

\- - - - - - -

117. Let us connect a capacitor to a battery as shown below. — electric charge

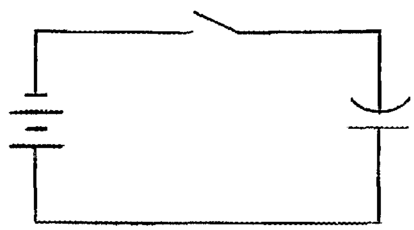

Fig. V-9. Simple Circuit with a Capacitor

When the switch is closed, the voltage across the capacitor plates becomes the same as the _____ voltage.

\- - - - - - -

118. When the switch is closed, electrons are moved by the battery (and through the battery) away from one plate and are deposited on the other plate. This action continues until the capacitor potential difference is equal to that of the _____. — battery or source

\- - - - - - -

119. If the switch is then opened, there is no conducting path for charges to move from one plate to the other; so the voltage between the plates (decreases, increases, remains the same).

battery

\- - - - - - -

120. For this reason, a capacitor is said to be a storage device for electric charges. The negative charge on one plate and positive charge on the other remain that way until a conducting path is placed between them.

remains the same

\- - - - - - -

121. Charging a capacitor is the process of producing a positive charge on one plate and a _____ charge on the other so that, between the plates, there is a _____ difference.

\- - - - - - -

122. If a conducting path is placed between the two plates of a charged capacitor, the excess free electrons on one plate are attracted by the positive charge on the other plate; they move through the conductor to the other plate until there is no difference in the charge on the two plates. This process is called discharging the capacitor.

negative, potential

\- - - - - - -

123. A capacitor stores electric _____. Condenser is also a common name for the electrical device also called the _____.

\- - - - - - -

124. The unit defining the electrical storage capacity of a capacitor is the "farad", named in honor of the English physicist, Michael Faraday. A capacitor is said to have a rating or capacitance of one farad if one coulomb of electricity stored in the capacitor produces a potential difference of one volt between its terminals. — charges, capacitor

\- - - - - - -

125. A capacitor with a rating of one farad is physically quite large and would have few uses. In practical electrical circuits, most capacitors are small and are rated in "microfarads". One microfarad is one millionth of a farad. You would expect, then, that when the potential difference between the terminals of a one-microfarad capacitor is one volt, the amount of electricity stored in it would be _____ of a coulomb.

\- - - - - - -

1.1e. Resistance-Capacitance (RC) Circuit

126. Now let us add a high-valued resistor to our capacitor circuit and measure the voltage across it as shown. — one millionth

\- - - - - - -

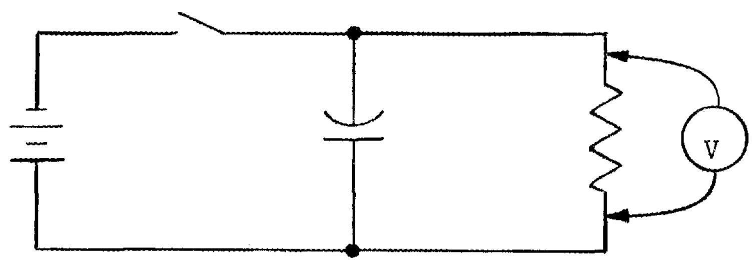

Fig. V-10. Circuit with a Resistor and a Capacitor in Parallel

\- - - - - - -

127. When the switch is closed, the capacitor will charge to the same voltage as the battery. Also, a current will flow through the _____.

- - - - - - -

128. If the switch is opened, the capacitor will, at first, be found to be charged to the same potential difference as the _____. resistor

- - - - - - -

129. The capacitor can now act as a source of voltage and cause _____ to continue to flow through the resistor. battery

- - - - - - -

130. However, the capacitor cannot continue to retain its potential difference as the battery does, so we say that the capacitor discharges through the resistor. The electron flow from the negative side through the resistor to the positive side is the _____ through the resistor. electrons or current

- - - - - - -

131. The current through the resistor is not constant because, as the capacitor discharges, the potential difference across its plates (increases, decreases). current

- - - - - - -

132. When the voltage gradually decreases and the resistance remains the same, the amount of current must also gradually _____. decreases

- - - - - - -

133. In the circuit shown below, the charging path of the capacitor is through a resistor. — decrease

- - - - - - -

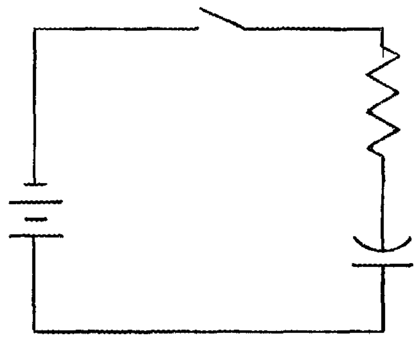

Fig. V-11. Resistor and Capacitor in Series

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134. In this case, the capacitor charges slowly because the charging current is made (smaller, larger) by the resistance in the path.

- - - - - - -

135. When the switch is opened after the capacitor is charged, it cannot discharge and so retains the full _____ of the battery across its plates. — smaller

- - - - - - -

136. When the capacitor is charged and the switch is opened, the capacitor (will, will not) discharge because there (is a, is no) discharge path. — voltage or potential difference

- - - - - - -

1.1f. Magnetic Effects of Electric Currents

137. In 1819 a Danish physicist, Hans Christian Oersted, proved that electricity and magnetism are related. Figure V-12 illustrates his discovery that a compass needle brought near a wire conducting dc (direct current) is deflected. — will not, is no

\- - - - - - -

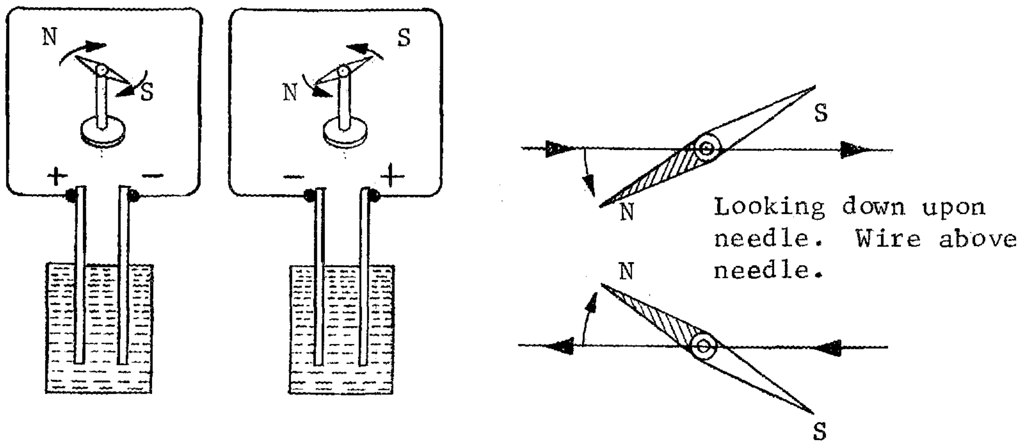

Fig. V-12. Oersted's Discovery

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138. Both a conductor carrying direct current and a magnet cause a deflection of the needle of a nearby compass. This discovery by Oersted showed that _____ and electricity are related.

\- - - - - - -

139. Figure V-13 shows that the magnetic effect of a conductor carrying direct current extends completely around the conductor. — magnetism

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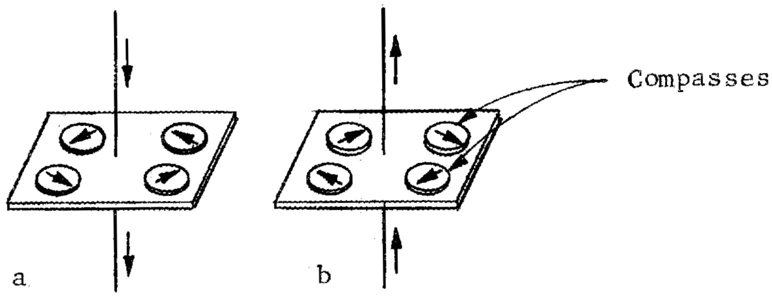

Fig. V-13. Magnetic Effect Extends Around Conductor

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140. It is convenient to think of a magnetic effect as a "field" made up of "lines of force". Figure V-13 shows the direction the lines of force are assumed to take around the conductor carrying dc.

- - - - - - -

141. In working with magnetic effects, it has been found convenient to use the concepts of magnetic _____ and magnetic _____ _____ _____.

- - - - - - -

142. By definition the direction of a line of force about a conductor carrying direct current is that indicated by the direction of deflection of the north-seeking pole or end of the compass needle.

fields, lines of force

- - - - - - -

143. In part A of Figure V-13, the lines of force are counterclockwise and in part B they are clockwise. This gives rise to the following rule; grasp a conductor with the left hand, the thumb extending in the direction of the electron flow. The lines of force are in the same direction as are the fingers extended around the conductor.

- - - - - - -

144. The left-hand rule relates the direction of flow of electrons in a conductor to the direction of the magnetic ______ ______ ______ around the conductor.

- - - - - - -

145. In Figure V-14 application of the left-hand rule shows that all lines of force within the wire loop are in one direction, upward. Because the lines of force are collected or concentrated within the loop of wire, the magnetic field will be (stronger, weaker) within the loop than along the straight portion of the conductor. lines of force

- - - - - - -

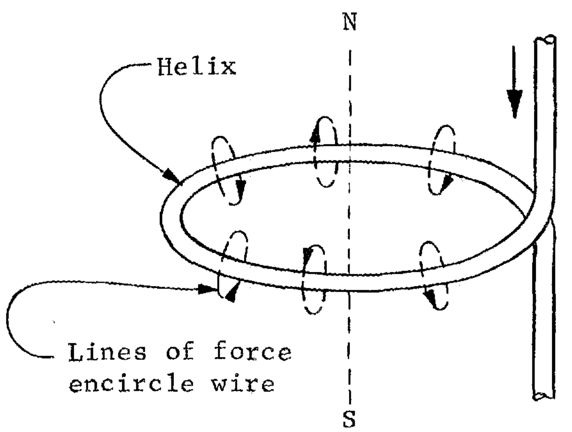

Fig. V-14. Flux and Magnetic Poles of Loop of Wire Carrying Direct Current

- - - - - - -

146. A solenoid is a number of turns of wire typically wound in cylindrical shape as shown in Part b of Figure V-15. When direct current is passed through stronger

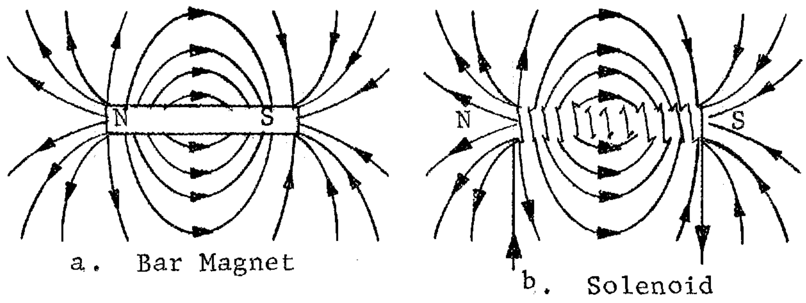

Fig. V-15. Magnetic Fields of a Bar Magnet and a Solenoid Carrying Direct Current

a solenoid, a magnetic field will develop which duplicates that of a bar magnet. Many of the lines of force are concentrated along the coil's axis although others leak out between turns of the winding as indicated.

- - - - - - -

147. A solenoid carrying direct current is sometimes referred to as an "electromagnet". The strength of an electromagnet's field will (increase, decrease) as the number of turns increases.

- - - - - - -

148. Also, the strength of an electromagnet's field will (increase, decrease) as the current through the solenoid increases. increase

- - - - - - -

149. The magnetic polarity of a solenoid is related to the direction of the current flow along the conductors. If the fingers of the left hand are wrapped around the solenoid in the direction of the current flow, the thumb will extend in the direction of the solenoid's north pole. A left-hand rule also relates the direction of a _____ in a conductor to the direction of the magnetic _____ _____ _____ around the conductor. increase

— — — — — — —

150. Some metals offer lower resistance to the flow of an electric current than others (see Frames 46, 47, and 54). Likewise, some materials offer lower resistance to a magnetic field than others. Figure V-16 illustrates the effect of adding an iron core to the solenoid of Figure V-15,b. Notice that the current, lines of force

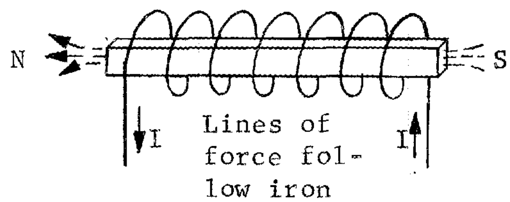

Fig. V-16. An Iron Core Solenoid

lines of force no longer leak around the individual turns of the winding but pass completely through the length of the solenoid. The strength of the electromagnet is increased by adding an iron core.

— — — — — — —

151. If an iron core is added to a solenoid, the strength of the magnetic field is increased because the iron offers (more, less) resistance to the magnetic field.

— — — — — — —

152. The "reluctance" of a magnetic path is a measure of the resistance the path offers to a magnetic field. The reluctance of the path of the lines of force of a solenoid is (lower, higher) after an iron core has been added. less

- - - - - - -

153. Figure V-17 illustrates the effect on a current-carrying conductor if placed in a magnetic field. Part A shows the physical arrangement of the conductor and the poles of the magnet furnishing the flux, and part B shows lines of force between the magnet's poles when the conductor is carrying current away from the reader. The lines of force around the conductor due to the current in it distort the magnet's field thereby increasing its apparent intensity on one side and decreasing it on the other. The net effect is that there is an unbalanced force on the conductor tending to move it from the more intense to the less intense field (upward). The magnetic field is distorted because the lines of force around the conductor add to the magnet's lines of force on one side while opposing them on the other. lower

- - - - - - -

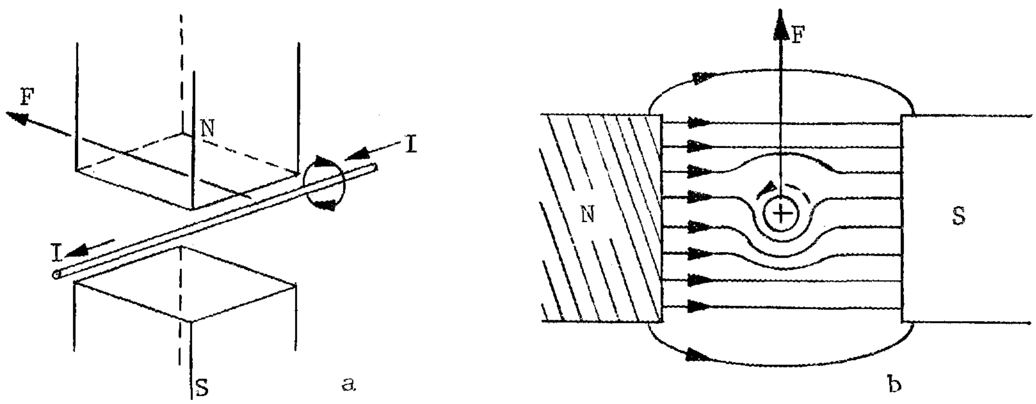

Fig. V-17. Current-Carrying Conductor in a Magnet Field

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154. If the poles of the magnet in Part b of Figure V-17 were reversed, the force on the conductor would be (up, down).

— — — — — — —

155. If the direction of the current in the conductor in Part b of Figure V-17 were to be reversed, the force on the conductor would be (up, down). down

— — — — — — —

156. Eleven years after Oersted discovered that an electric current produced a magnetic field about its conductor Joseph Henry discovered how to induce an electric current in a conductor by means of a magnetic field. The important factor overlooked by other experimenters was that the conductor had to be subjected to a moving or changing magnetic field. Referring to Figure V-17--if a force is applied to the conductor to move it through the magnetic field, a voltage is induced in the moving conductor. down

— — — — — — —

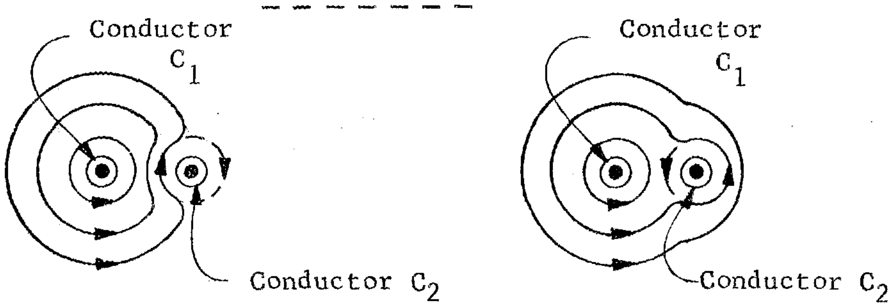
157. If a conductor is placed in a magnetic field and current is passed through it, a _____ will act on the conductor to move it across the field. If, on the other hand, a conductor is moved through a magnetic field, a _____ appears across the ends of the conductor.

— — — — — — —

158. The effect is the same whether a conductor is moved through a stationary field, such as that between the poles of a magnet, or its position is fixed and it is subjected to a field whose intensity is changing. Figure V-18 shows two conductors placed near each other so that C_2 is in the field set up about C_1 when C_1 is carrying a current. It is helpful here to assume that as the current in C_1 starts to flow the magnetic field about it builds up and the lines of force move farther and farther away from it. If current in C_1 is decreased, the magnetic field decreases and the lines of force move back toward it. As C_1's field increases it moves out across C_2 and is distorted as indicated in Part a of Figure V-18. A voltage is induced in C_2 such that a current would tend to flow from the paper toward the reader.

force, voltage

- - - - - - -



a. Current increasing (magnetic field expanding)

b. Current decreasing (magnetic field contracting)

Fig. V-18. A Conductor in a Changing Magnetic Field

- - - - - - -

159. The current induced in the conductor follows the left-hand rule in that if the conductor is grasped with that hand, fingers extended around in the direction of the lines of force with the thumb extended along the conductor, the _____ will point in the direction in which the current tends to flow.

- - - - - - -

160. When the current in conductor C_1 of Figure V-18 is reduced, the field about it (see Part b) _____; and, from the left-hand rule, the current in C_2 would tend to flow in the (same, opposite) direction as in Part a.

thumb

- - - - - - -

161. Conductors C_1 and C_2 in Figure V-18 may be adjacent turns of wire on a solenoid; and, if they are, the same effects noted in Frames 158 to 160 occur. This means that the field from the current in any one turn of a solenoid induces a voltage in other turns of the solenoid whenever the current in the solenoid changes.

decreases, opposite

- - - - - - -

162. From Part a of Figure V-18, the induced voltage during the time the solenoid current is increasing is such that it opposes the applied potential; and during decreases in solenoid current, the induced voltage reverses its polarity so that it tends to add to the applied potential.

- - - - - - -

163. Taking this one step further, a solenoid or other wire winding or coil has a property such that it offers opposition to any change in the current through it. This property is called "inductance" and it is measured in "henries" in honor of Joseph Henry (mentioned in Frame 156).

- - - - - - -

164. A solenoid or other coil offers opposition to any change in current through its windings. This property is called _____.

- - - - - - -

165. When the current in a solenoid or coil (inductor) is changing, the magnetic _____ about the individual conductors changes. — inductance

- - - - - - -

166. When the current in a solenoid or other inductor changes, a voltage is _____ in its conductors. — field or lines of force

- - - - - - -

167. The polarity of the induced voltage is such as to (aid, oppose) the voltage being applied to the inductor when the current in the solenoid is increasing. — induced

- - - - - - -

168. The special characteristic of an inductor, such as a solenoid, is that it tends to keep the current through itself (changing, constant). — oppose

- - - - - - -

169. The inductance of a coil of wire or other inductor is measured in _____. — constant

- - - - - - -

170. The inductor, like the capacitor, is an energy storage device. In the capacitor the energy is stored as an electric _____. In the inductor the stored energy is in the form of the magnetic field about it. — henries

- - - - - - -

1.1g. Alternating Currents

171. So far only dc electricity has been considered. While it is useful in applications such as flashlights and automobile electrical systems and is necessary for telephone, radio, instrumentation, and other systems, another kind of electricity, alternating current (ac), is far more common. As far as electrical technology has progressed to date, ac power is appreciably easier to generate and distribute in the large quantities required and, in most instances, is easier to use than dc power. charge

\- - - - - - -

172. Batteries depend on chemical actions for their operation and are made of certain definite combinations of plates and electrolytes. They can only produce direct currents. Batteries do not produce _____ electricity.

\- - - - - - -

173. The point was made in Frames 156 and 157 that a potential difference develops between the ends of a conductor moved across a magnetic field. A practical arrangement for moving a conductor continuously in a magnetic field is illustrated in Figure V-19. ac

\- - - - - - -

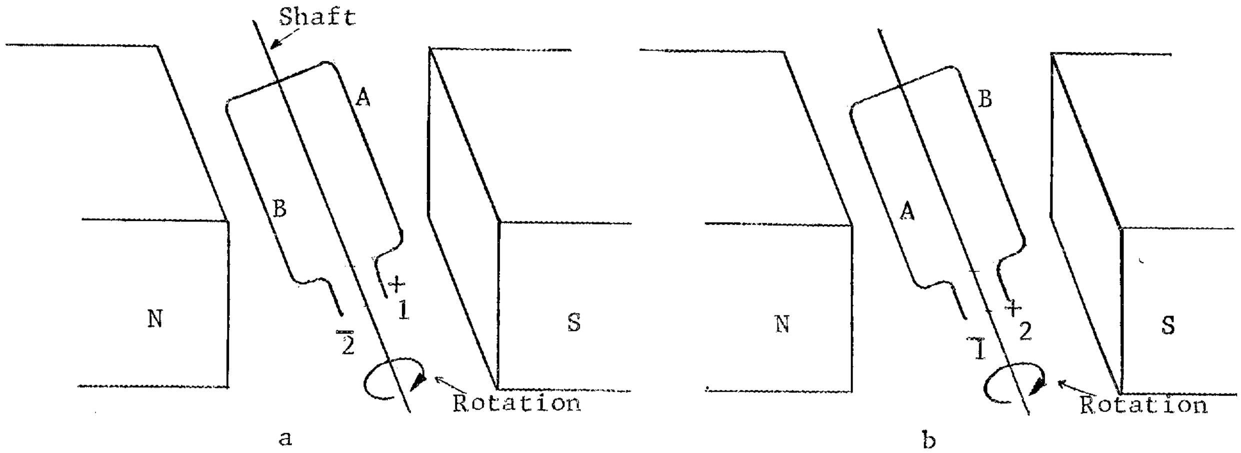


Fig. V-19. Wire Loop Rotating in a Magnetic Field

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174. The direction in which the current will tend to flow in sides A and B of the wire loop in Figure V-19 can be determined by applying the _____-_____ rule.

- - - - - - -

175. From this rule it will be found that the current tends to flow in (the same, a different) direction in the two sides of the loop. — left-hand

- - - - - - -

176. The voltage induced in side A of the loop of the wire in Figure V-19 is of such polarity that it (adds to, opposes) that induced in side B. — a different

- - - - - - -

177. The loop in Figure V-19 generates (ac, dc) when rotated. — adds to

- - - - - - -

178. If the loop in Figure V-19 were made of two turns of wire instead of one, there would be four conductors crossing the magnetic flux field; and the potential difference between the terminals (1 and 2) would be (the same, twice as much) as with one turn. ac

– – – – – – –

179. The voltage developed in an arrangement such as that of Figure V-19 depends on the number of magnetic lines of force the conductor crosses per second. The voltage, therefore, may be changed by changing (1) the speed of rotation of the loop, (2) the strength of the magnetic field, and (3) the number of turns of conductor in the loop. twice as much

– – – – – – –

180. Figure V-20 illustrates the change in the voltage and polarity of the potential difference between the ends of the loop in Figure V-19 as it is rotated.

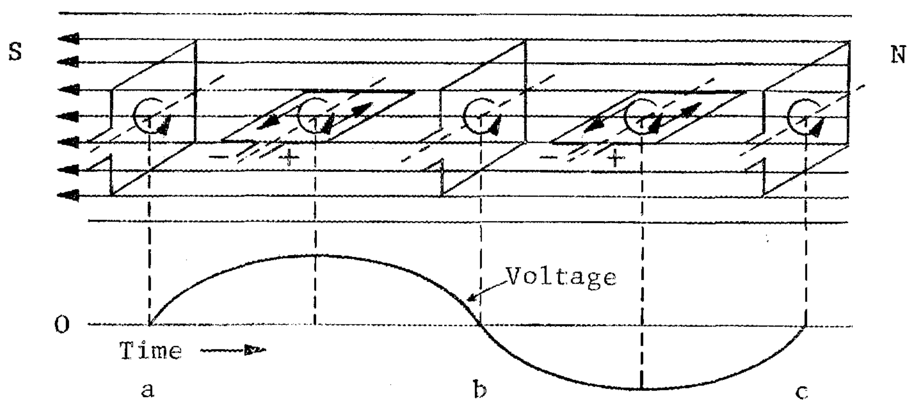

Fig. V-20. Voltage Generated in a Loop of Wire Rotating in a Magnetic Field

The shape of the curve is that of a "sine" wave encountered in mathematics and other studies. As the loop continues to rotate the curve repeats itself.

– – – – – – –

181. An important measure of an alternating current is its "frequency". The frequency is given in "cycles per second" or "hertz" (abbreviated "hz"). One ac cycle is plotted in Figure V-20. At time "a" the voltage developed in the loop is zero. Between "a" and "b" it rises to a maximum and then returns to zero. Between times "b" and "c" the voltage again rises to a maximum and returns to zero, but during this interval the polarity of the voltage is opposite to that developed between "a" and "b". After time "c" the voltage repeats the same changes-with-time or cycle.

- - - - - - -

182. If the loop in Figure V-20 rotated once per second, it would produce an induced voltage having a frequency of one cycle per second or one _____.

- - - - - - -

183. Frequency is a measure of an (alternating, direct) current. — hertz

- - - - - - -

184. The voltage induced in a loop of wire rotating in a constant magnetic field (increases, decreases) if the loop is turned faster. — alternating

- - - - - - -

185. Referring to Frame 184, the _____ of the ac changed in the same way as the voltage. — increases

- - - - - - -

186. A capacitor will alternately charge in one direction, discharge, then charge in the other direction with the voltage changes in an ac circuit but will become charged in only one direction in a dc circuit; therefore, you could expect that a capacitor will pass _____ currents but will block _____ currents.

frequency

- - - - - - -

187. Since an inductor tries to oppose the flow of a changing current, you could expect that it will pass _____ current but will tend to block the flow of _____ current.

alternating, direct

- - - - - - -

1.1h. Ionization

188. The abundant supply of "free" electrons in metals makes them relatively excellent conductors of electric currents. Gases and nonmetallic substances generally make much better insulators than conductors because they contain _____ free electrons

direct, alternating

- - - - - - -

189. Under certain conditions, gases may be made to conduct electricity. To become a conductor a gas must be "ionized".

few

- - - - - - -

190. Gases ordinarily are good insulators until they become _____.

- - - - - - -

191.	Ionization is the process of stripping one or more of the outer electrons from the atoms or molecules of a gas. The electrons have _____ charges; and, since these have been removed from the previously neutral atoms or molecules, the latter have net _____ charges.	ionized
192.	Both the freed electrons and the charged atoms or molecules are called ions.	negative, positive
193.	The process of forming ions in a gas is called _____.	
194.	If an ionized gas is placed between two plates, one of which is charged negatively and the other positively, the positive ions will be attracted toward the negatively charged plate and the electrons will move toward the _____ charged plate.	ionization
195.	The positive ions, on reaching the negatively charged plate, pick up as many electrons as they had lost earlier and become neutral atoms or molecules again. They thus _____ the negative charge on the plate.	positively
196.	The negative ions (electrons) move to the positively charged plate and thus _____ the positive charge on that plate.	reduce

197. If there are sufficient ions present, all the _____ on the two plates will be _____ just as though a metallic conductor had been connected between them. — reduce

- - - - - - -

198. The ionized gas will act just like a _____ connecting the two charged plates. — charge, equalized

- - - - - - -

199. If a suitable battery had been connected between the two plates to maintain their potential difference, an electric current would have existed in the circuit as long as _____ gas was present. Relatively speaking, ionized gases most often are rather poor conductors although under some special conditions their conductivity can be increased very substantially. — conductor

- - - - - - -

200. As in the case of magnets (see Frames 140-148), it is convenient to consider that a "field" exists between two oppositely charged bodies. In this case, the field is termed "electric" to distinguish it from a magnetic field. — ionized

- - - - - - -

201. The strength of an electric field depends upon the difference in potential that exists between the charged bodies as well as the distance between these bodies. The field weakens as the bodies are moved farther apart but becomes stronger as the potential difference is increased.

- - - - - - -

202. The field which is considered to exist between two oppositely charged bodies is called an _____ field.

- - - - - - -

203. The field between two oppositely charged bodies (increases, decreases) as the bodies move apart and (increases, decreases) as the potential difference increases. — electric

- - - - - - -

204. Gases may be ionized by placing them in a sufficiently high (or intense) electric field or by bombarding their atoms or molecules with high-energy beta rays or other particles. — decreases, increases

- - - - - - -

205. One or more of the outer electrons of gas atoms subjected to an intense electric field may be stripped away, thus ionizing the gas. The force on the electrons due to the attraction of the _____ charged body and the repulsion of the _____ charged body can be high enough to overcome the forces which hold the electron in place in the atom.

- - - - - - -

206. An electron struck with sufficient force by a particle will be knocked out of the range of influence of the atom to which it had been attached thus becoming a _____ ion. — positively, negatively

- - - - - - -

207. Lightning is thought to start when the electric field between two clouds, for example, is sufficiently high to ionize some of the air between them. The freed electrons attracted to the positively charged cloud, moving more and more rapidly, bombard other air molecules releasing other electrons. The process is cumulative and the effective resistance of the path drops to a low value. The current here, as in other conductors, is principally one due to the displacement of the electrons. Few electrons leaving the negatively charged cloud actually reach the positively charged one, rather they replace the electrons lost by the air molecules nearby. — negative

- - - - - - -

208. Gases may be ionized by _____ them with high-energy particles or by subjecting them to _____ _____ of high intensity.

- - - - - - -

209. Electric currents in gases are due to the movement of both negative and positive _____. — bombarding, electric fields

- - - - - - -

1.1i. Self Test

210. Electrical charges are of two kinds, _____ and _____. (Frame 3) — ions

- - - - - - -

211. A nonflowing electrical charge on an object such as a comb is called _____ electricity. (Frames 18, 23, and 26) — positive, negative

- - - - - - -

212. The movement of electrical charges along a wire is known as an electrical _____. (Frames 9-11) — static

- - - - - - -

213. An electrical current that moves only in one direction through a conductor is called _____ current. (Frames 31, 32, and 43) — current

- - - - - - -

214. An electrical current that continuously reverses its direction of flow through a conductor is called _____ current. (Frame 171) — direct

- - - - - - -

215. The unit of electrical current is the _____. (Frames 11-13, 17, and 49) — alternating

- - - - - - -

216. The unit which is a measure of electrical potential difference is the _____. (Frames 27 and 28) — ampere

- - - - - - -

217. The path through conductors and loads that electrons traverse in moving from one pole to the other of an electrical source is termed an electrical _____. (Frames 44 and 45) — volt

- - - - - - -

218. The amount of current flowing through a circuit can be measured with an _____; the potential difference applied to a circuit can be measured with a _____. (Frames 43 and 46) — circuit

- - - - - - -

219. A device consisting of an electrolyte into which two dissimilar electrical conductors are partly submerged produces an electrical current if a wire is connected between the two conductors. It is called an electrical _____. (Frames 33, 34, and 38)	ammeter, voltmeter
220. A group of electrical cells connected in series or in parallel to increase the available potential difference or the available electricl current is called a _____. (Frames 39-41)	cell
221. A potentiometer is a device used to vary the _____ applied to components of an electrical circuit. (Frames 97 and 104-108)	battery
222. A rheostat is used to vary the _____ in an electrical circuit. (Frames 109-113)	voltage or volts
223. A material through which an electrical current can readily flow is called a _____. (Frames 7, 8, 55, and 61)	current or amperes
224. A material through which an electrical current cannot, for practical purposes, flow at all is called an _____. (Frames 19, 22, 59, and 60)	conductor

- - - - - - -

225.	A material through which an electrical current can flow but "not readily" is called a _____. (Frame 57)	insulator
226.	A high resistance will allow a (small, large) current to flow. (Frames 51-57)	resistor
227.	Resistance is measured in _____. (Frames 51 and 52)	small
228.	The "watt" is the unit of electrical _____ and is equal to the product of the _____ applied to the circuit and the _____ of current passing through the circuit. (Frames 66-71)	ohms
229.	Ohm's law states that _____ of electrical current flows whenever there is _____ of potential difference across _____ of resistance. (Frame 72)	power, volts, amperes
230.	If there are 10 volts across a 500-ohm resistance, _____ amps of current will flow. (Frames 72-74)	one ampere, one volt, one ohm
231.	The above-mentioned current could be written _____ ma. (Frames 14 and 50)	0.02

232. A circuit component that will store electrical charges is called a _____. (Frames 25-27 and 114-123) — 20

- - - - - - -

233. Capacitance is measured in _____. (Frames 124 and 125) — capacitor or condenser

- - - - - - -

234. A wire conducting an electrical current is surrounded by a _____ field. (Frame 139) — farads

- - - - - - -

235. It is conventional to say that the direction of magnetic lines of force is the same as that of the _____-seeking end of a compass needle placed in the magnetic field. (Frame 142) — magnetic

- - - - - - -

236. If a conductor is passed through a magnetic field so that it cuts through the lines of force, an _____ _____ will be induced in the conductor. (Frames 157-159) — north

- - - - - - -

237. If one grasps a suitably insulated wire, carrying a direct current, with his left hand so that his thumb points in the direction of the electron flow in the wire, his fingers will point in the direction that the _____-seeking end of a compass needle will point if placed beside, above, or below the wire. (Frames 143 and 144) — electric potential or voltage

- - - - - - -

238. The property of an electrically conducting coil to resist changes of the electron current through its windings is called its _____ and this is measured in _____. (Frames 163, 164, and 169)

north

— — — — — — —

239. An inductor stores energy in the form of a _____ _____. (Frames 161-170)

inductance, henries

— — — — — — —

240. The _____ of a magnetic path is a measure of the resistance the path offers to a magnet field. (Frame 152)

magnetic field or magnetic flux

— — — — — — —

241. Adding an iron core to an energized solenoid (decreases, increases) the strength of its magnetic field. (Frames 150-152)

reluctance

— — — — — — —

242. The direction of the magnetic lines of force about a conductor carrying ac (is constant, changes with time). (Frame 158)

increases

— — — — — — —

243. An alternating current reverses its direction each half cycle. The number of complete cycles that occur each second is called the _____ of the ac. The frequency is expressed in _____ which means _____ _____ _____. (Frames 181 and 182)

changes with time

— — — — — — —

244. Batteries produce _____ but not _____. (Frames 31-34, 43, and 172)

frequency, hertz, cycles per second

- - - - - - -

245. An alternating current of 10 cycles per second (or hertz) changes its direction of flow along a conductor (10, 20) times a second. (Frames 180 and 181)

dc, ac

- - - - - - -

246. When two oppositely charged bodies are placed close together, a force field exists between them. This is called an _____ field. (Frames 200 and 202)

20

- - - - - - -

247. An _____ gas will conduct an electric current. (Frames 188, 189, and 191)

electric

- - - - - - -

248. A positive ion is an atom or molecule that has lost one or more of its _____. (Frame 191)

ionized

- - - - - - -

249. The electrons stripped from the atoms or molecules of a gas by the ionization process are called _____ _____. (Frames 191-193 and 206)

electrons

- - - - - - -

250. Ions may be formed by subjecting a gas to a sufficiently intense electric field. They may also be formed by _____ the gas with beta rays of sufficient energy. (Frames 191, 204, 206, and 208)

negative ions

251. Ionized gases, unless subjected to special conditions, are (good, only fair) conductors of electric currents. (Frame 199).

bombarding

- - - - - - -

only fair

1.2. DC and AC Applications

1.2a. Alternators

1. As illustrated in Figure V-19, a wire loop spun in a magnetic field will generate a voltage within itself. Figure V-21 shows the principle of the alternating current generator or alternator which uses this effect to produce useful electricity. As drawn, the coil rotates and the magnet is stationary. The same effect may be obtained by rotating the magnet (and thus its field).

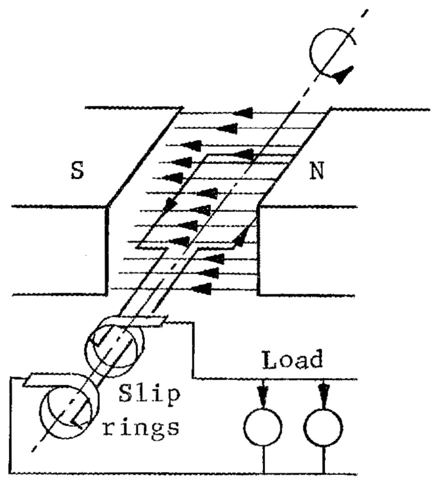

Fig. V-21. Principle of the Alternator

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2. Electromagnets are capable of producing much stronger magnetic fields than do currently practical permanent magnets and are used almost exclusively in this application. It is also more convenient to make the electromagnet the rotor (the part that rotates) of the alternator and to wind the ac conductors in an iron structure around the rotor.

---

3. If the rotor of the alternator in Figure V-21 rotates 3600 revolutions per minute (or 60 revolutions per second) and, according to Figure V-20, the output is one cycle per revolution, the alternator is generating _____ cycles-per-second (or hertz) ac. Public utilities in the U.S. normally generate 60-cycle ac power.

- - - - - - -

4. The alternator in Figure V-21 generates what is called "single-phase" ac. Power is transmitted by two conductors and is suitable for lighting, small motors, home appliances, electronic instruments, and many other loads. The abbreviation for single phase is "1 Ø" (Ø is the Greek letter "phi", pronounced either "fye" or "fee"). 60

- - - - - - -

5. Single-phase power (is, is not) suitable for domestic (home) use.

- - - - - - -

6. Electric utilities generate and distribute 3 Ø rather than 1 Ø power. In addition to its advantages in generation and transmission, 3 Ø power is necessary to run all large ac motors. Generally speaking, only motors rated at one horsepower or less are powered from 1 Ø circuits. is

- - - - - - -

7. Most ac generated by electric utilities is (1 Ø, 3 Ø).

- - - - - - -

8. Referring to Figure V-21, if the single-coil rotor were to be replaced with one having three separate coils spaced equally (120° apart) around the shaft then the voltage output of each coil would reach its maximum or minimum at a different time during each rotation of the shaft. 3 Ø

\- - - - - - -

9. If the coils were interconnected in the manner indicated in Figure V-22, three-phase power could be taken from points 1, 2, and 3. Each phase is carried by a separate conductor. Normally, a fourth conductor is provided as the "neutral" or "grounded" side of the circuit.

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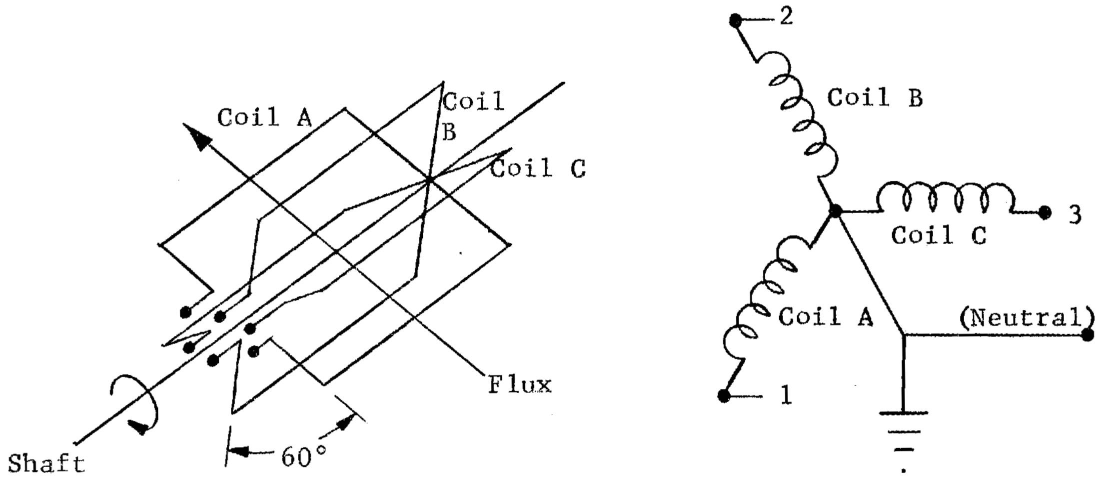

Fig. V-22. Coil Arrangement and Connections for 3 Ø Alternator

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10. Single-phase power (may be, is not) supplied from 3 Ø alternators.

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> This discussion of ac power sources is intended to be only superficial. The student should consult appropriate textbooks for a detailed explanation.

may be

- - - - - - -

1.2b. Relays and Transformers

11. The magnetic field about an energized solenoid (is, is not) similar to that of a bar-type permanent magnet (see Figure V-15).

- - - - - - -

12. The south magnetic pole of an energized solenoid (will, will not) attract the north pole of a bar magnet.

is

- - - - - - -

13. The reason for having iron cores in solenoids is to: (1) make the assembly mechanically strong, or (2) increase the strength of the solenoid's magnetic field.

will

- - - - - - -

14. The electromagnetic relay (or just "relay" for short) is a common electrical device which depends upon an iron-core solenoid for its operation. In Figure V-23, when the switch is closed, the armature (made of iron) is attracted to the core of the solenoid, thereby closing the relay contacts. The device is valuable in a number of ways. For example, it provides complete electrical isolation between the controlling and the controlled circuits. An ac circuit can be turned on and off using dc, or a high-voltage circuit may be controlled from one of low voltage. One important function of a relay is to provide electrical _____ between circuits.

(2)

- - - - - - -

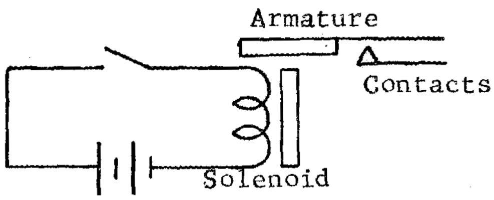

Fig. V-23. Diagram of a Relay, Relay Contacts, Battery, and Switch. (The core is shown outside the coil in the sketch, although it is actually within the coil.)

- - - - - - -

15. The relay may also be constructed with many sets of electrically isolated contacts so that one switch (or other relay contact) may turn many separate electrical circuits on and off at the same time. In effect, it multiplies the number of contacts of a switch. Relays can be built that (will, will not) control several independent circuits simultaneously. — isolation

- - - - - - -

16. Relays are widely used to control relatively large amounts of power by means of small amounts of power. In your automobile, for example, there is a relay which allows the low-current key switch to actuate a high-current relay which turns the starter motor on and off. Starter currents may be 100 amperes or so while the current controlled directly by the key switch or starter button is likely to be less than one ampere. — will

- - - - - - -

17. Power-controlling relays are often called "contactors", especially when they are used as either ac or dc motor starters. Relays designed to control large or relatively large amounts of power are called ____.

- - - - - - -

18. A transformer is an electrical device which "transforms" a high voltage to a low voltage or vice versa. contactors

\- - - - - - -

19. A transformer for use with 60-cycle ac systems consists of a special type iron core on which two or more windings of an electrical conductor have been placed. Because a complete iron path is provided for the magnetic flux produced by the current in the primary winding, practically all this flux passes through the secondary winding also and induces an electrical voltage in it. By definition the transformer winding to which power is applied is the "primary" while the "secondary" winding supplies power to the load. There may be one or more secondaries in any transformer, depending on the particular application.

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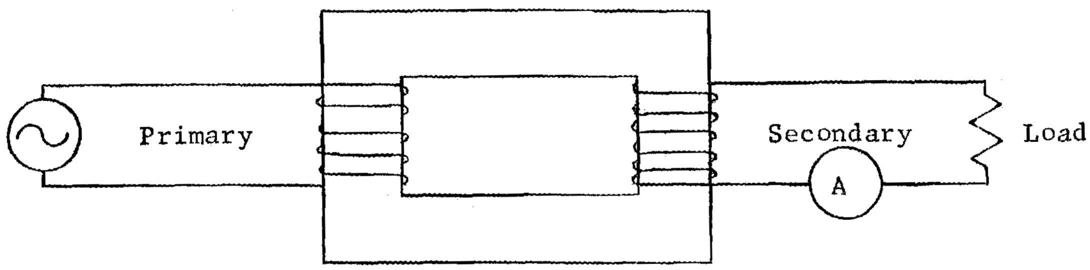

Fig. V-24. Transformer with Power Source and Secondary Load

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20. In a transformer, electrical power is fed into the _____ winding and electrical power of a different voltage is removed from the _____ winding.

\- - - - - - -

21. You will recall from Frames 156, 158, etc., of Section 1.1f, that a conductor placed in a changing magnetic field has a voltage induced in it. Since the primary of the transformer in Figure V-24 is passing ac, there will be a magnetic field in the core which varies from zero to a maximum in one direction, then back to zero, then to a maximum in the other direction, and back to zero again. This will repeat once with each cycle of the ac. This magnetic flux passes through the iron core in the secondary winding also and, because it is a continuously changing flux, it induces an alternating voltage in that winding.

primary, secondary

\- - - - - - -

22. The changing magnetic flux in the core produced by the _____ in the primary of a transformer induces an alternating _____ in the secondary winding.

\- - - - - - -

23. Frame 19 states that a special type of iron core is needed in a power transformer. (This is also true for the cores and armatures of ac relays.) This special type of iron core is made up of many thin electrically insulated iron plates called laminations stacked together to build up the size core needed. A "laminated" core does not overheat due to wasted electrical power producing "eddy currents" as would happen in the case of a solid iron core.

ac, voltage

\- - - - - - -

Part a of Figure V-25 shows the cross section of a solid iron core. Although the core is solid iron, let's make believe that the dotted line divides the core into two parts, a solid inner section and an outer shell having some thickness X. When an alternating flux is present in the core, the outer shell acts as an electrical conductor around the magnetic flux in the inner section of the core just as wire windings would. A voltage is induced in this iron conductor, too; and the resulting induced current circulates around the shell heating it and wasting power. Any other "shell" of iron inside the outer one will also generate heat but less than the outer one because each smaller shell encloses less magnetic flux. The electric currents induced in this solid core in this manner are called "eddy" currents. They produce so much heat that solid-core transformers are impractical!

- - - - - - -

Fig. V-25. Cross Section of a Solid and a Laminated Power Transformer Core

- - - - - - -

Part b of Figure V-25 shows the cross section of a typical core used routinely in power transformers. The iron is in the form of thin "laminations" or sheets which are stacked or piled up to form whatever size of core is required. The laminations are coated with an insulating material, before stacking, to break up the conducting paths that would be followed by the eddy currents in a solid core. Each lamination still encloses some flux so the eddy currents are not entirely eliminated. However, the flux enclosed in each layer is small so the induced voltage is small, and the length of the path the eddy currents must follow is relatively long. The situation is further improved by making the laminations of a special iron containing silicon to increase its electrical resistance. Carefully designed transformers have operating efficiencies as high as 99%, and 90 to 95% is attained in practically all commercial models. Most electrical equipment and machines have much lower operating efficiencies; ac relays also have laminated cores and armatures.

\- - - - - - -

24. Eddy _____ induced in transformer and relay cores cause the cores to _____.

\- - - - - - -

25. Power transformer cores are normally made of sheet iron _____.

currents, heat

\- - - - - - -

26. The laminations are electrically insulated to reduce _____ currents.

laminations

\- - - - - - -

27. It is important to minimize eddy currents in transformer cores since they produce _____ and thus losses of power. — eddy

- - - - - - -

28. Suppose that the transformer in Figure V-24 had a primary and secondary of one turn each. Because the iron core has very low reluctance (see Frame 142, Section 1.1f), very nearly all of the _____ _____ induced in it by the current in the primary winding will pass through the secondary winding also. If one volt is required to produce the primary current, then it is reasonable to expect the resultant flux to induce _____ volt in the secondary winding also. Such is the case. — heat

- - - - - - -

29. The voltage ratio of the two coils is the same as the turns ratio of the coils. The ratio of the primary voltage to the secondary voltage equals the ratio of turns of the primary coil to the turns of the _____ _____. — magnetic flux, one

- - - - - - -

30. This relationship is often written: — secondary coil

$$\frac{V_p}{V_s} = \frac{T_p}{T_s}$$

where V_p = primary voltage

V_s = secondary voltage

T_p = turns on the primary coil

T_s = turns on the secondary coil.

This means that if T_p is 1000 turns and T_s is 5000 turns the turns ratio is _____. Also, the ratio of primary voltage to _____ voltage is _____.

- - - - - - -

31. If the potential difference across the primary coil is 100 volts, we can find the V_s by the equation: — 1/5 or 1:5, secondary, 1:5

$$\frac{100\text{ v}}{V_s} = \frac{1}{5}$$

V_s = _____ volts.

— — — — — — —

32. This transformer (Frame 31) is often referred to as a "step-up" transformer because the secondary voltage is higher than that of the primary. A transformer having a lower secondary than primary voltage would be said to "step down" the voltage. — 500

— — — — — — —

33. A doorbell transformer takes 120 volts ac in the primary coil and changes it to 12 volts ac in the secondary. Thus, a doorbell transformer is a type of (step-up, step-down) transformer.

— — — — — — —

34. Lest we begin to think we are getting something for nothing in a step-up transformer, we should hasten to add that a transformer does not step the power (watts) up or down. In theory, there is 100% transfer of power from primary to secondary; however, even though the power transfer efficiency can be quite high, as stated earlier, it is never 100%. — step-down

— — — — — — —

35. If we consider the power transfer to be 100%, we can write:

watts of primary = watts of secondary

volts x amps = watts

$$V_p \times I_p = V_s \times I_s.$$

— — — — — — —

36. A transformer that takes 10 amps at 120 volts and changes the voltage to 240 volts will be able to furnish only _____ amps if we consider the power transfer to be 100%.

- - - - - - -

37. Show here how you worked the above problem. | 5

_____ v x _____ a = $V_s \times I_s$

_____ watts = _____ v x I_s

_____ amps = I_s

- - - - - - -

38. When the secondary voltage increases in a step-up transformer, the secondary current must (increase, decrease). | 120, 10; 1200, 240; 5

- - - - - - -

39. A transformer can change both volts and amperes but will not step-up or step-down _____. | decrease

- - - - - - -

40. The output power of a transformer is always a little (more, less) than the input power. | watts or power

- - - - - - -

1.2c. Circuit Protection and Grounding

41. The resistance of electrical conductors influences their practical current-carrying capacities. When long runs are necessary, the voltage drop due to the current and the resistance in the circuit may be unacceptably high even though the current "rating" of the wire is not exceeded. The conductor in such a case is selected not for its current rating but on the basis of its resistance. | less

- - - - - - -

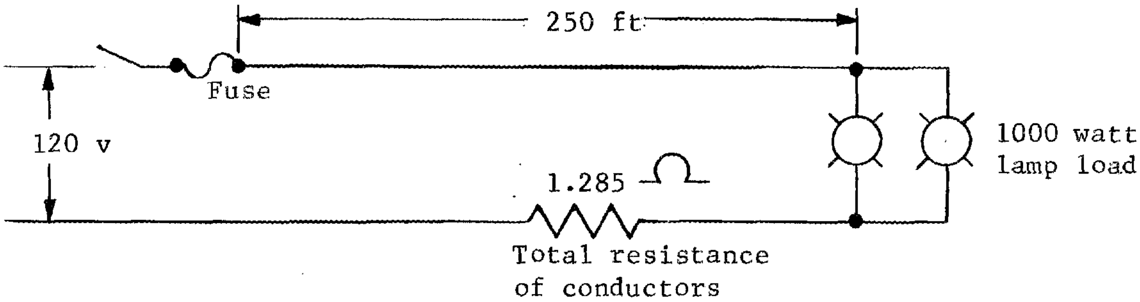

Fig. V-26. Resistance in Long Conductors

- - - - - - -

42. In Figure V-26 the 1000-watt-lamp load is located 250 feet from the power distribution panel. If #14 gage wire is installed, the 250-ft run would have a total resistance of 1.285 Ω (ohms). The current in the circuit will be $I = \frac{W}{E}$. If the lamps are rated for 110 v they would be expected to require _____ amps.

- - - - - - -

43. The voltage lost in the conductors would be E = IR where I is that listed above; E, therefore, equals _____. | 9.09

- - - - - - -

44. The voltage at the lamps, then, is supply voltage (120) – IR drop in the line = _____. | 11.68 v

- - - - - - -

45. The actual voltage at the lamps will be between 110 and the 108.32 v calculated but in either case is appreciably below the voltage at the distribution panel and explains why 110-volt lamps were selected in the first place. It might have been better to buy larger (more expensive) wire than to continue to buy the power wasted in heating the smaller wire. | 108.32 v

- - - - - - -

46. Extension cords frequently are made of #18 gage wire whose resistance is appreciably higher than that of the #14 gage just considered. Long extensions, if well loaded (7 to 10 amp), can introduce appreciable voltage losses and thus interfere with the operation of equipment being powered. If #18 wire had been used in Figure V-26, the same voltage loss would have occurred in slightly less than 100 ft of run.

\- - - - - - -

47. The electrical current ratings of a conductor are determined principally by the characteristics of its insulation. Processed natural rubber and a number of rubber-like plastics, that make economically acceptable insulation for conductors, deteriorate at rates which increase with temperature. Standard conductor ratings are based on the conductor's being operated in ambient (surrounding) temperatures of 30°C (86°F). At this temperature the insulation will dissipate the heat due to power losses in the conductor without damage when the conductor is carrying its rated current.

\- - - - - - -

48. The current ratings of conductors are determined principally by the type of _____.

\- - - - - - -

49. Standard conductor ratings are based on operation in _____ ambient temperatures.

insulation

\- - - - - - -

50. If a conductor rated to carry 15 amps is installed where 40°C is the ambient temperature, its allowable current capacity (is the same as, is greater than, is less than) its normal (design) rating. — 30°C or 86°F

\- - - - - - -

51. The life of extension cords will probably be shortened if they are run near steam lines, across hot-air registers, or under rugs because of _____ damage to the insulation. — is less than

\- - - - - - -

52. The _____ of an extension cord or other insulated conductor must be considered as well as its current rating when selecting either for a particular application. — heat or thermal

\- - - - - - -

53. The size of a fuse or circuit breaker is determined by its application. When the fuse or circuit breaker is protecting an electric circuit to a group of ordinary 120-v receptacles, it is sized to protect the conductors rather than devices plugged into the receptacles. — length

\- - - - - - -

54. The typical 120-v receptacle circuit is wired with conductors rated at 20 amp and would be protected with a _____ amp fuse. An extension cord rated at 7 to 10 amp (#18 gage) (would, would not) be protected from overloading (passing excessive current) if plugged into one of these receptacles.

\- - - - - - -

55. A <u>fuse</u> or <u>circuit breaker</u> usually depends for its operation on the <u>heat generated</u> within it by the current through it. When power-distribution panels are installed in such a way that internally generated heat (power losses in connections, fuses, and conductors) cannot be properly dissipated or when subjected to <u>high ambient</u> temperatures, on occasion the fuses may blow or the breakers may trip when handling loads <u>within</u> their ratings. <u>Motor starters</u> frequently depend on thermally sensitive <u>overload</u> protection devices (trips). When exposed directly to ordinary weather extremes, these starters <u>may trip unnecessarily</u> in hot weather if they are set to provide <u>close control</u> in average or cold weather.

20,
would not

- - - - - - -

56. A tripped breaker, tripped motor starter, or blown fuse (always, usually but not always) is indication of an overload in its load circuit.

- - - - - - -

57. Fuses <u>don't blow</u> or other protective devices don't <u>trip</u> just when their load current reaches their "<u>rated</u>" or "<u>set</u>" value of current. Essentially <u>instant action</u> occurs <u>only</u> when currents reach <u>five or more times</u> the rated or set value. <u>Between</u> rated and instant values of current, the time necessary to act <u>decreases nonuniformly</u>. Fuses (are, are not) designed to blow the instant the rated current is exceeded.

usually but not always

- - - - - - -

58. The ordinary 120-v single-phase power-distribution system found in the home, as well as in industrial plants, has one of its conductors intentionally connected to the earth (grounded). This "identified" neutral or grounded conductor has a white jacket or white insulation. The other conductor (or "hot side of the line") nominally is 120 volts above ground and has a black jacket or insulation. This arrangement is required by the National Electric Code and is followed uniformly in this country. — are not

\- - - - - - -

59. It is standard practice in the USA in wiring homes to install white insulated wire for the _____ conductor and _____ for the "hot" one.

\- - - - - - -

60. "Grounding" means to electrically connect a metallic object, such as a cabinet or the steel framework of a building or an electric-circuit conductor, to the earth through suitable conductors connected at the other end to grounding electrodes, such as driven metal rods or buried metal plates, mesh, or wire grids. Underground water piping is frequently used as a grounding electrode. Heavy wires or cables are customarily installed as the grounding conductors to provide low resistance paths between the object to be grounded and the grounding electrodes. — grounded, black

\- - - - - - -

61. "Grounding" the frame of a control console means electrically connecting it with electrodes driven into or otherwise buried in the _____.

\- - - - - - -

62. Underground water piping (usually, never) makes a good ground electrode. earth

- - - - - - -

> The term "ground potential" is usually intended to mean that anything at this potential may be touched or worked on without fear of electric shock. It should be recognized, however, that the identified (grounded) conductor of an ac circuit may not always be at ground potential as far as adjacent objects are concerned. This conductor carries current of the same magnitude as the hot conductor and may be tied to "ground" at some relatively remote point with the result that it may actually be many volts above the adjacent grounded objects in some areas. Only after actually measuring the potential between this conductor and an adjacent grounded object can it be decided that the conductor is safe to handle. Generally speaking, if the measured voltage is less than 50 there is little likelihood of shock hazard; however, such a large voltage would be quite unusual. When an unusual condition such as this is discovered, the operator should be required to report it to his supervisor before proceeding.

usually

- - - - - - -

63. Since the grounded conductor of an electric circuit may or may not be at the same potential as an adjacent grounded object, it should not be used to connect other equipment to "ground".

- - - - - - -

64. The grounded conductor of an electric circuit should (always, never) be used for grounding a console or other metal structure, for example.

- - - - - - -

never

Appliances such as electric hand drills or instruments such as oscilloscopes usually have metal housings that are intended to be insulated from both sides of the electric circuit which supplies them with power. The insulation on the hot wire sometimes fails and this side of the circuit may actually come in contact with the equipment housing so that anyone handling the equipment is subject to electric shock. The present standard practice is to include a third conductor in the power cord along with the white and black wires--its purpose being to ground the equipment housing. Receptacles now have three connections to handle the three conductors. The cord cap (plug) on the appliance cable has two flat pins for the AC power and a longer U-shaped pin for the ground wire. The ground pin is long so that when the cap pins are inserted into the receptacle the appliance is grounded before AC power is connected. The ground conductor is colored green. From the receptacle, the green wire is run directly to the building ground system.

- - - - - - -

65. The purpose of the green wire in the power cord of an appliance is to _____ the frame and housing of the appliance to the building grounding system. This minimizes the _____ _____ hazard to the operator.

- - - - - - -

66. The green wire is not part of the electric power wiring and therefore does not carry current under normal conditions. If the hot ac conductor should accidentally contact the housing of a piece of equipment, the green wire will complete the ac circuit back to ground and the resulting relatively heavy current will blow the circuit fuse or trip its circuit breaker, thus cutting the current off. Therefore, the operator is not subjected to an _____ _____ hazard.

connect or ground, electric shock

- - - - - - -

67. The green wire (is, is not) permitted to carry current under normal conditions. — electric shock

- - - - - - -

68. The grounded conductor and the grounding (or ground) conductor (are, are not) names for the same wire in an appliance power cord. — is not

- - - - - - -

1.2d. Rectifiers and Filters

69. We stated earlier that batteries supply _____ but that utilities supply ac. There are occasions when ac must be changed to dc for use in electronic equipment or to charge batteries. — are not

- - - - - - -

70. The process of changing ac to dc is called rectification. A rectifier is a device used to change _____ to _____. — dc or direct current

- - - - - - -

71. The plot, or graph, of an alternating voltage, such as that of a standard commercial ac power system, would probably look like this: — ac, dc

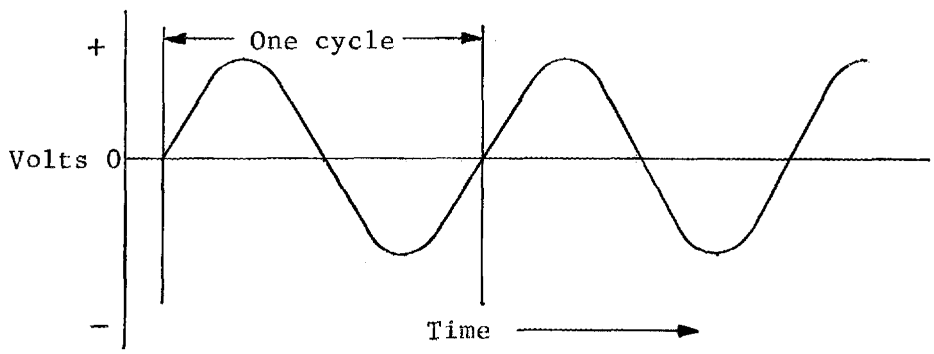

Fig. V-27. Graph of an AC Voltage

- - - - - - -

72. In order to rectify ac to dc, something must be done to limit the flow of current through the load to one direction only. The rectifier must act like a check valve in a water system.

----

73. One device that is commonly used is called a "diode". This device allows current to flow through it in one direction but does not allow flow in the other direction.

----

74. Perhaps we should explain the term "diode". Originally, diode meant a two-electrode electronic vacuum tube (di- means two and -ode for electrode; i.e., two-electrode tube). However, the term is commonly used now to mean either a tube or a solid-state device such as a silicon or selenium rectifier which performs the same function as an electronic tube diode; i.e., allows current flow in one direction and does not allow flow in the opposite direction.

----

75. Although there are many different types of diodes, each having its own special characteristics, the principal application continues to be that of _____ ac to dc.

----

76. The diode can be used as a _____ because it will conduct during one-half of a cycle but will not conduct during the second half of the cycle. A graph of the voltage output of such a device would appear as: rectifying

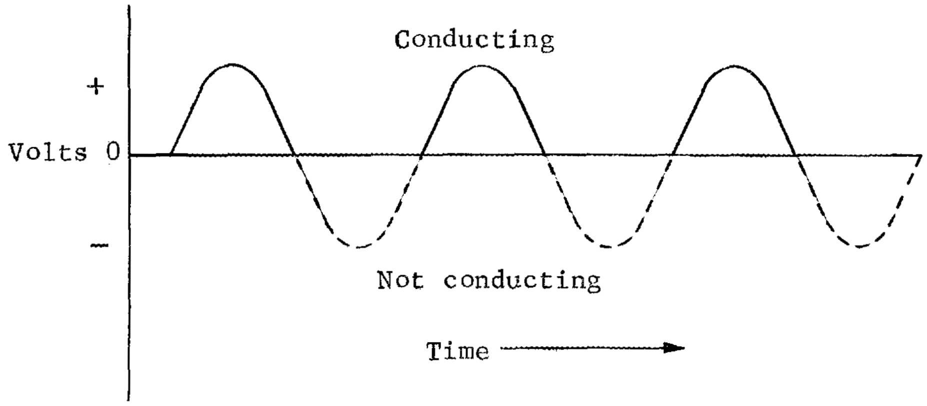

Fig. V-28. Graph of Voltage Output of a Half-Wave Rectifier

- - - - - - -

77. Such a voltage would produce a current as shown below which would follow the voltage variations. rectifier

- - - - - - -

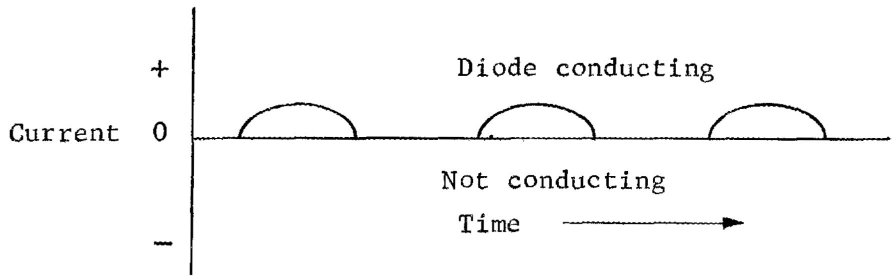

Fig. V-29. Graph of a Current Output of a Half-Wave Rectifier

- - - - - - -

> No significance is to be attached to the fact that the heights of the current wave and the voltage wave are different in the two graphs.

- - - - - - -

78. Quite "lumpy", isn't it? But it is electricity which flows in only one direction, i.e., _____.

- - - - - - -

79. This is the purpose, to take ac and change it to dc. It is called pulsating dc because the flow is not continuous. | dc

- - - - - - -

80. Alternating current, which changes direction periodically, may be changed to _____ current by use of a _____.

- - - - - - -

81. A diode can be used as a rectifier because it will allow current flow in (either, only one) direction. | direct, rectifier

- - - - - - -

82. The output of a diode rectifier is pulsating, but it is still _____ current. | only one

- - - - - - -

83. For many purposes, we would need to smooth out the pulses; but for charging batteries this is not necessary and would be an unnecessary expense. | direct

- - - - - - -

84. The device we have just described is called a "half-wave" _____. If the name is not obvious, remember that each dc pulse represents only one-half of the input ac wave.

- - - - - - -

85. It is desirable, however, to make use of both half-waves; and to do this two different circuit arrangements have been developed. Figure V-30 shows one of these. Two half-wave rectifiers are connected so that current flows through one during one-half of each cycle and through the other during the alternate half cycle. Each of the transformer windings furnishes power during one-half of each cycle. rectifier

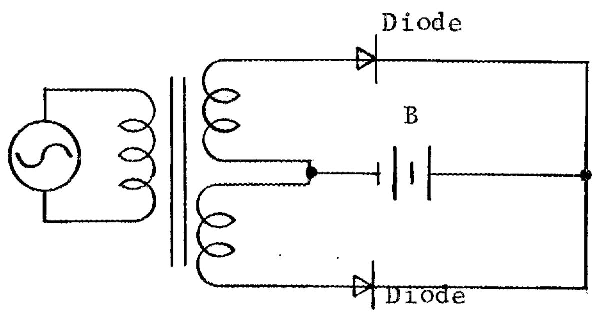

Fig. V-30. Full-Wave Rectifier Circuit Charging a Battery

The arrangement is called a "full-wave" rectifier. Figure V-31 is a plot of charging current or voltage to the battery.

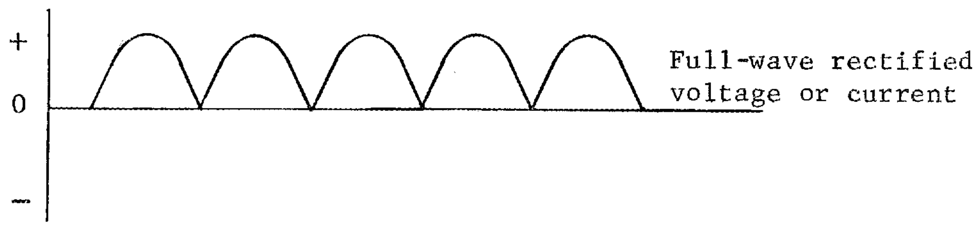

Fig. V-31. Output of Full-Wave AC Rectifier

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86. The full-wave rectifier circuit provides current during _____ half-cycle instead of during alternate half-cycles of the ac.

---

87. Power for ion chambers, most electronic amplifiers, and instruments, for example, must be "pure" dc; that is, dc without any lumps such as rectifiers supply. Direct current straight from rectifiers (is, is not) suitable for powering most electronic instruments. — each

\- - - - - - -

88. If rectified ac is passed through a suitable "filter", the lumps (ripple or ripple voltage) can be eliminated, leaving only dc. — is not

\- - - - - - -

89. What is frequently referred to as "dc supply" consists of a power transformer to raise or lower the voltage as needed, a full-wave rectifier, and a good filter. Such supplies make suitable replacements for batteries in practically all cases. All ac-powered radio and TV receivers, electronic instruments, and similar devices contain built-in dc supplies.

\- - - - - - -

90. In addition to a rectifier and transformer, a dc supply contains a good _____ to eliminate the ripple voltage.

\- - - - - - -

91. Practically all ac-powered electronic instruments include built-in _____ supplies. — filter

\- - - - - - -

92. In most cases a dc supply makes a satisfactory replacement for a _____. — dc

\- - - - - - -

93. Sections 1.1d and 1.1e pointed out that a capacitor stores energy in the form of a difference in charge between its two plates. The capacitor illustrated in Figure V-32 will charge while the output voltage of the rectifier is higher than that of the capacitor and will give up its charge to the load at other times.

battery

— — — — — — —

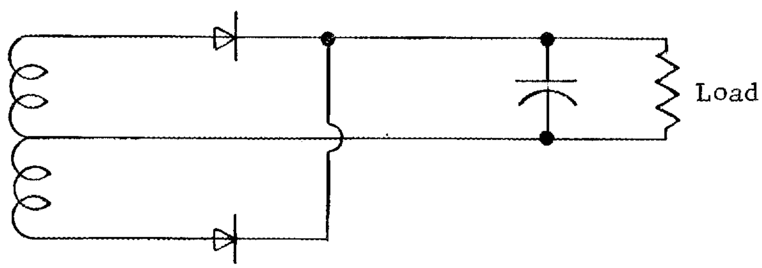

Fig. V-32. Rectifier with Capacitance Filter

— — — — — — —

94. Figure V-33 shows the wave form of the voltage across the load and, in dotted lines, the output voltage of the rectifier.

— — — — — — —

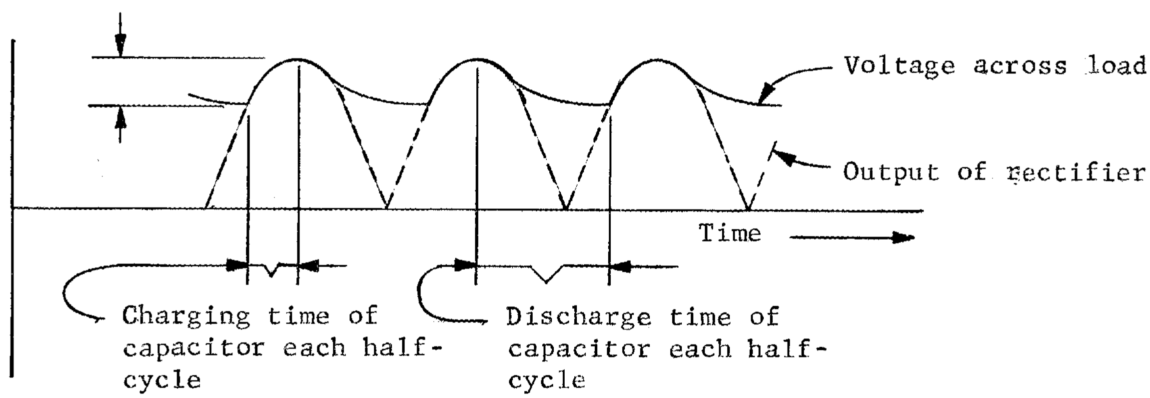

Fig. V-33. Load Voltage with Capacitor Filter

— — — — — — —

95. The effect of a capacitor connected across the output of a rectifier is to reduce the _____ voltage applied to the load.

\- - - - - - -

96. From Figure V-33 the smaller the ripple is, the nearer the load current will be to pure _____. ripple

\- - - - - - -

97. The filtering provided by a single capacitor is usually insufficient for many applications. Additional filtering may be provided by a combination of inductors (choke coils) and capacitors. Figure V-34 shows one satisfactory filter for a dc supply. dc

\- - - - - - -

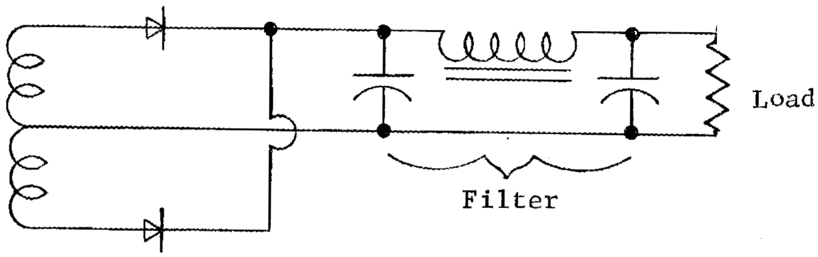

Fig. V-34. Capacitance-Inductance Filter

\- - - - - - -

98. You will recall (Frames 149-160, Section 1.1f) that an inductor, like a capacitor, stores _____.

\- - - - - - -

99. You will also recall that an inductor acts in such a way that it tends to keep the current through itself _____. energy

\- - - - - - -

100. The effect of the capacitors in Figure V-34 is to tend to hold the voltage across themselves constant and the effect of the inductance is to keep the current through itself constant. If the current out of the inductance is constant and the voltage across the load is constant, then, as far as the load is concerned, its power could be coming from a _____ instead of a dc supply. constant

- - - - - - -

101. The purpose of the filter in a dc supply is to remove the ac _____ from the rectifier output and pass only _____ to the load. battery

- - - - - - -

102. As with most other electrical equipment, there are many types and arrangements of filters for dc supplies. The purpose is the same in all cases. ripple, dc

- - - - - - -

1.2e. Amplifiers

103. In the electrical sense, "amplifiers" are devices which, in effect, boost, increase, or amplify small voltages or currents to larger voltages or currents as required for the application at hand. Large output voltages alone are seldom needed but rather it is large currents or varying amounts of power.

- - - - - - -

104. Amplifiers practically always require power from dc supplies. In fact, it is the power from this supply that the amplifier feeds into its load. The amplifier controls this power or converts it to ac as required.

- - - - - - -

105. The power or current furnished by an amplifier to its load usually comes from the amplifier's _____ _____.

\- - - - - - -

106. Another way of looking at an amplifier is as a device which permits a small signal voltage or current to control a relatively large current or amount of power. dc supply

\- - - - - - -

107. In many of the control and instrument systems of a reactor, the initial (signal) current or voltage is very small. It is so small that it can be detected only with very sensitive instruments (which themselves contain amplifiers). However, it is necessary for this signal to cause relays or recorders or motors to operate and this capability is provided by suitable amplifiers.

\- - - - - - -

108. The signal current from an ionization chamber (discussed in Section V-2) is very small (often 30 μa or less). This is strengthened by an _____ so it can operate a recorder.

\- - - - - - -

109. The signal out of a phonograph pickup or tape head is quite small. Most of the equipment which goes to make up such equipment is electronics whose purpose is to amplify the signal until it is large or powerful enough to drive (or power) one or more loudspeakers. amplifier

\- - - - - - -

110. One measure of the capability of an amplifier is its "gain". For example, if the input to an amplifier is a current of 10 μa and its output is 5 ma (milliamperes), its current _____ is 500.

\- - - - - - -

111. The same amplifier would be expected to increase a 1 μa signal to one of _____ ma. gain

\- - - - - - -

112. A voltage amplifier having a gain of 400 would increase the output of 5 mv (millivolts) from a phonograph pickup to a signal of _____ volts for driving the power amplifier. 0.5

\- - - - - - -

> Amplification was obtained in most electronic equipment with vacuum tubes until recently when transistors became more popular. Although the two devices function in somewhat different ways, the effect is that a small amount of power from a signal source applied to the input of the device will control a much larger amount of power in its output circuit. In fact, in the case of many vacuum tubes and some of the more recently developed transistors, the control signal need be only a potential (voltage) for all practical purposes.

2

\- - - - - - -

113. A triode (or three-element) vacuum tube is illustrated in Figure V-35. It consists of three elements: a cathode (with integral heater); a wire helix or other open grid structure separated from, but surrounding, the cathode; and beyond that the anode or plate.

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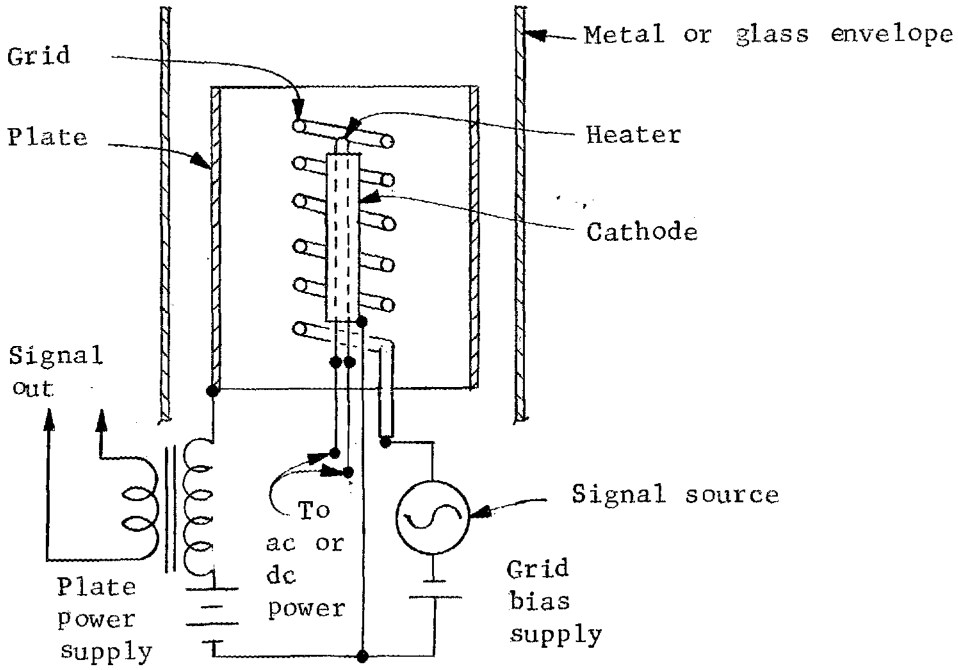

Fig. V-35. Triode Tube with Cylindrical Elements

---

114. The working elements of a triode vacuum tube are the _____, the _____, and the _____.

---

115. The essential difference between a triode and a diode is the grid in the triode. We shall first review the "diode-type" behavior of the triode by considering only the cathode and the plate before taking up the action of the grid.

cathode, grid, plate or anode

A vacuum tube is so named because its components are surrounded by a glass or metal envelope or tube from which all gases have been removed before the tube was sealed. It is necessary to remove the gases because gas molecules would interfere with the flow of electrons between components within the tube. Also, under proper conditions, gases would become ionized and cause too great a current to flow between components. Some types of rectifier tubes take advantage of the high currents that can be obtained using ionized gases, but these will not be discussed here.

- - - - - - -

116. For various reasons, not of interest here, vacuum-tube elements are fabricated in many different shapes besides cylindrical. Vacuum-tube elements (are, are not) always cylindrical shape.

- - - - - - -

117. The cathode, when suitably heated, emits electrons copiously. The heat is generated by passing an electric current through the "heater" which, typically is a loop or number of loops of resistance wire placed inside the cathode. Heat is transmitted to the cathode by radiation and conduction. The heater wire is frequently coated with ceramic insulation to isolate it electrically from the cathode. Heating of the cathode causes it to emit _____. are not

- - - - - - -

118. When the cathode is heated to its operating temperature, many of the electrons in the atoms in and near the surface of the cathode are given sufficient thermal energy to break loose from these atoms and move out into the space between the grid and cathode. Thermal energy supplied by the heater causes atoms at or near the surface of the cathode to emit _____.

electrons

- - - - - - -

119. The purpose of the heater is to (emit electrons, heat the cathode to its operating temperature).

electrons

- - - - - - -

120. If the plate of the vacuum tube in Figure V-35 is made positive with respect to the cathode, it will (repel, attract) the electrons _____ by the cathode.

heat the cathode

- - - - - - -

121. When the cathode emits electrons, it acquires as many positive charges as it loses electrons. Because the cathode is positive with respect to the "cloud" of electrons around it, it (attracts, repels) these electrons.

attract, emitted

- - - - - - -

122. When the plate of the tube is positive, both it and the cathode are attracting electrons from the cloud around the cathode. As the plate potential is made more and more positive, it will attract (more, less) of the electrons emitted by the cathode.

attracts

- - - - - - -

123. If the plate voltage is increased enough, the attraction of the plate will completely overcome that of the cathode and all the emitted electrons will go to the plate. Increasing the positive voltage on the plate any further (will, will not) increase the electron flow to the plate. — more

– – – – – – –

124. You will recall that a flow of electrons between two points is called an electric current. The flow of electrons in a vacuum tube to the plate is referred to as the plate _____. — will not

– – – – – – –

125. The electrons, in moving from the cloud to the plate, pass through the open spaces in the grid structure. If a negative potential is applied to the grid, it will tend to (attract, repel) the electrons passing through it. — current

– – – – – – –

126. The more negative the grid the (more, less) it repels the electrons. — repel

– – – – – – –

127. The more negative the grid is made the (more, less) the current flow from the electron cloud to the plate. — more

– – – – – – –

128. If the grid is made sufficiently negative with respect to the cathode, the plate current will drop to zero. If, on the other hand, the grid is made positive it will act like the plate and will (attract, repel) electrons. — less

– – – – – – –

129. The number of electrons emitted by the cathode depends principally upon its temperature and the material of which it is made. When all the electrons emitted by the cathode go to the plate, the tube is said to be "saturated". Increasing the plate voltage further or making the grid more positive under such conditions (will, will not) increase the plate current. — attract

\- - - - - - -

130. If the vacuum tube is not saturated, making the grid positive (will, will not) increase plate current. — will not

\- - - - - - -

131. The grids of vacuum tubes are normally operated at a potential which is negative with respect to the cathode. The negative grid, for all practical purposes, will collect no electrons and thus there will be no _____ in the grid circuit. — will

\- - - - - - -

132. The fixed potential applied to the grid is called the "bias". When the bias is negative, there is no _____ in the grid circuit and the bias supply in Figure V-35 is not required to furnish any power. — current

\- - - - - - -

133. If a signal voltage (see Figure V-35) is added to the negative bias in the grid circuit, the grid will swing more negative or less negative, depending on the polarity of the signal, and the plate current will _____ or _____ in step. — current

\- - - - - - -

134. As long as the total voltage (signal plus bias) is such that the grid is always negative with respect to the cathode, there will be essentially no current flow in the _____ circuit.

decrease, increase

- - - - - - -

135. If the signal source supplies no current, it is required to supply no _____.

grid

- - - - - - -

> Measuring devices which require little or no signal power are capable of monitoring processes which involve relatively little energy without perturbing the process. Other features of such devices are that high-impedance signal sources may be monitored successfully or long electrical leads may be interposed between the signal source and the instrument without loss of signal strength due to conductor resistance.

power

- - - - - - -

136. A means is required for developing a measurable amplified signal in the plate circuit of the amplifier tube as it responds to changes in the signal source. One method is to pass the plate current through a resistor (see Figure V-36).

- - - - - - -

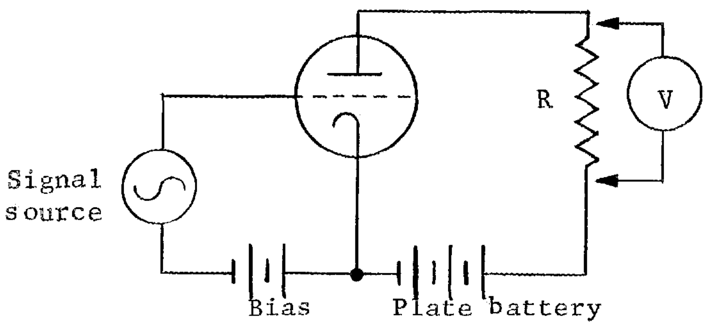

Fig. V-36. Triode Tube Amplifier Circuit

- - - - - - -

137. Because the changes in the grid voltage produce proportional changes in the plate current of the vacuum tube, the potential drop across R (will, will not) be proportional to the grid voltage.

- - - - - - -

138. Assume R = 10,000 Ω and the "idling" (no signal) plate current is 2 ma. If a one-volt change of grid potential causes a 1-ma change in plate current, it will produce a _____-volt change in the IR drop across R. — will

- - - - - - -

139. Under the conditions stated in Frame 138, the amplifier of Figure V-36 will have a voltage gain of _____. — 10

- - - - - - -

Depending on the tube and circuit design, a single-stage amplifier similar to that illustrated in Figure V-36 may have voltage gains as high as 80 to 90. With specially designed tubes and circuits, appreciably higher gains are practical. It will be noted that the voltage (or IR) drop across R in Figure V-36 is equal to the amplified signal plus the drop due to the idling current. Figure V-35 shows one means of eliminating the portion of the IR drop in the plate circuit due to the idling current, leaving only the amplified signal voltages. You will recall that in a transformer only variations in the primary current cause voltages to be induced in its secondary. Because the idling current is constant, it induces no voltage in the transformer secondary. — 10

- - - - - - -

1.2f. Self Test

140. TVA and other utility-company generators produce _____ electricity. (Frames 3 and 6)

- - - - - - -

141. The frequency of the alternating current produced by TVA and other public utilities is _____ cycles per second. (Frame 3) ac

- - - - - - -

142. The electromagnet below has a north pole at the (right, left) end. (Frames 146-149, Section 1.1f) 60

- - - - - - -

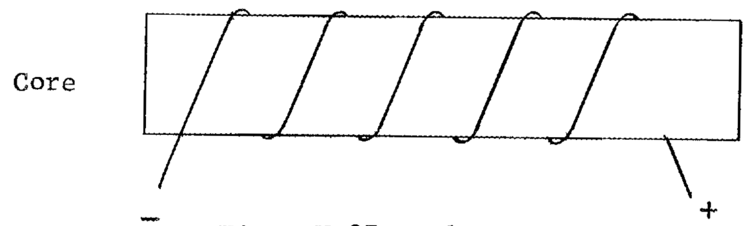

Fig. V-37. Electromagnet

- - - - - - -

143. The transformer below is a (step-up, step-down) transformer and has a secondary voltage of _____ volts. (Frames 28-32) right

- - - - - - -

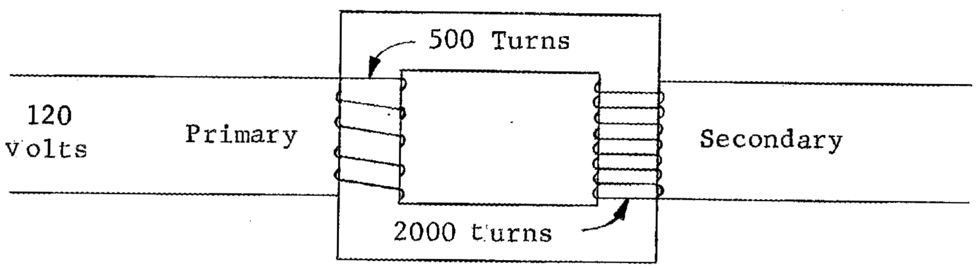

Fig. V-38. Transformer

- - - - - - -

144. The changing magnetic field that is necessary for transformer action is produced by flowing (ac, dc) through its primary winding. (Frames 21 and 22)

step-up, 480

- - - - - - -

145. The iron cores of transformers must be _____ in order to reduce core _____ caused by eddy currents. Transformers for 60-hz (cps) ac systems (would, would not) be practical with solid iron cores. (Frames 19 and 23-27)

ac

- - - - - - -

146. One function of a relay is to _____ one electric circuit from another. (Frame 14)

laminated, heating or losses, would not

- - - - - - -

147. The name "contactor" is given to a _____ having contacts designed to handle heavy currents. (Frame 17)

isolate or separate

- - - - - - -

148. Alternating current relays and contactors can be expected to have _____ iron cores similar to those of transformers. (Frames 23 and 24)

relay

- - - - - - -

149. The current rating of a conductor depends largely on the thermal characteristics of its _____. (Frames 47 and 48)

laminated

- - - - - - -

150. Conductors to be operated continuously in ambient temperatures of 50°C must be derated, that is, run at (less, more) than rated current. (Frames 47-51)

insulation

- - - - - - -

151.	It may not be desirable to carry rated currents on long runs of conductor because of its _____. (Frames 41-46)	less
152.	The white (identified) conductor in an electric circuit should (always, never) be used for grounding equipment or as a ground wire. (Frames 58, 60, and 64)	resistance or IR drop
153.	The purpose of the "green" wire in the cord to an electric drill, for example, is to _____ the frame of the drill. This minimizes the _____ hazard. (Frames 65-67)	never
154.	A blown fuse or a tripped motor starter is (always, not always) an indication that the current through it had been too high. (Frame 55 and 56)	ground, shock
155.	Conductors carrying currents in excess of their rating are said to be _____. Such operation often causes premature failure of the conductor's _____. (Frames 47-54)	not always
156.	A grounded conductor (may, may not) always be safe to handle. (Frame 63)	overloaded, insulation
157.	A rectifier is used to change _____ current to _____ current. (Frames 69-79)	may not

158. The following waveform is the output of a half-wave _____. (Frames 76-79)

alternating, direct

- - - - - - -

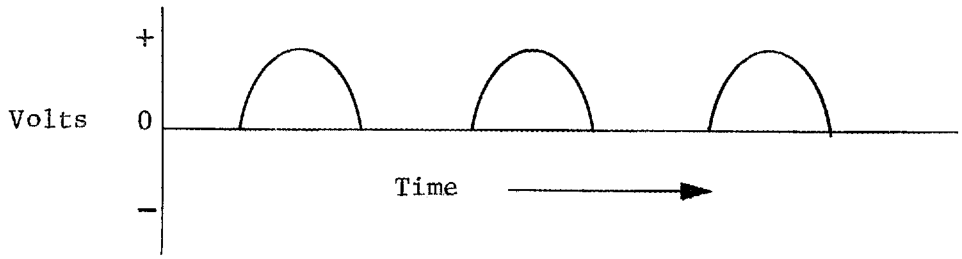

Fig. V-39. Voltage Output of a Half-Wave Rectifier

- - - - - - -

159. A full-wave rectifier produces one current pulse per _____ cycle instead of one per cycle. (Frame 85)

rectifier

- - - - - - -

160. The output of a full-wave rectifier (is, is not) suitable to replace batteries directly in amplifier service. (Frame 87)

half

- - - - - - -

161. The purposes of a filter used with a rectifier are to eliminate the _____ voltage and pass _____ to the load. (Frames 97-101)

is not

- - - - - - -

162. A "dc supply" which replaces batteries for use with ion chambers, electronic instruments, and the like consists of three main parts: _____, _____, and _____. (Frame 89).

ripple, dc

- - - - - - -

163.	A device that is used to increase the strength of a weak electrical signal is an _____. (Frames 103, 106, and 107)	transformer, rectifier, filter
164.	The amount of amplification that a device produces is referred to as its _____. (Frames 110 and 112)	amplifier
165.	An amplifier that has an input of 2 ma and an output of 1 amp has a current gain of _____. (Frames 110 and 111)	gain
166.	The elements of a diode tube are a _____ and a _____. (Frame 115)	500
167.	The elements of a triode amplifier tube are a _____, a _____, and a _____. (Frame 113)	cathode, plate
168.	The electrons which make up the plate current come from the _____. (Frame 117)	cathode, grid, plate or anode
169.	In order to emit electrons, the cathode must be _____. (Frames 117 and 118)	cathode
170.	The current which flows in an amplifier tube from cathode to plate is controlled by the _____. (Frames 125-128)	heated

171. Because the signal voltage which is developed across the load in the plate circuit of a triode tube is larger than the controlling signal applied to its grid, the tube is said to _____ the input signal. (Frames 103, 106, and 108)

grid

- - - - - - -

amplify

V-2. RADIATION DETECTION

The purpose of this section is to present the basic principles of electrical methods of radiation detection, especially as applied in reactor operation.

\- - - - - - -

2.1. Ionization Chambers

1. Radiation is detected by a number of instruments such as electroscopes, ionization chambers, scintillation crystals, and cloud chambers. We shall confine our study to ionization (or ion) chambers because almost all radiation detection devices for reactor applications make use of such chambers. A typical chamber, illustrated in Figure V-40, is a gas-filled can with a metal conductor (wire) located in the center of the can and insulated from the conducting wall of the can.

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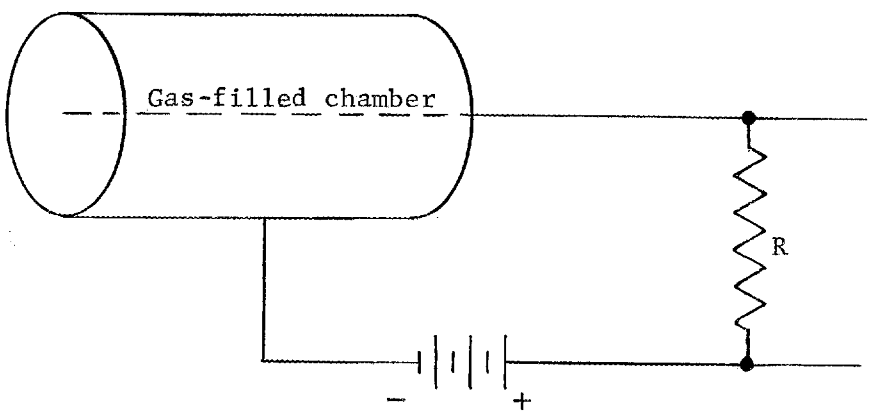

Fig. V-40. Diagram of Simple Ionization-Chamber Circuit

\- - - - - - -

2. When ionizing radiation passes through the chamber, it produces ion pairs in the gas along its path, as in Figure V-41. An ion pair, you may recall, is composed of the positively charged atom and the negatively charged electron that has been separated from the atom by the radiation. Usually only the charged atom is referred to as an ion.

- - - - - - -

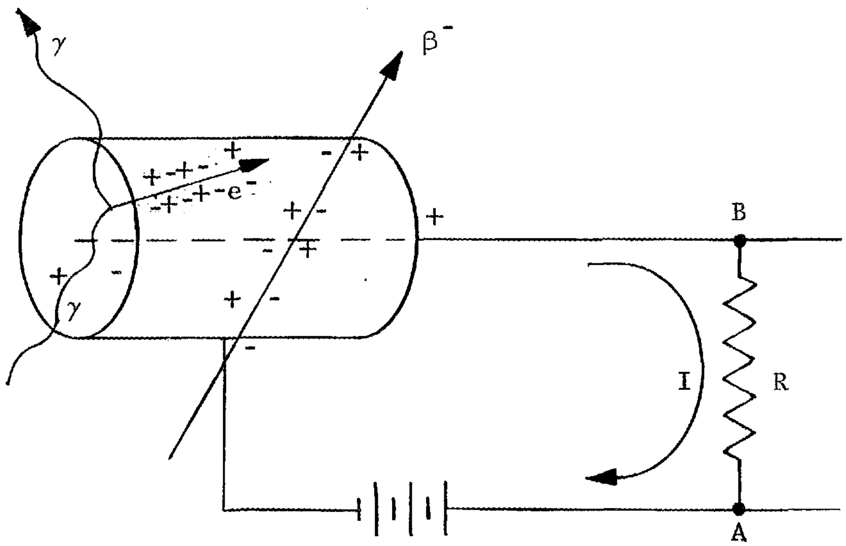

Fig. V-41. Ionization Chamber Conducting
(I represents electron current)

- - - - - - -

3. The charged pair (the electron and the charged atom from which it has been removed) is called an _____ _____.

- - - - - - -

4. When a potential difference is placed between the center wire and the can surface of the ionization chamber, each particle of the ion pair is attracted by its opposite charge and will move toward that charge.

ion pair

\- - - - - - -

5. In Figure V-41 the wire is positively charged and the can is negatively charged. Thus, the electrons will move toward the center wire and the positively charged ions will move toward the inner surface of the _____ charged can.

\- - - - - - -

negatively

6. When ionizing radiation enters the ionization chamber, the movement of the resulting ion pairs constitutes an electric current in the chamber and thus completes the electrical circuit of battery, ionization chamber, and load (resistor, R). The chamber therefore becomes a _____.

\- - - - - - -

conductor

7. When there is radiation, the gas in the chamber is ionized and acts as a _____ for the electric current. The circuit is then (an open, a closed) circuit.

\- - - - - - -

conductor, a closed

8. When there is no radiation, the gas remains unionized and the circuit remains open. Thus, the ionization chamber acts as a nonconductor. (Actually it is more like a high-valued resistor whose value is decreased by radiation--the higher the amount of radiation, the lower the value of the resistor.)

\- - - - - - -

9. The path of the radiation through the gas of the ionization chamber is marked by _____ pairs, as shown in Figure V-41. Some other types of ionizing radiation and particles not illustrated are alpha particles, secondary radiation from neutron absorption, photo electrons, etc.

- - - - - - -

10. The gas which was a nonconductor is now, because of the ion pairs, a _____. — ion

- - - - - - -

11. The electrons which are freed from gas atoms by radiation are attracted to the center wire (often called center electrode) because it is _____ charged. — conductor

- - - - - - -

12. The positively charged gas atoms (ions) are attracted to the inner surface of the chamber "can" (the can is also called an electrode) which is _____ charged. — positively

- - - - - - -

13. Before explaining the effect of this ion movement on the external circuit, let us look at the effect (on the ions themselves) of various potential differences which might be applied across the chamber. — negatively

- - - - - - -

14. The charged particles produced by the radiation will be attracted to the electrode which is charged (the same as, opposite to) their charge. The attractive force will be proportional to the amount of voltage applied across the _____.

- - - - - - -

15. The electrons will be attracted to the _____ charged center wire, and the much heavier positive ions will be attracted to the _____ charged shell.

opposite to, chamber

- - - - - - -

16. At low applied voltages, the positive ions will move so slowly that most of them will be able to recombine with electrons before they reach the electrodes, see Region I in Figure V-42.

positively, negatively

- - - - - - -

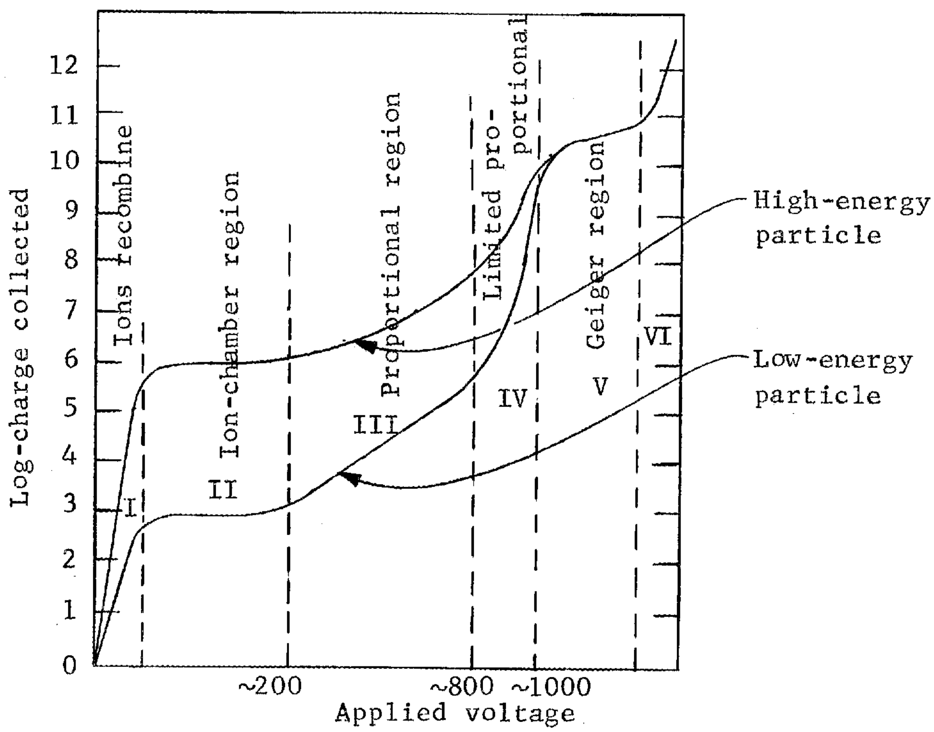

Fig. V-42. Variation of Charge Collected Versus Applied Voltage for Particles of Two Energy Levels

- - - - - - -

17. Above a certain voltage, as in Region II, the positive ions and electrons move so fast that recombination is almost impossible and practically every ion and electron will reach an _____.

- - - - - - -

18. This <u>movement</u> in the chamber of <u>electrons</u> to the center wire and <u>positive ions</u> to the can surface constitutes a <u>current</u>. In this condition, the ion chamber acts as (a conductor, an open circuit) in that it <u>allows a current to flow</u> in the circuit. — electrode

\- - - - - - -

19. When the <u>voltage</u> is <u>high enough</u>, as in Region II, (few, most, essentially all) ions reach the electrodes. — a conductor

\- - - - - - -

20. After the applied voltage is just high enough to cause <u>all the ions</u> to reach the electrodes, the voltage can be <u>further increased</u> to about <u>200 volts</u> (Figure V-42) <u>without</u> any <u>increase</u> in ion current. (Ion current is the current through the ionization chamber due to ion movement.) This voltage "region" is called the "<u>ionization-chamber region</u>". — essentially all

\- - - - - - -

21. <u>Within</u> the <u>ionization chamber region</u>, the applied voltage can be increased or decreased with no appreciable change in _____ current.

\- - - - - - -

22. <u>Also within</u> the ionization chamber region, the ion current <u>increases</u> if the <u>energy</u> of the radiation particles (or photons) <u>increases</u> or if the <u>number</u> of radiation particles (or photons) <u>increases</u> but does <u>not</u> increase if the <u>applied voltage</u> is _____. — ion

\- - - - - - -

23. Within the ionization chamber region, the ion current can be increased only by increasing the _____ or the _____ of the radiation particles (or photons).

increased

- - - - - - -

24. Although, in this region, the ion current does not increase with a change in voltage, the speed of the individual ions does increase as the voltage increases.

energy, number

- - - - - - -

25. The ionization-chamber region of the curve is the region (below about 200 volts) in which an increase in voltage across the chamber produces essentially no change in ion current because every _____ produced by the radiation reaches an electrode.

- - - - - - -

26. However, an increase in voltage does produce an increase in the _____ of the ions.

ion

- - - - - -

27. When the applied voltage is increased above about 200 volts, another interesting thing happens; there is a "population explosion". Some of the negative ions (electrons) are accelerated to such speeds toward the positive electrode that, before they reach it, they strike gas molecules hard enough to cause additional or secondary ions to be formed. These add to the original (primary) ionization current.

speed

- - - - - - -

28. In Region III of the curve (Figure V-42) the ions produced by the radiation move toward the electrodes with such speed that when they hit other gas particles they produce _____ ionization.

\- - - - - - -

29. Within the proportional region, the ion current increases proportionally if the energy of the radiation particles (or photons) increases, or if the number of radiation particles (or photons) increases, or if the applied voltage is _____. secondary

\- - - - - - -

30. The "population explosion" or formation of secondary ionization explained earlier is called "avalanche" or "cascade" ionization. At the lower electrode voltages the avalanches form near the positive electrode and are scattered along it, depending on where the primary ionization occurred. At higher voltages the _____ begin to form farther from the positive electrode since the primary electrons reach ionizing speeds when farther away. increased

\- - - - - - -

> Radiation detectors designed to be operated in the "proportional region" are no longer, strictly speaking, simple "ionization chambers" since the avalanche effect has been added. They are more commonly called "proportional counters". avalanches

\- - - - - - -

31. As the applied voltage is increased, the avalanches grow larger. This makes the ion population increase in proportion to the applied _____.

\- - - - - - -

32. As the applied voltage is increased further to about 1000 volts (Figure V-42) the avalanches have increased until the chamber volume becomes filled with ions each time a ray (photon) or particle of radiation enters the _____. This Region V is called the "Geiger" region. — voltage

- - - - - - -

33. In the Geiger region, radiation producing a large amount of primary ionization will produce no greater secondary ionization effect than radiation producing a small amount of primary ionization. The ion current from the avalanche effect is practically the same, regardless of the amount of _____ ionization. — chamber

- - - - - - -

34. The term "ionization chamber" is generally used to refer to those chambers operating in the ion-chamber region of Figure V-42. Chambers operating in the Geiger region are called "Geiger-Mueller tubes" or simply "G-M tubes". — primary

- - - - - - -

35. Ionization chambers are used to monitor high-intensity radiation where many radiation particles enter the chamber every second causing a continuous electrical current to flow through the chamber. When the amount of radiation increases, the current flow increases; and when the amount of radiation decreases, the current flow _____.

- - - - - - -

36. When the amount of _____ entering an ionization chamber increases, the _____ through the chamber increases. — decreases

- - - - - - -

37. Geiger-Mueller tubes are used to monitor low-intensity radiation when only a few radiation particles enter the chamber each second or even fewer than one per second. Since each radiation particle can produce a large avalanche of ionization, it is possible to detect each _____ of radiation.

radiation, current

- - - - - - -

38. Since both high-energy and low-energy particles of radiation entering a G-M tube produce about the same amount of ionization, a G-M tube can only monitor the number of radiation particles entering it per second instead of the _____ of the particles.

particle

- - - - - - -

39. Geiger-Mueller tubes are used to monitor (low-intensity, high-intensity) radiation. Ionization chambers are used to monitor _____-intensity radiation.

energy

- - - - - - -

40. Chambers operated in the proportional regions can also be used to monitor single particles of radiation. These have an advantage over G-M tubes because they can be used to distinguish high-energy particles from _____ particles.

low-intensity, high

- - - - - - -

41. A high-energy radiation particle passing through a proportional chamber produces more ionization than a low-energy particle would. This means there would be a _____ pulse of electric current through the chamber for a high-energy particle than for a low-energy particle.

low-energy

- - - - - - -

42. An appropriate electronic system can distinguish between a large pulse of electric current and a small pulse from an ion chamber working in the _____ region.

larger or higher

- - - - - - -

43. A radiation-monitoring system which uses an ionization chamber operating in the proportional region or range is generally referred to as a proportional counter.

proportional

- - - - - - -

44. Proportional counters can be used to distinguish between _____-energy radiation _____ and low-_____ energy _____ _____.

- - - - - - -

45. Now let us return to the subject of what happens to the electrons and gas ions as they are swept to the _____.

high, particles, radiation particles

- - - - - - -

46. When a particle or ray (photon) of radiation enters an ionization chamber, the gas becomes a conductor because of the _____ pairs formed.

electrodes

- - - - - - -

47. The movement of _____ pairs toward both the center wire and the can surface makes the chamber act as a conductor to produce a _____ in the external circuit.

ion

- - - - - - -

48. Even when there is no ionizing radiation, the battery keeps the center wire deficient in electrons. Thus, when the free electrons in the chamber contact the center wire, they become a part of the total circuit current and move through the resistor toward the battery and the can surface where the battery maintains (a deficiency, an excess) of electrons. — ion, current

- - - - - - -

49. At the same time, the positively charged ions move toward the _____ charged can surface. — an excess

- - - - - - -

50. As the _____ _____ reach the can surface, they combine with free electrons there and become uncharged atoms again. This action completes the circuit. — negatively

- - - - - - -

> The same number of electrons must be taken from the negatively charged electrode to neutralize the positive ions as was lost by them to the positively charged center wire. The atoms become ionized (lose electrons which go to the center wire) and then go to the can wall for a new supply which again will be lost to the center wire by ionization. In continuing this action, they could be considered as acting something like ferry boats hauling electrons from the negative electrode to the positive electrode.

positive ions

- - - - - - -

51. When radiation stops passing through the chamber, all of the gas molecules return to their uncharged state and the gas becomes nonconducting, so the chamber again acts as a _____ until more radiation comes through.

- - - - - - -

52. When the gas in the chamber (Figure V-41) is ionized, the battery causes current to flow through the chamber and the resistor, R, making point "B" negative with respect to the point "A". The potential difference is proportional to the current flow which is, in turn, proportional to the amount of _____ in the chamber.

nonconductor

- - - - - - -

53. When radiation causes the gas in the chamber to become conducting, a _____ is developed across the resistor, R (Figure V-41).

ionization

- - - - - - -

54. We should note that while the ionization chamber is nonconducting there is no potential difference across the resistor, R, since there is no _____ through the chamber to cause the potential difference.

voltage or potential difference

- - - - - - -

55. The voltage across R is produced when radiation passing through the chamber makes it a conductor and allows an electron _____ to flow.

current

- - - - - - -

56. Thus, the external signal that _____ has caused ionization in the G-M tube is the pulse of voltage across R.

current

- - - - - - -

57. The term "signal voltage" is often used to designate the voltage developed across the resistor, R, (Figure V-41) by the "signal current" produced by _____ in the ion chamber.

radiation

- - - - - - -

58. When a particle or photon of radiation goes through a G-M chamber, there is a pulse of _____ _____ across the resistor, R.	radiation or ionization
59. From the preceding statement, we might think that every particle or photon that goes through the G-M chamber produces _____. This is not strictly true. There is always the chance that the G-M chamber is already conducting when the radiation enters and the new ionization is masked by the ionization of the preceding radiation.	signal voltage
60. If the signal voltage developed across the resistor, R, (Figure V-41) is constant, the ion chamber is in a radiation field of _____ intensity.	ionization
61. Signals from G-M tubes and proportional counters (chambers) are in the form of _____ of current. Signals from ordinary ion chambers, as they are customarily used, are _____ _____ of varying magnitudes.	constant
62. One of the simplest ways to detect a pulse of signal current is through the movement of the pointer of a very sensitive current-measuring instrument or "galvanometer" connected in place of the resistor (Figure V-41). Each up-scale movement of the pointer would be an indication that a particle of _____ had passed through the chamber.	pulses, direct currents

63. Referring to Frame 62, the movement of the galvanometer pointer is an indication that radiation has produced _____ in the chamber. — radiation

- - - - - - -

64. There is a current in the external circuit only when radiation passing through the chamber ionizes the gas. So, a movement of the galvanometer pointer means that _____ has passed through the chamber; that the gas has been _____, completing the circuit; and that a _____ flow has developed--resulting in the instrument indication. — ionization

- - - - - - -

65. Although galvanometers can be made sensitive enough to measure fairly small currents, such as those obtained from ion chambers as ordinarily used, they are unsatisfactory for handling signals from pulse chambers. The present practice is to employ electronic type current amplifiers rather than galvanometers with current chambers and to employ voltage amplifiers with pulse chambers. The outputs from the amplifiers may then be fed to ordinary indicating and recording instruments. — radiation, ionized, current

- - - - - - -

66. There are several types of ionization chambers; these vary as to size, shape, materials, and the gas which fills the chamber. However, they all detect radiation as a result of the fact that radiation causes _____ when it passes through the _____.

- - - - - - -

67. And, although all ionization chambers are designed to detect radiation, not all designs will detect all types of _____. | ionization, chamber

- - - - - - -

68. The materials and design of an ionization chamber determine the type of _____ which it can detect. | radiation

- - - - - - -

69. Gamma and beta radiation are detected by ionization chambers which are filled with gases such as air, nitrogen, or argon. However, beta radiation is not as penetrating as gamma radiation; and so, to detect beta particles in addition to gamma radiation, the chamber walls must be thin enough for the _____ _____ to penetrate them. | radiation

- - - - - - -

70. The walls of the ionization chambers must be thinner for _____ than for _____ radiation because the beta particles are not as penetrating as gamma rays. | beta particles

- - - - - - -

71. If you have a G-M survey meter, note that the shield around the probe of the meter is solid on one side and slotted on the other. Hold the solid side of the probe against a luminous-dial watch face and note that the count is about background. Then turn the slotted side to the watch and note the increased counting rate. The luminous dial emits a lot of beta radiation and very little gamma. | beta, gamma

- - - - - - -

72. When the solid side is toward the watch face, very few of the many _____ particles emitted can penetrate the solid shield.

— — — — — — —

73. When the slotted side is toward the watch face, beta particles penetrate the thin wall of the G-M tube and the meter reading (increases, decreases, remains the same). — beta

— — — — — — —

74. Alpha particles, which are even less penetrating than beta particles, would require that the ionization chamber walls be (thicker, thinner) than are required for beta particles. — increases

— — — — — — —

75. You will recall from your studies of radiation that the ionization produced by a charged particle is related to its charge, mass, and energy. In addition to being relatively heavy, an alpha particle has two positive charges and, thus, would be expected to leave a very dense trail of _____ pairs when it travels through any material. — thinner

— — — — — — —

76. So, if alpha particles could get inside the chamber, they would produce (more, less) ion pairs per distance traveled than beta radiation because their charge is greater. — ion

— — — — — — —

77. Neutrons are very penetrating, but they are unlikely to cause ionization except when they collide directly with an atom. Since the density of gas in an ionization chamber is low, a neutron would be very likely to pass through the chamber without causing _____ and thus would go undetected. — more

\- - - - - - -

78. To detect slow neutrons, the inside of the walls of some ionization chambers are coated with a neutron-absorbing material such as ^{10}B or ^{235}U; to detect fast neutrons, a hydrogen-rich material such as paraffin may be used. — ionization

\- - - - - - -

79. You will recall that the hydrogen atom consists of a nucleus of one proton and one orbital electron. Thus, a hydrogen-rich material, such as paraffin, would have a lot of protons (hydrogen nuclei) with which the fast _____ could collide.

\- - - - - - -

80. Although the neutrons would not be affected by the _____ charge of the hydrogen nucleus, there is a good chance that some nuclei will be hit by the fast neutrons. — neutrons

\- - - - - - -

81. A hydrogen nucleus can be knocked completely out of the paraffin if it is hit by a _____ neutron. — positive

\- - - - - - -

82. The speed of a fast neutron (1 to 2 MeV) is about ten to twenty million meters per second. If a fast neutron should collide with a proton at rest, it can be shown that the proton, on the average, will be given enough energy to give it half the speed of the neutron--five to ten million meters per second. — fast

- - - - - - -

83. While this is not proof that every proton hit by a fast neutron will leave the paraffin (some will go deeper into the paraffin after the collision), it does indicate that a proton near the edge of the paraffin can be propelled into the chamber gas when struck by a _____ _____.

- - - - - - -

84. The positively charged protons that are propelled into the chamber gas can have enough energy to produce _____ pairs along their paths. — fast neutron

- - - - - - -

85. If fast neutrons are allowed to bombard a hydrogen-rich material such as parafiin, there is a good probability that some _____ will be knocked out of the paraffin. — ion

- - - - - - -

86. Some of these charged particles (protons) will have enough energy to produce _____ pairs along their paths. — protons

- - - - - - -

87. Thus, a paraffin-coated ionization chamber can be used as a detector of _____ neutrons. — ion

- - - - - - -

88. When a ^{10}B atom absorbs a slow neutron, it often becomes energetic enough to eject the excess energy as an alpha particle. When this happens near the boron surface in an ionization chamber, the alpha particle can enter the gas in the chamber and produce _____ _____ along its path. — fast

- - - - - - -

89. A ^{10}B-coated ionization chamber can be used to detect _____ neutrons. — ion pairs

- - - - - - -

90. Uranium-235 coated on the inside of an ionization chamber will also absorb slow neutrons and then fission. In this case, the highly charged, very energetic fission fragments escape from the chamber wall and cause _____. — slow

- - - - - - -

91. An ionization chamber which uses ^{235}U as a coating to detect neutrons is usually referred to as a "fission chamber". — ionization

- - - - - - -

92. A ^{10}B-coated chamber would not be called (an ionization, a fission) chamber.

- - - - - - -

93. Ionization chambers which have their inner surfaces coated with paraffin, ^{10}B, or ^{235}U are all used to detect _____. — a fission

- - - - - - -

94. However, only the chamber coated with ^{235}U is called a _____ chamber. — neutrons

- - - - - - -

95. Now let us return to the circuitry associated with the detection of radiation. When _____ passes through a chamber operating in either the ionization or the proportional range, it causes ionization, which allows a _____ to flow in the circuit. | fission

— — — — — — —

96. The number of ion pairs produced per second determines the strength of the current through an ionization chamber. Many ion pairs produced per second in the chamber will result in a (strong, weak) current in the external circuit. | radiation, current

— — — — — — —

97. Since the voltage drop across the resistor in the circuit is proportional to the current strength, a strong current in the circuit will produce a relatively (large, small) voltage drop across the resistor. | strong

— — — — — — —

98. The preceding frame stated that the voltage drop would be relatively large. In practice in ORNL reactor nuclear instrument systems, the ion chambers typically pass currents of 30 μa when the reactor is operating at full power. The resistor through which this current flows is, typically, 330,000 Ω. From E = IR, the signal voltage developed is therefore _____ volts. | large

— — — — — — —

99. Standard portable and panel-mounted voltmeters require 1 ma of current or more to produce full-scale readings. Even the most sensitive of these instruments require at least 50 μa. Such instruments clearly are not suitable for measuring ion-chamber signals directly since insufficient current is available. Recourse must be taken to using relatively complicated electronic amplifiers and circuitry since these systems can be designed to require only a very small signal _____ for normal operation. 10

- - - - - - -

100. The important thing to remember is that when the chamber is in a strong radiation field and a large number of ion pairs is being continuously produced in it a relatively _____ voltage is developed across the resistor. current

- - - - - - -

101. You will recall that the fission chamber is unique in that its electrodes are coated with ^{235}U. Although it operates in the ion-chamber portion of its range (Figure V-42), it is designed to detect single radiation particles. The voltage signal from such a chamber is not continuous but consists of a series of _____ _____. large

- - - - - - -

102. A gamma photon which loses little energy in the chamber will cause only a small amount of ionization in the chamber and thus a small signal pulse. An alpha particle which normally expends all of its energy in the chamber will produce a larger amount of ionization and thus the signal pulse will be _____. voltage pulses

- - - - - - -

103.	The strongest signal results when a neutron causes a ^{235}U atom to fission. The fission fragments are both heavy and charged; thus, they are capable of producing (large, small) numbers of ion pairs, a large current, and a _____ pulse of signal voltage.	larger
104.	If you are using a chamber coated with ^{235}U so that neutrons as well as beta, gamma, and alpha radiation can be detected, which of these types of radiation do you think will cause the largest voltage pulse across the resistor in the external circuit? _____	large, large or strong
105.	A neutron causes the largest voltage drop across the resistor because the heavy and highly charged fission fragments produce the _____ amount of ionization in the chamber gas.	neutron
106.	Now we have a new problem. If all types of radiation produce ionization in a fission chamber, how do we distinguish one type of _____ from another?	greatest
107.	Chamber design allows us to make some separations. For example, a thick-walled chamber can keep alpha and beta particles from outside sources from entering the _____.	radiation

108. We are primarily concerned with detecting radiation sources that are outside the chamber. A thick-walled fission chamber will effectively eliminate the detection of _____ and _____ from sources outside the chamber but cannot eliminate the alpha and beta radiation arising from the normal decay of the uranium which is used within the fission chamber. — chamber

- - - - - - -

109. Figure V-43 is a plot of the output of such a chamber showing the height of neutron-induced voltage pulses relative to the shorter pulses caused by the internally produced alpha and beta radiation and the gamma radiation from both external and internal _____. — alpha, beta

- - - - - - -

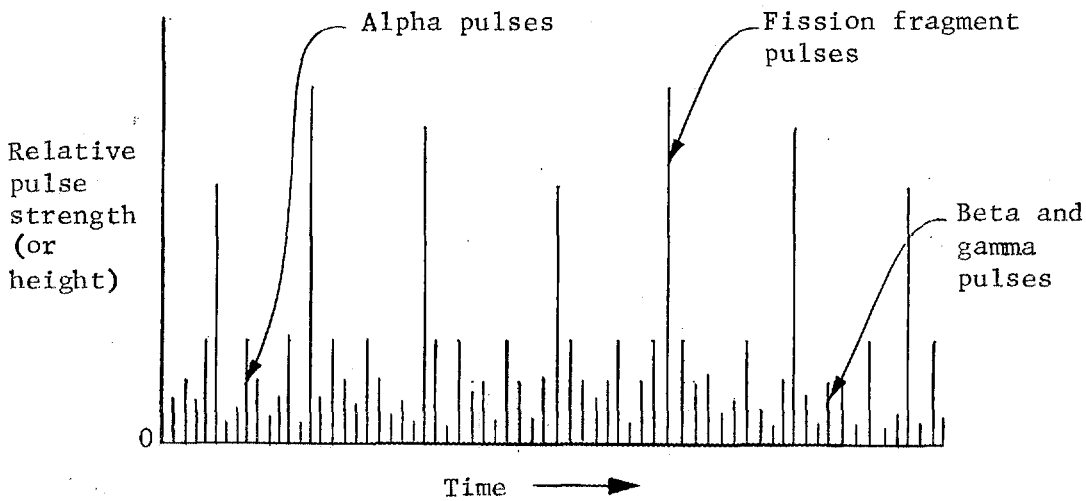

Fig. V-43. Current Pulses from Fission Chambers

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110. Such a chamber will allow us, with the proper electronic circuitry, to select for observation only the large pulses produced by the _____ caused by fission fragments, which were produced by _____ entering the chamber.

sources

- - - - - - -

111. Relatively simple electronic circuits are available that will pass large signals, such as those resulting from neutron capture in the fission chamber, but will block the smaller ones caused by other radiation. Such a combination of chamber and circuit makes it possible to detect only _____ in the presence of alpha, beta, and gamma radiation.

ionization, neutrons

- - - - - - -

112. The signal pulses in Figure V-43 could be the output from a fission chamber as displayed on an oscilloscope. Because the height of the lines depends on the sizes of the current pulses from the chamber, the term "pulse-height" is often used instead of pulse size. The pulse height is dependent on the amount of ionization produced by the _____ particles entering the chamber.

neutrons

- - - - - - -

113. The electronic apparatus that is used to analyze the pulse sizes, allowing large pulses to pass while blocking small ones, is called a "pulse-height selector".

ionizing or radiation

- - - - - - -

114. By using a "_____-_____ _____", the large pulses generated by neutrons can be selected from the rest of the pulse signals and transmitted to a counting apparatus. Thus the counting signal will be due to _____ only.

- - - - - - -

115. Knowledge of the neutron flux in the reactor is necessary at all times. The fission chamber and pulse-height circuitry are used generally to furnish this information while the reactor is shut down or is being started up. At these times the gamma flux is quite strong compared to the neutron flux.

pulse-height selector, neutrons

- - - - - - -

2.2. Counting Systems

116. Figure V-44 shows a simplified pulse counting system. It depends for its operation on an "integrator" or integrating circuit which consists of a capacitor and a resistor in parallel.

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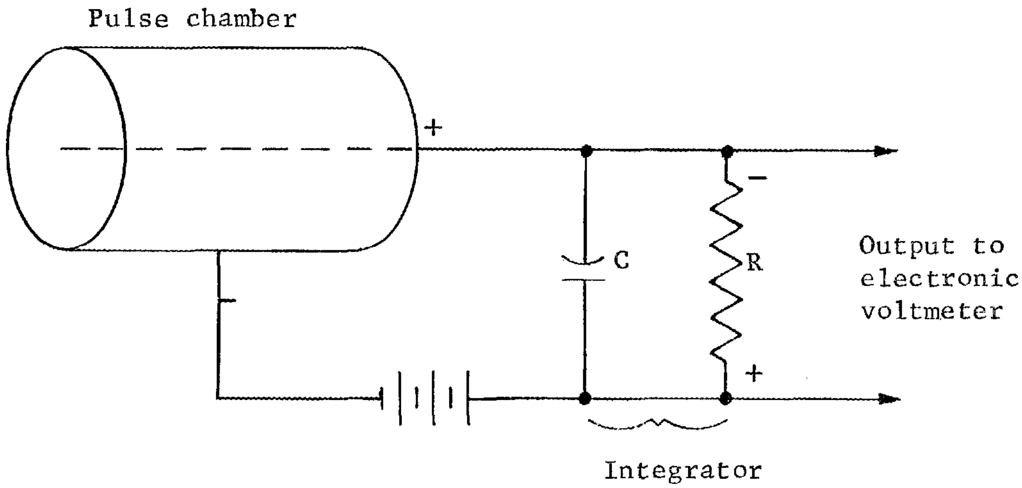

Fig. V-44. Counting System

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117. When radiation enters the chamber, each pulse of current from the chamber places a small charge on the plates of the capacitor. Between (and during) pulses the charge leaks off (discharges) through the resistor, R.

- - - - - - -

118. If the pulses are close enough together in time, the capacitor will have insufficient time to _____ between pulses and the charge will build up on the capacitor.

\- - - - - - -

119. As the charge builds up on the capacitor, so does the voltage across it. The higher the voltage across the resistor, the higher the _____ through it. — discharge

\- - - - - - -

120. When the charge added to the capacitor just equals the charge that leaks off the capacitor through the resistor in any given time, the voltage across the capacitor stops rising. The steady voltage finally reached is a measure of the intensity of the _____ in counts per unit of time. — current

\- - - - - - -

121. If the radiation intensity decreases, the number of current pulses per second goes down, the number of charges per second added to the capacitor goes down, and the voltage across the resistor also goes _____. — radiation

\- - - - - - -

122. On the other hand, if the radiation intensity increases, so does the charge on the capacitor. The voltage across the resistor goes _____. The voltage across the resistor is a measure of the strength of the radiation _____. — down

\- - - - - - -

123. If the number of pulses per second or per minute (often referred to as the "counting rate") goes down far enough, the capacitor charge will have time enough to leak off completely, or nearly so, between pulses. The pointer of the counting-rate indicator (voltmeter in Figure V-44) would jump up and down once for each radiation particle detected. — up, field

\- - - - - - -

124. For example, when using a G-M survey meter on its lowest scale, you can see a needle movement for each radiation-induced pulse which occurs. If you use an earphone, you hear each _____.

\- - - - - - -

125. Because of the avalanche effect in a G-M tube, the various particles of radiation detected produce (the same, different) sized signal pulses. — pulse

\- - - - - - -

126. In Figure V-44 the charge on the capacitor depends not only on the number of pulses detected per second or per minute, but also on the size of the pulses. The system in Figure V-44 probably (would, would not) indicate the same field strength if a proportional counter were used in one case and a G-M tube in another to measure the same radiation field. — the same

\- - - - - - -

127. In Figure V-43 the fission fragment pulses, which represent the detection of _____, are not all of the same height. Counting-rate systems employing fission chambers require "pulse-shaping" circuits in addition to pulse-height selectors and integrators for measuring neutron flux. — would not

\- - - - - - -

128. The pulse shaping circuitry produces pulses of only one size from pulses of _____ sizes coming from the pulse-height selector.

neutrons

\- - - - - - -

129. Even in what are called steady or constant radiation fields the particles enter the chambers of detecting instruments in a random fashion. This means that the current pulses from the chambers are not uniformly spaced in time.

all or different

\- - - - - - -

130. Figure V-45 illustrates the variation in the occurrence of current pulses from a chamber in a so-called "constant" radiation field. Because of this variation in the number of pulses per second, the intensity of the radiation is apparently not uniform or constant. The capacitor, C, in Figure V-44 also tends to smooth out these random variations.

\- - - - - - -

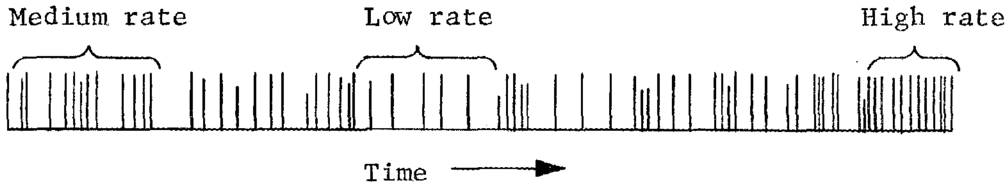

Fig. V-45. Distribution of Pulses in Time

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131. The pulses of current from a chamber in a constant field of radiation are spaced (uniformly, randomly) in time.

\- - - - - - -

132. In addition to summing the pulses from a G-M tube, the capacitor in the integrating circuit tends to _____ _____ the variations in the indicated counting rate due to the random occurrence of pulses in time.

randomly

- - - - - - -

133. Pulses may also occur so close together in time that they are practically coincident. Two gamma rays, for example, arriving at a G-M tube at the same time would produce only one pulse of current from it. This pulse would be (twice as large, the same size) as the pulse produced by a single gamma ray.

smooth out

- - - - - - -

134. The stronger the field of radiation being measured, the more the particles or rays will tend to enter the detector coincidentally. For this reason, counting systems are (more, less) accurate at high counting rates than at lower ones.

the same size

- - - - - - -

135. The size of a pulse from a fission chamber, which operates in the proportional-voltage region, depends on the energy and charge of the _____ particles (see Frames 102-105). Two coincident particles would produce a pulse in a fission chamber that is (twice as large, the same size) as one particle.

less

- - - - - - -

136. Frames 110-115 explained that the pulse-height selector used with a fission chamber could be adjusted to pass only _____ pulses which result when neutrons enter the chamber.

ionizing or radiation, twice as large

- - - - - - -

137. Fission chambers frequently are used to detect weak neutron fluxes in the presence of strong gamma fluxes. In strong gamma fluxes, many rays often enter the chamber practically simultaneously. The sum or "pile up" of pulses from these coincident gamma rays may be a pulse as large as some of the _____-caused pulses. — large

- - - - - - -

138. At low counting rates in the presence of a heavy gamma flux, gamma pile-up in fission chamber counting systems may cause the apparent neutron flux to be (lower, higher) than it actually is. — neutron

- - - - - - -

139. A finite length of time, although short, is required to collect the ionization formed in a chamber. This means that even in complete absence of any coincidence effects there is a maximum counting rate beyond which a counter isn't reliable. At some rate the pulses run together and under such circumstances there is a continuous current from the chamber and no pulses. The counting-rate readout thus becomes zero and the chamber is said to be "saturated" or "overloaded". — higher

- - - - - - -

140. In the fission chamber counting system, the pulse shaper, in effect, stretches the length of the chamber pulses. The maximum counting rate is therefore (lower, higher) than without it. Counting channels are never used for reactor protection instruments because they become partially or completely saturated in the high neutron fluxes which may occur under abnormal operating conditions. The instrument is sometimes said to "fold over" since the output goes down with increasing input above its working range.

– – – – – – –

141. When good accuracy is required, many fission-chamber counting channels (ordinarily simply called "counting channels") are limited to a maximum of 10,000 counts per second. When some error is acceptable, this may go to 100,000 counts/sec. (Some newer systems provide good results up to about 10^6 cps.) lower

– – – – – – –

142. Counting systems (are, are not) suitable for reactor protection instruments.

– – – – – – –

143. Counting systems are frequently interferred with by "electrical noise". You have driven your car, while listening to the radio receiver, through certain areas or under power lines and observed the considerable increase in the frying sounds from the receiver. You were listening to electrical _____ picked up by our car antenna. are not

– – – – – – –

144. Electrical noise comes from electric currents leaking across or through insulation, from lightning, and from relays, switches, and contactors turning electric currents on and off. This noise follows electric conductors and also radiates into space like radio waves. There is always much _____ _____ of this sort around reactor installations. — noise

\- - - - - - -

145. As observed on an oscilloscope, noise is a series of spikes or pulses very similar to fission-chamber pulses. No method has been developed for separating noise pulses from chamber _____ by special electric circuitry. — electrical noise

\- - - - - - -

146. Counts resulting from electrical noise in a counting system are generally referred to as false or spurious. — pulses

\- - - - - - -

147. When the noise pulses picked up by a counting system are smaller than most of the "neutron" pulses, the noise can be practically or completely eliminated by properly adjusting the _____-_____ _____.

\- - - - - - -

2.3. Current Chambers

148. Earlier we explained that a fission chamber, when _____, puts out a continuous current. This type chamber may be operated in either of two ways or "modes"--pulse or current. In ORNL instrument systems, fission chambers are usually operated only in the pulse mode. — pulse-height selector

\- - - - - - -

149. Ion chambers are normally operated in the current mode and boron-lined chambers of this type are used almost exclusively at ORNL for measuring the neutron flux (or power) in a reactor when it is operating in the "power range" (from about 1% to 100% of full power). saturated

- - - - - - -

150. At ORNL, fission chambers are normally operated in the _____ mode and ion chambers are operated in the _____ mode.

- - - - - - -

2.4. Neutron-Detection Problems

151. At this time we shall discuss briefly some problems related to neutron detection through the whole range of reactor operations from startup to full power. Problems discussed here will again be referred to when we discuss all control instruments in Section V-4. pulse, current

- - - - - - -

152. The neutron intensity at full reactor power may be 10^{10} or more times greater than before startup.

- - - - - - -

153. Because there is such a great increase in the neutron intensity from _____ _____ to full-power operation, at least three types of neutron-detecting chambers may have to be used to cover this wide range.

- - - - - - -

154. In the low range of neutron intensity, ordinary fission chambers are used with pulse-type circuitry. In this low range, neutron production is small enough for individual neutrons to be counted if pulse-height selectors are used to select _____-induced pulses and to reject pulses caused by _____, _____, and _____ radiation.

before startup

- - - - - - -

155. In the low range of neutron intensity (when the reactor is shut down), gamma intensity may be so high that a fission chamber must be used with _____-type circuitry and a pulse-height selector to separate the larger _____-induced pulses from the more numerous but smaller _____-induced pulses.

neutron,
gamma,
beta,
alpha

- - - - - - -

156. In the intermediate range of neutron intensity, a chamber called a "compensated ionization chamber" (abbreviated CIC) is used as a current chamber, followed by a special type of current amplifier. In this range, ionization caused by gamma radiation and ionization induced by neutrons may be, relatively, about equal.

pulse,
neutron,
gamma

- - - - - - -

157. Counting systems using fission chambers operate satisfactorily, up to 10^4 or 10^5 counts/sec. This is equivalent to a power increase of 10^4 or 10^5. This still leaves about a 10^5 or 10^6 increase in power to be covered. The CIC's can be designed so that with special current amplifiers they will read neutron flux from 10^{-6} of full power to somewhat more than full power.

- - - - - - -

158. The above-mentioned two types of instrumentation used together (can, cannot) be used to cover the 10^{10} range of neutron flux encountered in reactor operation.

- - - - - - -

159. The fission chamber of the counting system could be, and often is, withdrawn into shielding when the counting rate reaches 10^4 cps, thus placing it where the flux is much _____ and, therefore, the system is back into its working range. can

- - - - - - -

160. In the intermediate range of neutron intensity, neutron-to-gamma ratio has increased such that the ionization caused by neutrons is about equal to that caused by gamma radiation. Compensated _____ chambers and _____ amplifiers are used from this power level upward because such instrument channels (systems) are more accurate and are not subject to "foldover" or saturation as are counting systems. less

- - - - - - -

161. Now for gamma compensation: A gamma-compensated ionization chamber (CIC) is actually two chambers or chamber sections in one assembly, as shown in Figure V-46. This design may consist of a small hollow cylinder inside a larger hollow cylinder. ionization, current

- - - - - - -

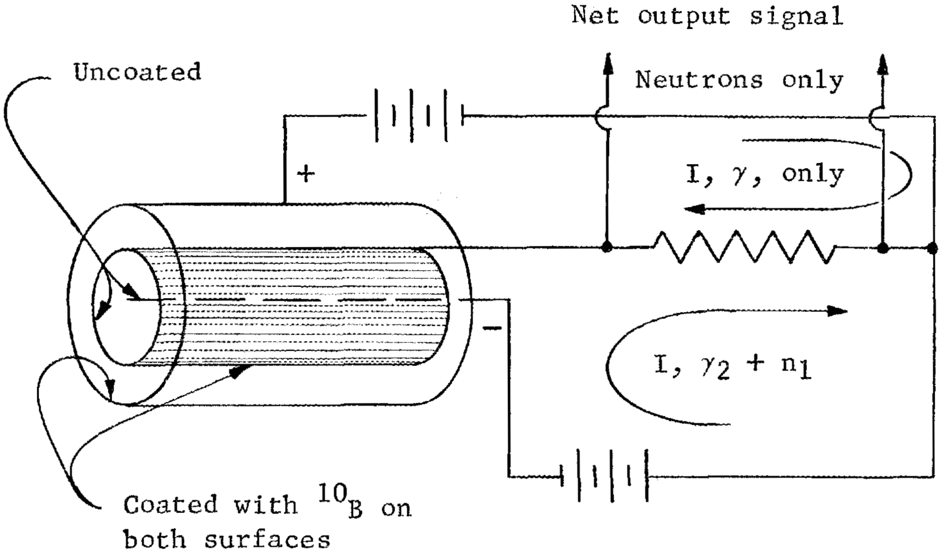

Fig. V-46. Gamma-Compensated Ionization Chamber

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162. The walls of one of the chamber sections (volumes), usually the outer, are coated with ^{10}B so that it is sensitive to neutrons, as well as to gamma radiation. The other chamber section is uncoated so that it is sensitive to _____ radiation only.

- - - - - - -

163. When a gamma ray goes through, it produces ion pairs in both chambers in about equal numbers because the volumes of the chambers are equal. Equal numbers of ion pairs will produce nearly equal _____ in the external circuits. These nearly equal currents try to flow in opposite directions through the resistor which, of course, is not possible. This causes the signals from the two chamber sections to cancel or give an approximately zero net voltage across the _____ and no appreciable gamma-signal net output. gamma

- - - - - - -

164. Neutrons will interact only with the boron-coated chamber lining to produce _____ only in that chamber. The current caused by the neutron-induced ionization is not cancelled by an equal opposing current and so produces an output signal which can be detected.

currents, resistor

— — — — — — —

165. In the intermediate-power range, neutron-induced ionization is (far more than, about equal to, far less than) the gamma-induced ionization.

ionization

— — — — — — —

166. In this range, a _____-type circuit and chamber may become saturated unless the chamber can be repositioned.

about equal to

— — — — — — —

167. In this range, a _____-type circuit and chamber are used.

pulse

— — — — — — —

168. Also, a different chamber, called a _____-_____ ionization chamber, is used.

current

— — — — — — —

169. The gamma-compensated ionization chamber (CIC) is actually _____ chambers in one. The interior surfaces of one of the chambers is coated with ^{10}B so that in addition to the ionization produced by gamma radiation _____ will produce alpha particles, which, in turn, produce ionization.

gamma-compensated

— — — — — — —

170. The other chamber is uncoated. Ionization in this chamber is produced only by _____ radiation.

two, neutrons

— — — — — — —

171. The current produced by gamma radiation in one chamber compensates for the same amount of current produced by gamma radiation in the other chamber so that the net output signal voltage caused by gamma radiation is nearly _____ or approximately cancelled. gamma

- - - - - - -

172. To say that only gamma radiation and neutrons are present is not exactly true. The effects of other types of radiation, however, are ordinarily too small to be of concern. zero

- - - - - - -

173. Since neutron-induced alpha particles (from ^{10}B) cause ionization in only one chamber, there is no compensating current from the other chamber; therefore, the net output-signal voltage, practically speaking, is the signal produced by _____ only.

- - - - - - -

174. In the highest power range (that is, after the reactor reaches a neutron-flux level of approximately 1% of full power), the relative amount of ionization produced in a chamber by gamma radiation is so much less than that due to neutrons that compensation for gamma radiation is not necessary. Thus, a boron-coated, uncompensated ionization chamber--the parallel-circular-plate (PCP) type chamber (Figure V-47)--becomes useful at this level. neutrons

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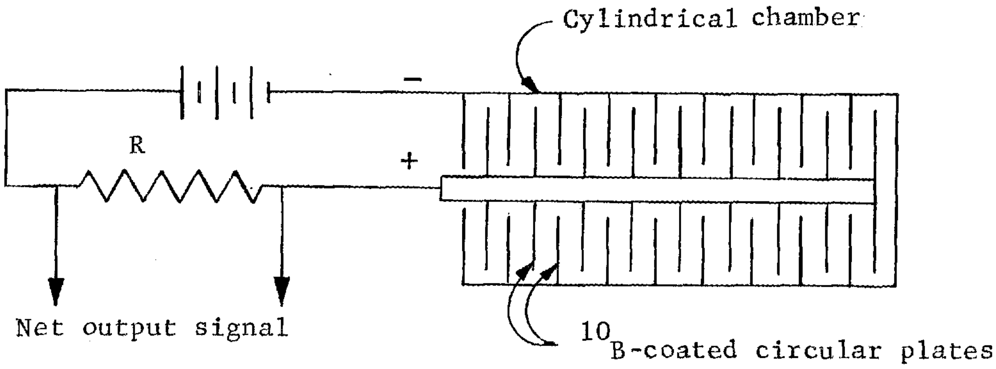

Fig. V-47. Simplified Diagram of a Parallel-Circular Plate (PCP) Ionization-Chamber Circuit

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175. The PCP chamber, used at higher power levels, is uncompensated because the amount of ionization caused by neutrons is so much greater than the amount caused by _____ radiation that _____ is not necessary.

- - - - - - -

176. Another reason that gamma compensation is not necessary at higher reactor power levels is that the gamma radiation also becomes essentially proportional to the reactor power level. Therefore, the combined gamma and neutron signals can be used to monitor the reactor _____ _____.

gamma, compensation

- - - - - - -

177. At power levels greater than 1% of full power, compensated ionization chambers are (used almost exclusively, not needed) to monitor the reactor power level.

power level

- - - - - - -

178. Although power (neutron flux) measurements above about 1% of full power are normally made with instrumentation employing uncompensated chambers, the intermediate-range instrumentation is usually kept in service because its measurements are still reliable also. not needed

- - - - - - -

179. As we have said, parallel-circular-plate (PCP) chambers customarily are used to measure neutron flux in the power range of reactor operation. The current output of these chambers is amplified and used to drive linear recorders in the _____ range of operation. These linear recorders are often called "safety" recorders. (These are discussed further in the following sections.)

- - - - - - -

180. The linear recorders that read the output of the PCP chambers are called _____ recorders. These read the reactor power level in the _____ range. power

- - - - - - -

181. Figure V-48 compares a linear and a logarithmic scale. The logarithmic scale may be read more accurately (above, below) 20% of full power (N_F). This is discussed further in a later section. safety, power

- - - - - - -

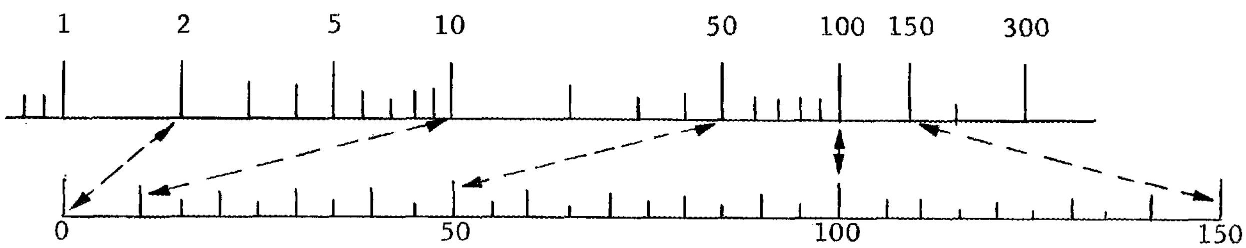

Fig. V-48. Comparison of Logarithmic and Linear Scales

- - - - - - -

182. Of the two scales in Figure V-48, the _____ one may be read more accurately at powers above 20% N_F. — below

- - - - - - -

2.5. Self Test

183. In an ionization chamber, a gas is ionized when _____ passes through the chamber. (Frame 2) — linear

- - - - - - -

184. An "ion pair" consists of a positively charged _____ and a negatively charged _____. (Frames 2 and 3) — radiation

- - - - - - -

185. In an electric field, the positively charged atom of an ion pair will be attracted to the _____ charged electrode and the negatively charged electron will be attracted to the _____ charged electrode. (Frames 4 and 5) — atom, electron

- - - - - - -

186. When the gas in an ionization chamber becomes "ionized", it will _____ an electric current. (Frames 6-10) — negatively, positively

- - - - - - -

187. As the voltage is increased across an ionization chamber operating in the proportional range in a radiation field, the gas becomes more conducting because of an increase in the number of _____ ions produced by the primary ions. (Frames 27-30) — conduct

188. When the voltage across an ionization chamber is high enough, each particle of radiation initiates enough ionization to "saturate" the chamber and produce a large pulse of current. Chambers that operate in this voltage region are called _____ tubes or chambers. (Frames 31-33)

secondary

- - - - - - -

189. The result of a beta particle moving through an ionization chamber is a pulse of _____ across a resistor in the external circuit. (Frames 52-57)

G-M or Geiger-Mueller

- - - - - - -

190. A beta particle entering an ionization chamber operating in the proportional region will cause a (higher, lower) pulse than one caused by a fission fragment. (Frames 103 and 104)

voltage

- - - - - - -

191. The design of an ionization chamber, in large measure, determines the type of _____ that it will detect. (Frames 57-82 and 106-107)

lower

- - - - - - -

192. When the inside walls of an ionization chamber are coated with a material such as ^{10}B, the chamber will detect _____. (Frames 78-88).

radiation

- - - - - - -

193. An ionization chamber coated with ^{235}U is called a _____ chamber and is used to detect (fast, thermal) neutrons. (Frames 78, 90, and 91)

neutrons

- - - - - - -

194.	An electronic device which will conduct electrical pulses above a selected energy level and block those of lower energy levels is called a ____-____ selector. (Frames 112-114)	fission, thermal

- - - - - - -

195.	The number of electrical pulses produced by an ionization chamber and its associated circuitry per length of time (per second or per minute) is called the "____ rate". (Frame 123)	pulse height

- - - - - - -

196.	Spurious counts in a counting system can be caused by electrical ____. (Frames 143-146)	counting

- - - - - - -

197.	Pulsed-type radiation-detection circuits are most effective in the ____ range of reactor operation. (Frames 115, 154, and 155)	noise

- - - - - - -

198.	Above the startup range of a reactor, ____ chambers and amplifiers are used. (Frames 156-165)	startup

- - - - - - -

199.	Compensated ionization chambers are used in the ____ range of reactor neutron flux. (Frames 156-165)	current

- - - - - - -

200.	Compensated ionization chambers are so constructed that the output voltage from ____ radiation is minimized. (Frames 161-165)	intermediate

- - - - - - -

201. In the "power" range, neutron flux intensity is such that the ionization chamber which detects neutron flux (does, does not) need to be gamma compensated. (Frames 174-178) — gamma

- - - - - - -

202. Parallel-circular-plate type ionization chambers usually used in the "power" range (are, are not) gamma compensated. (Frames 174, 175, and 179) — does not

- - - - - - -

203. The power-range instrument channels (safety channels) give more precise readout information beginning about 20% N_F because the scales are _____. (Frames 181 and 182) — are not

- - - - - - -

linear

V-3. REACTOR OPERATION SYSTEM

3.1. General Philosophy

1. The reactor operation system includes those groups of devices whose functions are to start the reactor plant; to monitor it and to exercise control during startup; to operate it routinely within its design limitations for its intended purpose; to reduce the power level when a monitored variable exceeds a preset limit (which is below that of the scram setpoint of the reactor protection system); and to shut down the reactor for such purposes as routine maintenance, refueling, etc. (The term control system is often used to designate the reactor operation system.) The reactor operation system regulates reactor power and process variables and provides information of operating conditions for operator surveillance (readout devices and annunciators).

\- - - - - - -

2. Although not part of the operation system, the fast-shutdown (protection) system needs mentioning for clarity. This sytem, sometimes called the "safety" system, has a single, distinct purpose--to protect the reactor by shutting it down automatically and as rapidly as possible upon detection, by its instrumentation, that the reactor operating conditions have strayed outside design limits. The "safety" channels, discussed later, scram (fastest possible shutdown) the reactor if the power exceeds an established safe maximum level. Other conditions may exist which also call for fast shutdowns.

\- - - - - - -

Reactors are normally operated at some maximum permissible power level known to be well below that level at which the fuel might be damaged by high temperatures. To guarantee that the power level never reaches this danger level, the reactor safety systems are designed to scram the reactors at some level between the maximum operating level and the danger level. At the ORR, the scram level is 43.5 MW (145% of full power) and at the HFIR it is 130 MW (130% of full power). Also at levels between the operating and scram level, control provisions are made to lower the power by automatic reduction of the servo demand (setback) or by automatic insertion of the control rods (reverse) to avoid a scram if some abnormal condition should cause the power level to start rising. The scram action of the safety instruments is accomplished in ORNL reactors, for example, by electronic reduction of the control-rod magnet currents; the power-reduction (control) functions are initiated by switches in the power-level (safety) recorders.

- - - - - - -

3. Figure V-49 is a block diagram that shows how both the operator and the instruments co-operate to control the reactor; it also shows the "outside" factors that must be considered in any problem of control.

- - - - - - -

4. Although all of the feedback paths or loops shown are important, the two with which we are most concerned are the one to the operator and the automatic one to the instruments.

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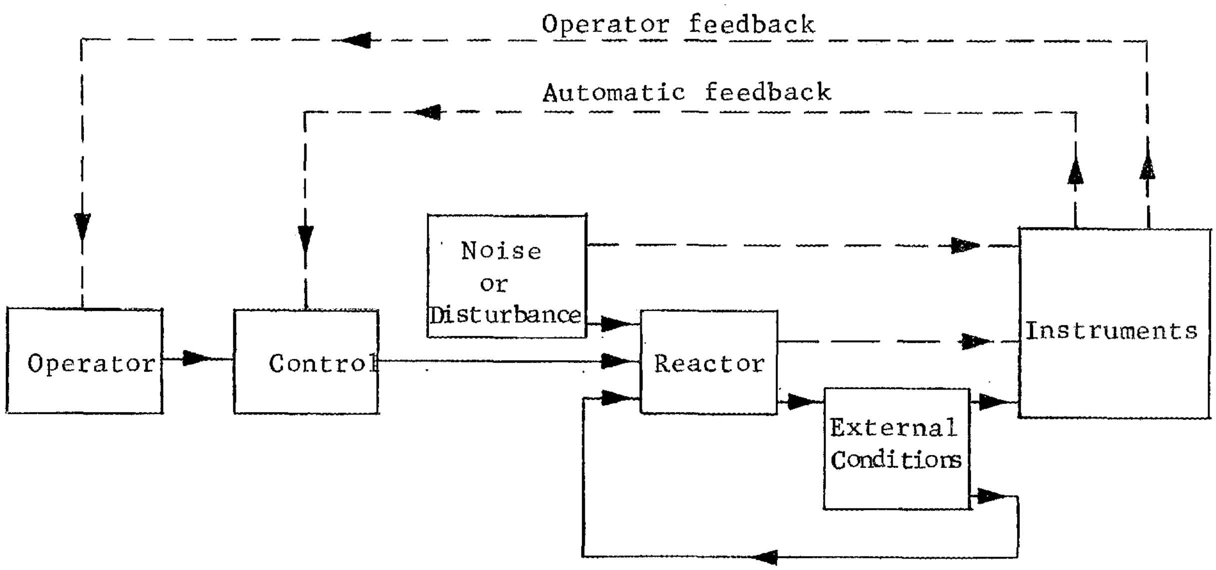

Fig. V-49. General Block Diagram of Reactor Operation System

3.2. Operator Decisions

5. Let us discuss first the operator loop. In this case the reactor produces effects which are sensed and displayed by the instruments. The operator reads the _____ and from their information decides what sorts of control actions to administer to the reactor.

---

6. The operator gets _____ from the instruments and feeds signals into the control block for any adjustments that are necessary and thus completes the "loop". instruments

---

7. In addition to getting information from the instruments, the operator must evaluate the _____ and make decisions as to the control measures. information

---

8. The key part of this loop is that the operator, as a result of his evaluation, must make a _____ as to what to do. information

- - - - - - -

9. Of course, the operator has help with the decisions through administrative control. An administrative control is one in which the operator is taught which decisions are the proper ones to make in a given set of circumstances. decision

- - - - - - -

10. Many of the responses of the operator are set by _____ control. By studying lists of procedures and also by experience, the operator learns that, to a given signal, a specific response must be made--not may be nor should be, but must be made.

- - - - - - -

11. Responses not set by administrative control call for the use of the operator's schooling, experience, and good common sense. There are times when these decisions might be very important to the continued safe operation of the reactor. administrative

- - - - - - -

12. Decisions to be made by the operator are (always, not always, never) set by administrative control.

- - - - - - -

13. For example, if the ORR is operating at full power and a setback occurs, the operator must notify the shift engineer. He should also do other things such as withdraw the other rods to hold the power level at N_L and announce the power-level change to the experimenters. not always

- - - - - - -

14. In the preceding illustration, the notification of the shift engineer of the setback is a response that is required by _____ _____.

- - - - - - -

15. Also in that same illustration, the operator should both withdraw the control rods to hold the power level at N_L and notify the experimenters of the change in power level. The decision as to which to do first or whether to do both at the same time is made by the _____.

administrative control

- - - - - - -

16. A better illustration of operator decision might be: an operator not at the control desk is given a list of pumps, motors, and tanks to check. Whether or not to empty a tank today or tomorrow is a decision he might make.

operator

- - - - - - -

17. In order to make decisions intelligently, whether by himself or with the aid of _____ control, the control-desk operator must often depend on instruments for information.

- - - - - - -

18. The control-desk operator can get information about the neutron flux at any given moment only from the (shift engineer, nuclear instrumentation, CAM).

administrative

- - - - - - -

19. The operator must be able to respond intelligently to the instrument information in order to (control the reactor, understand amplifiers, read the daily log of operations).

nuclear instrumentation

- - - - - - -

20. The operator must have continuous information about the reactor that only (instruments, guessing, the division head) can give him. — control the reactor

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21. We have been trying to emphasize that, although we are very much indebted to the experience, knowledge, and common sense of the reactor operator, without adequate instrumentation the control of a nuclear chain reaction would be (easy, difficult, impossible). — instruments

\- - - - - - -

3.3. Control Instrumentation

22. Now let us look at Figure V-49 again. Complete control of the reactor by operator response only would be quite difficult. When immediate response is necessary, people are much too slow. — impossible

\- - - - - - -

23. The automatic loop sends signals directly to the reactor control block and bypasses the ______.

\- - - - - - -

24. The automatic loop handles control information that calls for an (instrument response, operator response, administrative response). — operator

\- - - - - - -

25. Many control responses must be made much too quickly to depend upon either _____ or administrative response. These control responses which must be very fast are called "automatic" responses and are made by the _____. — instrument response

\- - - - - - -

26. Although it is true that an instrument response is faster than a human response, we must realize that the instrument response is limited.

operator, instrumentation

\- - - - - - -

27. The instrument can exercise only two prerogatives in most cases. It can attempt to control, and it can follow a programmed safety action if the proper response to the attempted control fails.

\- - - - - - -

28. The operator maintains surveillance over the instrumentation and evaluates its performance. Thus, the prime control of the reactor is always exercised by the _____.

\- - - - - - -

29. The conditions in Figure V-49 labeled "noise or disturbance" includes all of those factors that influence the reactor power to produce the random fluctuations and slow changes which make continuous control necessary. Some of these factors are xenon growth, fuel burnup, and coolant-flow variations.

operator

\- - - - - - -

30. The term "noise or disturbance" includes a number of factors which make continuous _____ necessary.

\- - - - - - -

31. Xenon growth would be considered a part of the "_____" block.

control

\- - - - - - -

32. The "external conditions" block is made up of those nonnuclear factors, such as coolant, which cause changes in the condition of the reactor. noise or disturbance

\- - - - - - -

33. The process portions of the reactor system, such as (fuel, moderator, coolant) would be a part of this "external conditions" block.

\- - - - - - -

3.4. Nuclear Instrumentation

34. Our discussion thus far has given us some information about all control loops. Now we wish to discuss the "automatic loop" further. coolant

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35. In order to understand better the functions of the various nuclear and process instruments, let us discuss those functions as they apply to both the control and safety systems.

\- - - - - - -

> In formally worded documents it is becoming customary to refer to control systems as "operations" systems and to safety systems as "protection" systems.

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36. For the present we shall limit our study to the information needed for optimum operation of the reactor. In a later section we shall study the instruments used in the safety system.

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37. In order to control the ORR adequately, for example, the operator must have knowledge of the neutron flux from about 10^4 n/cm^{-2}/sec^{-1} to about 10^{14} n/cm^{-2}/sec^{-1}.

- - - - - - -

38. Neutron flux information is necessary over all startup and operating ranges of the reactor because the power level is proportional to the _____ _____ of the reactor. In nuclear reactors the power level can change so rapidly that temperature monitors are too slow to be used for control; only by knowing the neutron flux can the operator or the automatic controls know how well the _____ _____ is being controlled.

- - - - - - -

39. If the neutron flux is low, the power level of the reactor is also _____.

neutron flux, power level

- - - - - - -

40. If the neutron flux increases from 10^4 n cm^{-2} sec^{-1} by a factor of one billion (that would be nine decades), the power level of the reactor is relatively (low, high). (To increase or to decrease a number by one decade, multiply or divide it by 10, respectively. Two decades is 10 x 10 or 10^2; three decades is 10^3, etc.)

low

- - - - - - -

41. In order to control a reactor reliably over a wide flux range from startup to full power (~10 decades), it is customary at ORNL to break the span into three ranges and to provide a separate set of instruments for each range. (The HFIR, which uses a wide-range counting channel, is an exception.)

high

- - - - - - -

42. The <u>three ranges</u> covered by the <u>nuclear</u> instrumentation for <u>reactor control</u> are: (1) the <u>lower startup</u> range of about <u>five</u> decades, (2) the <u>intermediate</u> or <u>upper startup</u> range of about <u>three</u> decades, and (3) the <u>power or operating</u> range of about <u>two</u> decades. Because the so-called <u>intermediate-range</u> instrumentation has a <u>usable</u> range of <u>five decades</u> or so, it <u>remains active</u> in the _____ range also.

- - - - - - -

43. These three instrument ranges, the _____, _____, and _____ ranges, are those used at reactors such as the ORR and BSR.

power

- - - - - - -

<u>Ion chambers</u>, as a class of radiation detectors, <u>deteriorate with use</u>. To get <u>maximum life</u> from these expensive devices, their operation in a <u>low-intensity neutron flux</u> is desirable. In the case of current chambers, the associated <u>electronics</u> determine the <u>minimum</u> useful <u>currents</u> which must be furnished. In light of these and other factors, ORNL installs its reactor chambers in neutron fluxes which produce from <u>30 to 50 microamperes</u> at <u>full reactor power</u>. These chambers are used only for <u>intermediate</u> and <u>power-range</u> measurements. In <u>counting instrumentation</u>, the <u>electronics</u> determine the <u>maximum rather than the minimum</u> neutron flux that may be measured. Because <u>counting</u> instruments will measure <u>very weak</u> neutron fluxes, they are the most practical of instruments for use in the <u>lower startup range</u> of reactors. Since they are operated only in relatively weak neutron fluxes, the <u>fission chambers</u> from which the counting pulses are received, <u>deteriorate very slowly</u> due to <u>neutron absorption</u>.

startup,
intermediate,
power

44. In the lower startup range at the BSR, PCA, and ORR, the neutron-counting rate may vary from one or two counts per second to 10,000 or more per second. This means that the counting-rate readout instruments will need to be able to span about _____ or _____ decades.

— — — — — — —

45. Since the range would be difficult to record on a linear scale, we use a counting instrument with a logarithmic scale. Such an instrument would have a scale as shown in Figure V-50. It is commonly called a log-counting-rate meter.

four, five

— — — — — — —

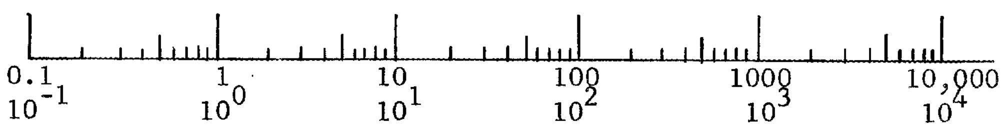

Fig. V-50. Logarithmically Calibrated Scale for a Counting-Rate Meter

— — — — — — —

46. The instrument scale shown above would encompass _____ decades.

— — — — — — —

47. An instrument with a logarithmic scale would be needed in the _____ range.

five

— — — — — — —

48. At the HFIR, when the counting-rate meter (CRM) reaches 10,000 counts/sec, the fission chamber is retracted automatically by a precision drive that positions the chamber so that the CRM always reads a set amount--10,000 counts/sec. An electronic instrument then combines the 10,000 counts/sec and the chamber-distance factor to arrive at an indication of the reactor power. Thus, the CRM is used to monitor the _____ _____ from startup to full power.

startup

- - - - - - -

49. You will recall from Section V-2 that the pulse-height selector makes it possible to distinguish between the neutron- and the gamma-induced pulses in the output of a fission chamber. This allows the higher _____-induced pulses to be counted and the lower _____-induced pulses to be ignored.

reactor power

- - - - - - -

50. Pulses from the pulse-height selector are counted, and the counting rate is recorded on a strip-chart recorder. The neutron counting rate is a measure of the neutron flux (or power) in the reactor. The counting rate usually is the only measure of reactor power available in the lower part of the _____ range of the reactor.

neutron, gamma

- - - - - - -

51. As reactivity is increased in a subcritical reactor, the neutron multiplication rate increases. During startup the operator must know the counting rate at all times so he can determine the increase in the _____ multiplication rate.

startup

- - - - - - -

52. The <u>rate of increase</u> in the <u>neutron-multiplication rate</u> indicates whether or not <u>reactivity</u> is being _____ in small enough or large enough increments. — neutron

- - - - - - -

53. In addition to knowing the approximate power at which the reactor is operating <u>during startup</u>, it is important to know whether the reactor is <u>subcritical</u> or <u>supercritical</u> following <u>each</u> reactivity increase. The <u>counting-rate period meter</u> furnishes this information. — increased

- - - - - - -

54. You will recall that the <u>reactor period</u> is the <u>length of time</u> during which the <u>neutron population</u> or flux <u>increases</u> or <u>decreases</u> by a factor of <u>e</u> (e = 2.718).

- - - - - - -

55. If the period meter indicates a 100-sec positive period, at the end of <u>every</u> 100 seconds the neutron population will have _____ by a factor of _____.

- - - - - - -

56. If it takes 50 sec for the neutron population to increase by a factor of 2.718, the period is _____ seconds. — increased, e or 2.718

- - - - - - -

57. If the neutron population <u>increases very slowly</u>, the reactor period will be (long, short) and will be <u>positive</u>. — 50

- - - - - - -

58. If the reactor is just critical, that is, the neutron flux is neither increasing nor decreasing, the reactor is said to have an "infinite period" because it would take an infinite length of time for the flux to change by a factor of e. This is to say that there will be no change in the neutron population until _____ is increased or decreased. — long

\- - - - - - -

> You will probably hear it said that one "adds" reactivity to a reactor or "removes" reactivity. It is also said that one "adds" positive or negative reactivity to cause a positive or negative period. This is exactly like saying that one "adds" speed or "removes" speed from a moving vehicle or that one "adds" positive or negative speed. Reactivity is a condition of a reactor like acceleration and deceleration are conditions of a vehicle in motion. If the acceleration of a moving car is zero, it is traveling at a constant speed. If the reactivity of an operating reactor is zero, it is operating at a constant (steady) power level. The reactivity of a reactor can be increased or decreased by adding or removing fuel, by removing or adding neutron "poisons", or by making other types of changes within or near the core.

reactivity

\- - - - - - -

59. If the neutron population is neither increasing nor decreasing, the reactor period is _____.

\- - - - - - -

60. If the neutron population is decreasing, the reactor period is neither infinite nor positive; it is _____. — infinite

\- - - - - - -

61. When the period recorder is showing a positive period, the reactor power will continue to _____ without the reactivity being further increased if there were no temperature effects and no fission-product "poisoning". — negative

- - - - - - -

62. However, as the temperature inside the reactor increases, it usually has the effect of decreasing reactivity so that the operator must continue to adjust the _____ to overcome this decrease. — increase

- - - - - - -

63. This effect is due to what is called negative temperature coefficient. When the reactivity decreases as the temperature increases, the temperature is said to have a _____ effect on reactivity. — reactivity

- - - - - - -

64. Two kinds of information are supplied by the counting instrumentation. One kind, the counting rate, is a measure of the _____ _____ in the reactor from its shutdown level upward. — negative

- - - - - - -

65. The information about the neutron population is displayed in the units (reactor period, counts per second, kilowatts). — neutron flux or population

- - - - - - -

66. The other information furnished tells how fast the reactor power is changing. The instrument determines and displays information called the reactor _____. — counts per second

- - - - - - -

A system of electronics with its detector or sensor, such as an ion chamber, for supplying the signal and any necessary readout devices (indicating or recording instruments) is often referred to as an "instrument channel" for convenience. A set of counting instrumentation, such as that being discussed, together with the fission chamber, counting-rate, and period indicators and recorders, constitute a "counting channel".

period

\- - - - - - -

67. At the BSR, PCA, and ORR, the electronics limit the counting rate to a maximum of about 10,000 counts/sec. This means the channel has a range of approximately _____ decades. If the range of the reactor from shutdown to full power is 10 decades and the intermediate range instrument channel is limited to about 5 decades, then there remains _____ _____ of range that, so far, is not instrumented.

\- - - - - - -

68. The solution is to withdraw the fission chamber into a neutron shield far enough that the counting rate is reduced three decades or so. This operation is done automatically, normally, and is repeated at the higher power levels to keep the counting channel within its _____-decade working range.

four,
one decade

\- - - - - - -

69. When the power of the ORR is decreasing, the period indicator shows a _____ period. While the fission chamber is being withdrawn (to change the operating range of the counting channel), the flux it measures is going from some higher value to a lower value. The reactor power seems to be (increasing, remaining constant, decreasing) so the period meter shows a _____ period.

four

— — — — — — —

70. The information received from the counting channel while its fission chamber is moving (is, is not) a true measure of the conditions in the reactor core.

negative,
decreasing,
negative

— — — — — — —

The counting rate, and more particularly the period information developed in the counting channel, is affected appreciably by the randomness of the signal pulses received from the fission chamber. Fortunately, power changes at low-reactor-power levels occur slowly so the counting channel need not have a high response rate and thus can include filtering to reduce the effects of the fluctuating signal. Nevertheless, under operating conditions the pointers of readout devices usually are in continuous and erratic motion and thus are difficult to read. The situation improves at the higher counting rates but, even so, the channel's information is considered to be of poorer quality than that obtained from the channels having current chambers. This latter type of instrumentation is not suitable for operating at power levels below about 10^{-5} N_F (N_F is "full power") because of the high gamma and very low neutron flux, however.

is not

— — — — — — —

71. Reactor neutron-flux information is needed over the whole range of operation from shutdown to _____ _____. Period information is often supplied over this same range, but it is usually considered most valuable at flux levels below the power range (below about 1 to 5% N_F).

- - - - - - -

72. At about 10^{-5} N_F (five decades down from full power) the neutron flux is still high enough that a compensated ion chamber (current chamber) will supply useful signal currents from which _____ and _____ information may be obtained.

full power

- - - - - - -

73. Because the signal from the compensated ion chamber (CIC) is a current signal and not a series of pulses, very little filtering is used in the associated electronics. Both the power-level and period information developed represent the currently existing conditions in the core. The period circuitry is fast-acting and capable of detecting very short periods even at low power levels. The CIC and its electronics are capable of covering more than six decades of range of reactor power so its power readout instrumentation has a logarithmic scale.

power, period

- - - - - - -

74. Figure V-51 shows the CIC and the input circuit to its electronics. The diode in the circuit converts the chamber current into a voltage proportional to the logarithm of the current.

- - - - - - -

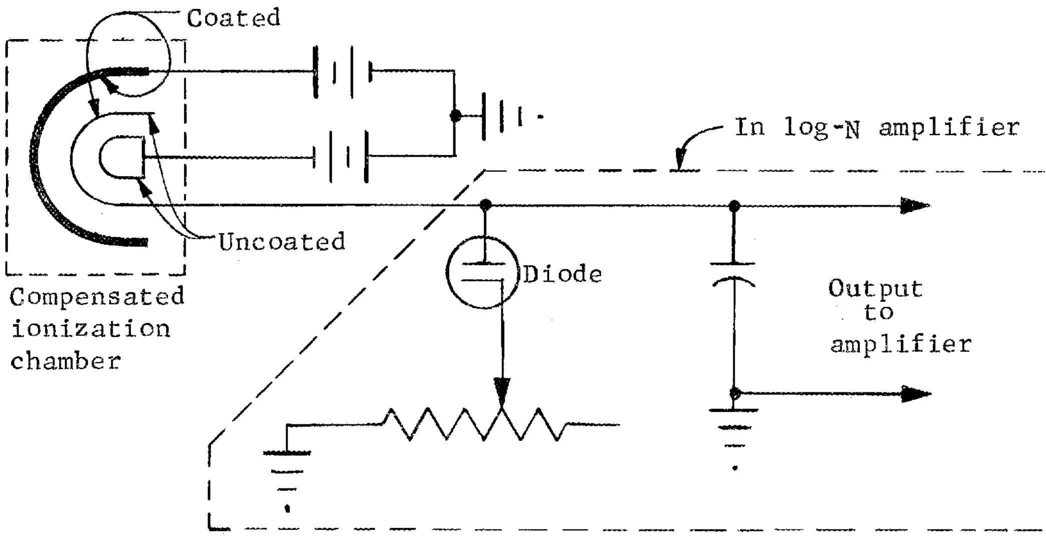

Fig. V-51. Log-N Amplifier Input Circuit

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75. Thus the output voltage varies in proportion to the logarithm of the _____-induced current from the chamber.

- - - - - - -

76. The instrument that uses this signal is called a log-N amplifier because its output is proportional to the _____ of the neutron flux. — neutron

- - - - - - -

77. As shown in Figure V-52, the log-N amplifier sends a signal to the period recorder, as well as to a flux (or power) recorder called the "log-N recorder". — logarithm

- - - - - - -

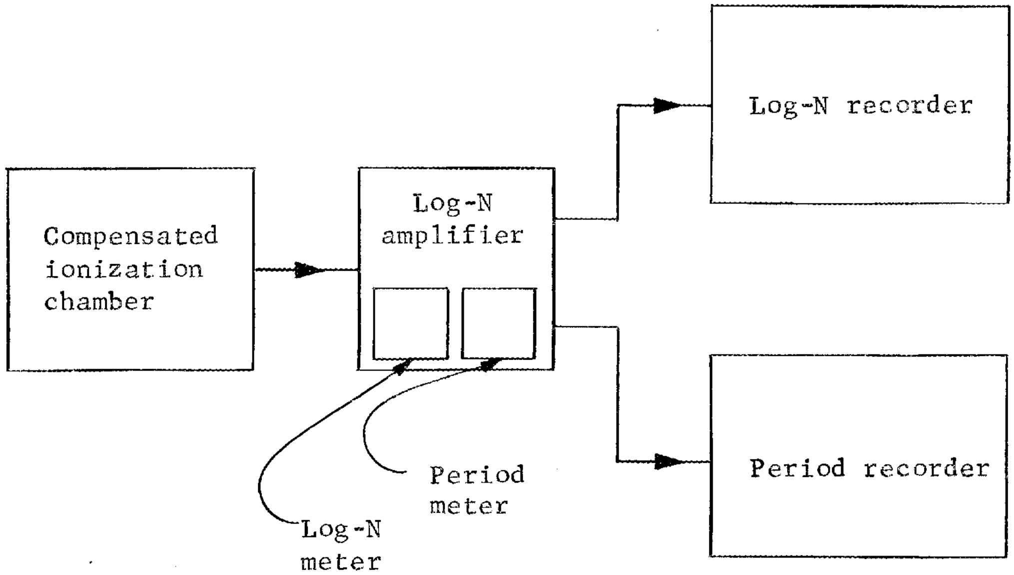

Fig. V-52. The Log-N Channel

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78. Since both the period and neutron-flux instrumentation use signals from the log-N amplifier, the whole instrument channel is called the _____-_____ channel.

\- - - - - - -

79. The instrument in the log-N channel that indicates the neutron-flux level uses the primary output of the log-N amplifier, and that output is proportional to the logarithm of the _____ flux. log-N

\- - - - - - -

80. The instrument in the log-N channel that indicates the reactor period uses the rate of change of the output of the log-N amplifier to show the rate at which the neutron flux is changing. This meter is called the _____-_____ period meter. neutron

\- - - - - - -

81. Since these two instruments are the most important nuclear instruments of the intermediate range, this range is often called the log-N range. log-N

- - - - - - -

82. Log-N meters or recorders could be calibrated in many ways, but at ORNL they are calibrated in percent of full power (abbreviated % N_F).

- - - - - - -

83. The log-N instruments are calibrated from 10^{-6} N_F to 3 N_F. Written in % N_F, this range is from 0.0001% N_F to _____ N_F.

- - - - - - -

84. At the lowest neutron-induced currents (correspond- 300%
ing to from 0.0001% to about 0.001% N_F), it is difficult to attain and maintain correct gamma compensation. Recently developed ORNL CIC chambers are less difficult to compensate, but, even so, the output often includes appreciable gamma-induced currents in the lowest decade. Thus the signal is not as accurate a measure of neutron flux in this range as it is over the remainder of the range.

- - - - - - -

85. The fission chamber of the counting channel is usually retracted to its second operating position before the neutron flux has risen high enough to be read by the log-N channel. Therefore, it will be supplying flux information at the time the log-N comes "on scale". The operator will observe both the log-N and counting-rate readings as the power increases to see if the two channels are "tracking" each other, that is, if they agree on the change in flux level as the power increases. Near 0.001% N_F, it should be possible to compare the log-N and counting-rate period indications for general concurrence. If the two channels track, the operator can be confident that the log-N channel is operating satisfactorily.

- - - - - - -

86. If the two channels do not track, the operator should (call this to the attention of the shift engineer promptly, ignore the log-N channel readings, ignore the counting-channel readings).

- - - - - - -

87. When the reactor power has reached 0.001% N_F or slightly above this, a switch in the log-N recorder is automatically actuated; and this signals the control system that log-N "confidence" has been achieved. The control system thereafter will use log-N rather than counting-rate information for "making decisions".

call shift engineer

- - - - - - -

88. As the reactor power is being increased, control functions are automatically shifted from the counting channel or channels to the log-N channel when log-N _____ is established.

- - - - - - -

89. The two instrument channels so far discussed are parts of the reactor operation (control) system. The counting-rate recorder, for example, is fitted with a control switch that is actuated by the pen drive when approximately 1.5 to 2 counts/sec are reached. Until this switch is actuated, withdrawal of control rods is prohibited and startups cannot be initiated. Other switches in this recorder are responsible for the automatic withdrawal or insertion of the fission chamber to keep the channel within its operating range.

confidence

- - - - - - -

90. The log-N and counting channels are considered part of the reactor _____ system.

- - - - - - -

91. Usually there is at least one active counting and one active log-N channel in each reactor system. To minimize possible delays in starting due to instrument troubles, the ORR (a production reactor) has a built-in spare channel of each type. Only one of each is available at the BSR or PCA, however.

operation or control

- - - - - - -

92. The HFIR operation system includes three counting channels, all of which are normally used in startups. Operation is possible with only two active channels. The reactor has no log-N channel so the counting channels have been given additional functions.

\- - - - - - -

93. The ORR requires (no, one, two) active counting channels for startup.

\- - - - - - -

94. The BSR (has a, has no) built-in spare counting channel. one

\- - - - - - -

95. The HFIR operating system includes (no, one, three) log-N channels. has no

\- - - - - - -

96. A third type of nuclear instrumentation is used in the power range (from about 1% N_F to N_F and above). Its primary function is reactor protection, and it prevents the reactor flux from reaching levels at which fission heating could damage or destroy the fuel elements. It also has control functions and supplies a readout of the reactor power on linear scales. The control and the power readout functions of these "safety" channels, however, are strictly of secondary importance and are not permitted to interfere in any way with their primary or protective functions. no

\- - - - - - -

97. To guarantee availability, on call, three identical safety channels are used in each reactor installation.

\- - - - - - -

98. In the process of reactor startup, the reactor power level is usually increased smoothly through the lower startup range and intermediate range without a pause.

\- - - - - - -

99. The intermediate range in startup terminates at a power level designated as N_L. This level is not the same in percent of N_F in all reactors since its value is determined by the design of the automatic power-level control system (servo). It varies from 1% N_F at the PCA to 10% N_F at the HFIR. In any case, it is the lowest power level at which the servo will control reactor power.

\- - - - - - -

100. The lowest power level at which the _____ _____ system will function is N_L.

\- - - - - - -

101. During startup when the power level reaches N_L, a regulating rod is adjusted, usually by the automatic control or servo system, to hold the power level constant until all systems are checked and the reactor is ready to be raised to full power. (Control of the reactor by servo will be discussed in Section V-4).

automatic or servo control

\- - - - - - -

102. During reactor startups, the power level increase is automatically stopped at _____ to allow a check of all systems before increasing the power further.

\- - - - - - -

103. When all systems have been checked and the operator is confident that the reactor is in condition to be taken to full power, reactivity is increased by increasing the "servo demand" setting, causing the servo system to withdraw the regulating rod as required. The "servo demand" governs the level to which the servo automatically brings and holds reactor power. If it is set at 100% N_F, it will increase the power to that level and keep it there. N_L

- - - - - - -

104. The servo system uses the _____ rod to adjust the reactor power level to the servo _____ setting selected by the _____.

- - - - - - -

> The servo system is designed to suit the characteristics of the reactor it is to control. The servo demand is designed to call for changes in power level at rates which are consistent with the capabilities and limitations of the reactor and are perfectly safe. In changing power levels, the servo demand is simply run full speed to the desired level and the control switch handle released. The servo will change the power level automatically and expeditiously. Changing power by changing the servo demand in short steps simply works both the demand set and servo excessively and in no way contributes to operating safety. Operations supervision may elect to operate differently under special conditions as set forth in operating procedures.

regulating, demand, operator

- - - - - - -

105. During the time the reactor is operating in its power range, power-level information is obtained from the _____ recorders, although such information is also provided by the log-N recorder.

- - - - - - -

106. The operator changes the power level at which the reactor is operating by changing the setting of the _____ _____. Power is changed and then held at the new level, automatically, by the _____.

safety

\- - - - - - -

3.5. Self Test

107. The function of the reactor operation system is to start, stop, and operate the reactor within its _____ _____ and for its _____ purpose. (Frame 1)

servo demand, servo

\- - - - - - -

108. The fast shutdown system (safety or scram system) (is, is not) part of the operation system. (Frame 2)

design limitations, intended

\- - - - - - -

109. The operator obtains information from the instruments that assists him in making _____ about what control actions to administer to the reactor. (Frames 4, 7, and 8)

is not

\- - - - - - -

110. When an operator is instructed to perform certain prescribed actions in response to a particular condition, his actions are said to be set by _____ control. (Frames 9, 10, and 12)

decisions

\- - - - - - -

111. Though the response of an instrument is faster than that of a human, the prime control of the reactor is always exercised by the _____. (Frames 26-28)

administrative

\- - - - - - -

112.	Although the reactor operation system will, by request of the operator, start and operate the reactor and shut it down safely (the operator, administration, the operation system) is responsible for orderly and safe operation. (Frame 28)	operator
113.	Neutron-flux information of two kinds is usually furnished at all power levels: neutron flux, which is an indication of _____ level, and the time during which the neutron flux changes by a factor of e, known as reactor _____. Of these, _____ information is the more important and is always furnished. (Frames 37, 38, 53, 54, 71 and 96)	operator
114.	The counting-rate instrumentation of the lower startup range usually uses a pulse counter with a pulse-height selector to sort out _____-induced pulses from _____-radiation-induced pulses. (Frames 43-50)	power, period, flux or power
115.	In the lower startup range, the ionization chamber usually used is called a _____ chamber. (Frames 42-47)	neutron, gamma
116.	Reactor period instrumentation indicates the interval of time during which the neutron population increases or decreases by a factor of _____ (Frames 54-58)	fission

117. A positive period indicates that the reactor power level is _____; a negative period indicates that the power level is _____; and an infinite period indicates that the power level is _____. (Frames 59-61) — e or 2.718

- - - - - - -

118. In the intermediate startup range, the ionization chamber is usually gamma-_____ to cancel the gamma-radiation contributions to the chamber current. (Frames 74-76) — increasing, decreasing, constant

- - - - - - -

119. The neutron-flux-level instrumentation of the intermediate range is often called the _____-_____ channel because of the logarithmic amplifiers used. (Frames 74-76 and 81). — compensated

- - - - - - -

120. During reactor startups, control functions are automatically switched from the counting channel or channels to the log-N channel when log-N _____ is obtained. (Frames 87 and 88) — log-N

- - - - - - -

121. Power escalation in the intermediate range is usually terminated at a power level called _____. (Frame 99) — confidence

- - - - - - -

122. Log-N instrumentation (is, is not) reliable in the power range. (Frames 41, 73, 83, and 105) — N_L

- - - - - - -

123. The power level, N_L, (is, is not) the lowest level in the power range at which the servo will hold the reactor automatically. Its value may be from 1% N_F to _____ N_F depending on the reactor. (Frame 99) — is

- - - - - - -

is,
10%

V-4. CONTROL INSTRUMENTATION

In this section we wish to emphasize (1) the control features of the startup nuclear instrumentation, (2) an automatic controlling system called a "servo", and (3) certain parts of the process system which have some control actions.

4.1. Control During Startup

1. The startup of most reactors is divided into at least two stages based upon the relative power level and the types of controlling instrumentation. The first stage is done with the instrumentation in a condition often called the "start mode" and extends from first rod withdrawal to N_L. The second stage is accomplished with the instrumentation in what is called the "run mode" and extends from N_L to full power.

\- - - - - - -

2. In this part we shall discuss control actions during the first stage of startup, while the reactor is being raised to the power level called _____.

\- - - - - - -

3. Let us define a control action as any action which either causes or inhibits control-rod adjustment. We will use the word "adjustment" to differentiate between movement of a control rod for control and the fast insertion that is a safety action. N_L

\- - - - - - -

4. You will recall that in ORNL reactors the control rods are normally moved by electric-motor-operated drives which are clutched to the rods by electromagnets and that the rods can be dropped into the reactor by turning off the current to the _____.

\- - - - - - -

5. Now let us discuss the control actions which occur during the startup and operation of two ORNL reactors, the ORR and the HFIR. — electromagnets

- - - - - - -

6. Most reactors have a startup checklist which is an administrative control to ensure that all systems necessary for startup are operative.

- - - - - - -

7. These checks should include having all recorders calibrated and set on "operate", rod-release times checked and approved, startup ionization chambers checked and operative, coolant systems checked and operative, and others that we will not take time to mention here.

- - - - - - -

8. The above-listed control functions we call _____ controls because they are the result of procedures established by administration as minimum startup requirements.

- - - - - - -

9. These particular administrative requirements are called the ____ checklist. — administrative

- - - - - - -

> Operators who are interested in the ORR controls systems should continue to study the following frames. Those interested only in the HFIR control systems should skip to Frame 95.

startup

- - - - - - -

4.2. Startup Controls - ORR

> Under special conditions and for the benefit of special tests, the ORR can be started up to low power levels without coolant flow or with low coolant flow. Also, it is possible to start up the reactor and control the power manually without benefit of automatic control. These special modes of startup and operation are not discussed in this work but are left to on-the-job training.

- - - - - - -

10. Normally, the counting-rate meter (CRM) has to show a minimum of 1.5 counts/sec (at the ORR) before the control rods can be withdrawn. This requirement is enforced by a switch in the CRM set at about 1.5 counts/sec which "inhibits" the rod-drive motors from being energized in the rod-withdraw direction below that point.

- - - - - - -

11. This "inhibit" ensures that the fission chamber is positioned (away from, near to) the reactor core during startup.

- - - - - - -

12. The 1.5-counts/sec switch in the counting-rate recorder ensures that the counting channel is operating. It would be unsafe to increase reactivity if the _____-_____ meter could not tell the operator about changes in the neutron population. near to

- - - - - - -

13. Thus, if the CRM shows no counts (even at shutdown with the chamber fully inserted), something is not right and control-rod withdrawal should be _____. counting-rate

- - - - - - -

14.	As mentioned earlier, the reaction time of the instrumentation used in the lower startup range (below 0.001 N_L or log-N confidence) is relatively (short, long).	prevented or inhibited
15.	It is important, therefore, that reactivity be increased slowly during startup; so, in the startup mode, a timing device is connected to the rod-drive motor circuits. This timer causes the rods to withdraw as a group for only 1 sec in each 6 sec. (This is the only group-rod-withdrawal rate available below "log-N confidence".) Further, if the counting channel detects a period shorter than 30 sec, it will automatically block further rod withdrawal until a longer period exists.	long
16.	This "intermittent" group-rod withdrawal is necessary only below _____ confidence.	
17.	Intermittent rod withdrawal is accomplished by using a _____ device which allows the rod-drive motors to be energized only 15-20% of the time.	log-N
18.	You will recall that at a power level of 0.001 N_L you should have _____ confidence.	timing

19. When log-N confidence is reached, the intermittent rod-withdrawal requirement is automatically dropped out by a switch in the log-N recorder. At that time, all rods may be withdrawn _____, if the operator so desires, by bypassing the timing device. log-N

- - - - - - -

> There is a spring-loaded, manually operated switch which may be used to bypass the 30-second-period group-rod-withdraw inhibit. This is used by experienced operators when a fast startup is necessary to avoid xenon poisoning. If the operator removes his hand from the switch, the spring returns the switch to its neutral position, re-establishing the intermittent withdrawal rate.

continuously

- - - - - - -

20. When all rods are withdrawn continuously, large increases in reactivity may be made rather quickly; and the reactor period can become quite (long, short).

- - - - - - -

21. To control the rapid increase in reactivity, switches at the 30-sec-period marks in the period recorders inhibit group withdrawal of the control rods. short

- - - - - - -

22. As long as the reactor period is (more than, less than) 30 sec, the inhibit is in effect.

- - - - - - -

23. When the period becomes longer than 30 sec, the group-withdrawal permit switch must be reset by the operator (the operator at the ORR turns the "intermittent" switch to "normal" and then back to intermittent) before the rods can again be withdrawn. — less than

— — — — — — —

24. At the ORR, should the 30-sec inhibit malfunction, other switches at both the 20-sec and 10-sec marks should inhibit rod withdrawal and a switch at the 5-sec mark should cause insertion of all rods. If all switch contacts should fail, a 1-sec period signal from the log-N channel would scram the reactor.

— — — — — — —

25. If the period-recorder rod-withdrawal inhibit switches should fail during a startup, a _____ period will cause a reactor scram.

— — — — — — —

26. Although the 20-sec and 10-sec inhibits have other specific functions, their action is typical of what has been called a "backup" action. The term is largely salf-explanatory. Backup instruments are those which operate to inititate an action if the first instrument that is supposed to initiate the action fails. Thus, the 20-sec- and 10-sec-period inhibits and the 5-sec-rod reverse are said to _____ _____ the 30-sec inhibit. — 1-sec

— — — — — — —

27. Throughout the intermediate range, the neutron flux level should increase smoothly with the 30-sec period inhibit to keep rod withdrawal in check. — back up

— — — — — — —

28. Below N_L, control actions other than the 30-sec inhibit of control-rod withdrawal are made at the discretion of the operator through the use of manual switches. One of these is a "reverse" switch which is used to insert all control rods simultaneously at the full speed of the rod-drive motors. Although the "reverse" is available at any power level, it will be needed, if at all, only during fast restarts. For this reason, the same switch is made to control both conditions, "bypass" (30-second-withdraw inhibit) and "reverse". The operator using the bypass will already have his hand on the correct switch should he decide he needs the reverse when he is making a fast restart.

- - - - - - -

29. When an operator uses the reverse switch, he causes the rod-drive motors to operate at full speed to _____ the reactivity of the reactor.

- - - - - - -

30. The reverse stops reactor power increases almost immediately and, if continued, causes the reactor to become subcritical in a matter of seconds. Should the operator decide that prompt power reduction is necessary, the reverse is preferable to the scram since the reactor can be returned to power with little delay following a reverse. The scram signal de-energizes the rod _____, dropping the rods. A restart then requires time for the drives to run in to pick up the rods after which the startup program must again be followed to get back to power.

reduce or decrease

- - - - - - -

31. When the reactor reaches a power level of N_L, an automatic control system called the "servo" takes over the control and holds the power level at N_L. The operator will check all systems for proper conditions before proceeding to raise the power. The servo holds the power constant, thus freeing the operator to make the _____. magnets

- - - - - - -

32. The ORR normally remains in the "start mode" until it reaches _____. At this point, if all start-mode checks are completed and all conditions are normal, the reactor controls may then (following administrative procedures) be placed in the "run mode" by pressing the "run" button. checks

- - - - - - -

33. When the reactor power reaches N_L, it is customary to keep the reactor at that power level until all "_____-mode" checks are completed and the reactor is ready to be placed in the "run mode" and brought to full power. N_L

- - - - - - -

34. Interlocks will keep the reactor from being placed in the "run mode" if either (1) the period is less than 30-sec, (2) the power level is less than 0.6 N_L or greater than 1.8 N_L, or (3) the coolant system is not operating at full flow. start

- - - - - - -

35. While the reactor power is at N_L, the period should be infinite; however, if something should cause a reactivity increase sufficient to produce a reactor period shorter than 30 sec, the control system (can, cannot) be placed in the run mode.

- - - - - - -

The run-mode inhibit below 0.6 N_L and above 1.8 N_L is an administrative control to emphasize the pause at N_L for a general checkout of all systems. | cannot

- - - - - - -

36. When the reactor is ready to go to full power, the "run" button is pushed and the operator may then increase the power level by increasing the demand to the servo system. The servo power demand operates over the range N_L through N_F and the servo will automatically change the reactor power to the demand level and hold it there.

- - - - - - -

4.3. The ORR Servo System

37. In the power range of reactor operation, maintaining the power at a desired level is accomplished more accurately and more smoothly if an automatic system is used. So, let us consider a typical automatic control system, called a servo system.

- - - - - - -

38. A block diagram of an ORR-type servo system is shown in Figure V-53.

- - - - - - -

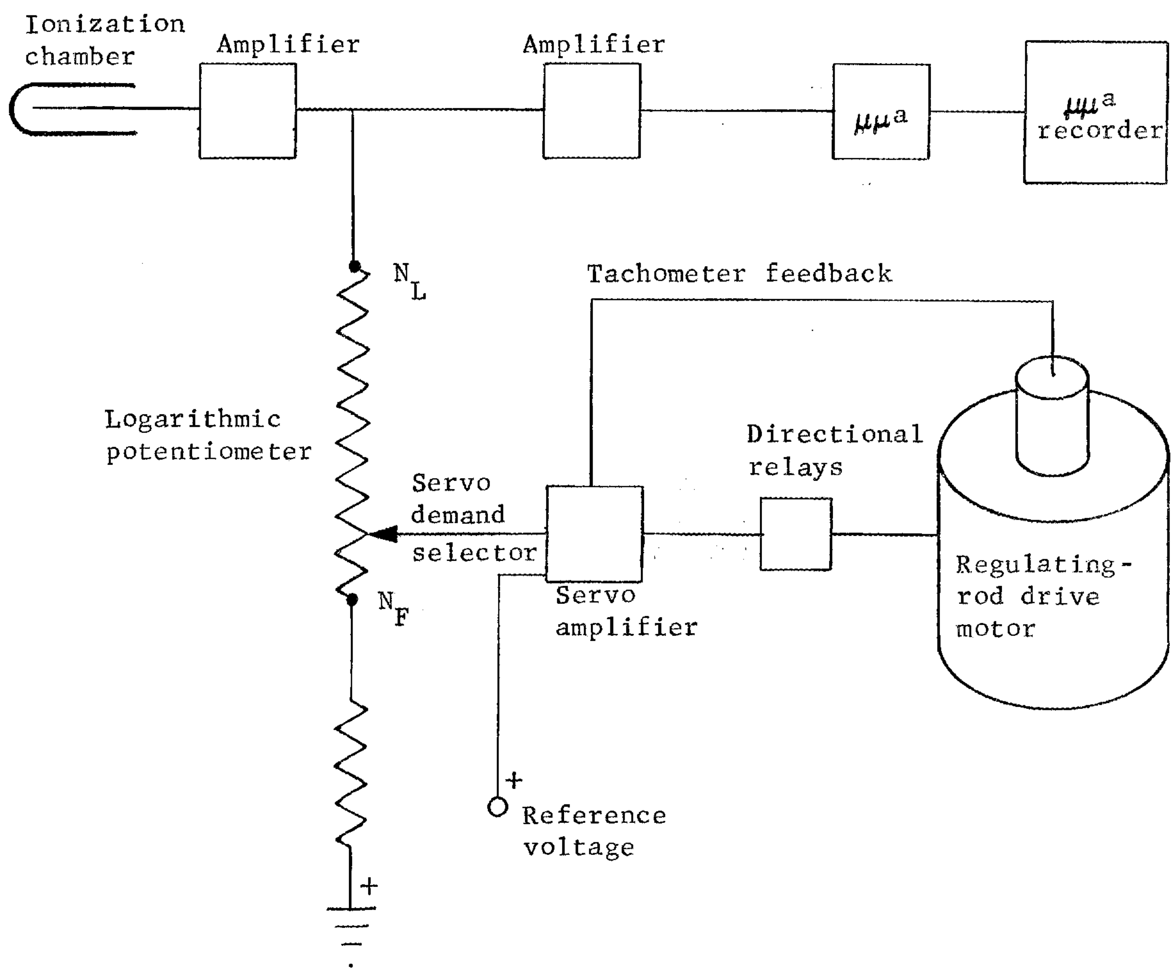

Fig. V-53. One Type of Servo System

- - - - - - -

39. The servo control signal is taken from a neutron-sensitive ionization chamber which may be either compensated or uncompensated.

- - - - - - -

40. The chamber signal is amplified and impressed across the demand potentiometer. A fraction of this voltage is tapped off and sent to the servo amplifier which compares it to a reference voltage (demand signal). The "difference voltage" (error signal) controls the regulating-rod-drive motor through "withdraw" and "insert" relays.

\- - - - - - -

> The voltage applied to the servo amplifier input by the reference voltage supply is constant (at the selected value). The voltage applied to the servo amplifier from the ionization-chamber amplifier varies with the reactor neutron flux and is opposite in polarity to the reference voltage. Thus, when these voltages are numerically equal, they cancel and the servo input voltage is zero (zero error). Under these conditions, the reactor-power level (neutron flux) at the chamber is at the demand value. If the demand is lowered (moved toward N_L), a voltage larger than the new reference voltage will be supplied by the ionization chamber amplifier. Thus, a net negative voltage (servo-error signal) will be applied to the servo-amplifier input (servo error = reference voltage + ionization-chamber-amplifier output voltage), causing the servo to insert rods to reduce the net voltage to zero. Remember that these voltages are always of opposite polarity so the servo error is the difference in the two voltages. Thus the error voltage may be plus or minus.

\- - - - - - -

41. The error signal causes the servo-controlled (regulating rod to move in the correct direction to adjust the reactor _____ to make the chamber signal equal the reference voltage (the error voltage becomes zero).

\- - - - - - -

42. The strength of the ionization-chamber signal varies with the reactor neutron flux (power level). An increase in neutron flux produces a (stronger, weaker) ionization-chamber signal.

power

- - - - - - -

43. If the chamber signal is greater than the reference voltage, the regulating rod is temporarily moved to (decrease, increase) the reactivity until the reactor power decreases and the chamber signal becomes (less, more)--thus approaching the reference voltage.

stronger

- - - - - - -

44. If the chamber signal is less than the reference voltage, the regulating rod is temporarily withdrawn and the neutron flux (decreases, increases), making the chamber signal increase and approach the reference voltage.

decrease, less

- - - - - - -

45. Because of the energy in the rod and drive due to motion, these coast a little after the error voltage goes to zero. In other words, there is a tendency to "overcorrect", with the result that the drive moves the rod in and out about the correct rod position (hunts). The reactor power is caused to oscillate about the desired level. Because of stored energy in the drive system, the servo system, as described, (does, does not) hold reactor power at the desired level.

increases

- - - - - - -

46. The tachometer in Figure V-53, also driven by the regulating-rod-drive motor, furnishes a voltage whose polarity is determined by the direction in which the regulating rod is moving. A portion of this voltage, taken from a potentiometer connected across the tachometer, is fed back to the servo amplifier (feedback signal) where it is combined with the error signal. The feedback and error signals are arranged to always be in opposite polarity. For proper servo operation, the feedback signal is adjusted so that it cancels the error signal just before the servo has brought the reactor power to the level called for by the servo demand. Because of the energy stored in the mechanism and rod, they coast the remaining distance needed to bring the reactor just to the desired power level. — does not

- - - - - - -

47. The tachometer-feedback arrangement provides a means for compensating for the effect of the _____ in the moving regulating rod and its drive mechanism.

- - - - - - -

48. The servo senses the reactor power level only through the _____ flux at its ionization chamber position. — energy

- - - - - - -

49. If anything happens to this neutron flux, the servo interprets it as a power change and tries to offset the change by adjusting the _____-_____ position. — neutron

- - - - - - -

50. The servo system can fail in several ways. One failure is loss of sensitivity of the servo ion chamber or the equivalent, due to a change in conditions in the vicinity of the chamber in such a way that the reactor flux seems to decrease. If the chamber signal indicates the power level is too low, the servo will (withdraw, insert) the regulating rod to compensate. The power will then be changed to a level (below, above) the correct one.

regulating-rod

- - - - - - -

51. The operation system takes corrective action automatically if the conditions outlined in Frame 50 allow the power to rise to 1.1 N_F (110% of full power) or higher. At 1.1 N_F the operator is warned by an annunciator that the power is too high and at the same time the servo demand is automatically reduced or "set back". The setback action continues only as long as the power is at or above 1.1 N_F.

withdraw,
above

- - - - - - -

52. The automatic _____ causes the reactor power to be reduced by action of the servo system to a level below 1.1 N_F.

- - - - - - -

53. Referring to Figure V-53, you can see that when the servo demand is lowered (moved toward N_L) a (smaller, larger) voltage is developed from the demand to ground and is fed to the servo amplifier. This larger voltage represents, to the servo amplifier, a higher-than-desired power level. The error signal, thus, is such that the servo-controlled rod is inserted to (raise, lower) the power level.

setback

- - - - - - -

54. Let us repeat what has just been said. If the power level is increased to (or above) _____ N_F, which at the ORR would be 33 Mw, the operation system will automatically initiate a _____. The servo demand is automatically (raised, lowered) which results in servo action to (increase, reduce) the power level.

larger, lower

- - - - - - -

55. The servo system may fail in such a way that it continually calls for either a reduction or an increase in reactor power regardless of the signal from the servo chamber. If the request is for a decrease in power, it is, at worst, only an operating inconvenience. The servo may be turned off and operation continued manually. Administrative procedures cover such operation; there is no automatic correction for such a reduction in power.

1.1, setback, lowered, reduce

- - - - - - -

56. The operation system is designed to take proper corrective action automatically should the servo fail in such a way that it continues to ask for regulating rod withdrawal (power increase). This failure, however, cannot be corrected by a setback since the servo is not being controlled by the error signal. The power will rise past 1.1 N_F, tripping the setback annunciator and initiating an ineffectual setback request and then rise on to 1.2 N_F, at which level a second annunciator is tripped and the reactor control system is put into reverse (see Frame 28).

- - - - - - -

57. A reverse is automatically initiated in this case when the power level reaches _____.

- - - - - - -

58. An automatic reverse called for by the operation system continues only so long as the condition initiating it continues. For the condition described in Frame 55, as soon as the power drops below 1.2 N_F the reverse will be stopped automatically. The 1.2 N_F reverse ends as soon as the reactor power is reduced below _____. 1.2 N_F

— — — — — — —

59. The reactivity under servo control is limited to 0.5% $\Delta k/k$, so the servo cannot make the reactor "prompt critical". The operation system's automatic reverse at 1.2 N_F easily terminates and turns back any power excursion which might be initiated by a run-away servo (sudden uncontrolled addition by the servo of all reactivity worth available to it). The 1.2 N_F _____ is to prevent an excessive power increase that might result from a servo-system failure (run-away). 1.2 N_F

— — — — — — —

60. Electrical contacts in the power-level safety recorders, which indicate and record reactor flux in the power range, initiate the 1.1-N_F alarm and setback and the 1.2-N_F alarm and reverse. There are three such recorders, each with one set of contacts for each type of control action. Because the three power-level instrument channels are independent of each other, any one that detects an excessively high power level will initiated the setback or reverse action. Automatic reverse is initiated at the ORR (if any one, only if any two, only if all three) level channels detect a 1.2-N_F power level of the reactor. reverse

— — — — — — —

61. In addition to initiating a reverse, the 1.2-N_F contacts also turn the servo "off". If the power level has reached 1.2 N_F, this is proof that the servo has probably failed. The servo is automatically turned off so it can interfere no further with reactor operation.

if any one

- - - - - - -

62. A reverse, regardless of its origin, may be expected to make the reactor subcritical. When a reactor that was operating at full power is made subcritical, the power level drops quickly to N_L and beyond. Operating procedures include instructions to be followed in handling such situations.

- - - - - - -

4.4. Control by Process Instrumentation

63. Other subjects of interest include the "scrams" and the control actions of the process instrumentation. A setback lowers the power level, and a reverse makes the reactor subcritical by a rod-drive insertion of all the rods; but a so-called "slow" scram causes a complete shutdown when, by relay action, the rods are released (by loss of their magnet currents) to fall into the reactor core.

- - - - - - -

64. A slow scram is initiated by an electrical signal which, through _____ action, causes the magnet current to be turned "off".

- - - - - - -

65. In comparison with a scram, a reverse reduces reactivity at a relatively slow speed, i.e., the speed at which the rod-drive motors move the ______ ______. — relay

- - - - - - -

66. When an instrument causes a relay to open the circuit to the control-rod magnets, a ______ ______ results. This scram is so named because an appreciable amount of time (200 milliseconds or longer) is needed for relays to operate and, thus, to turn the magnet amplifiers off. — control rods

- - - - - - -

67. When a neutron-detecting instrument, through electronic action, decreases the magnet current to the rod-drop point, the resulting shutdown is called a "fast" scram. The time delay in this case is short (200 milliseconds or less) compared to that required to effect a slow scram. — slow scram

- - - - - - -

68. Now let us discuss the more common control actions of other systems. Experiments have their own control and safety instrumentation. This instrumentation is tied into the reactor control system so that experiment conditions possibly hazardous to personnel, the experiment, or the reactor will cause a reduction of the reactor power or, in extreme cases, will actually initiate a slow scram.

- - - - - - -

69. Since most reactor-control actions from other than the the nuclear instrumentation are initiated by the coolant instruments, let us take coolant flow first.

- - - - - - -

70. If the ORR is operating at full power and the coolant flow is decreased from the normal 18,000 gpm to 17,000 gpm as indicated by flow and pressure-drop instruments, a setback is initiated which reduces the power to less than 60% N_F. If the flow is further reduced to 14,000 gpm, a slow scram is initiated.

— — — — — — —

71. The coolant flow is so important for the ORR that only a small decrease to _____ gpm will cause a setback.

— — — — — — —

72. If the flow drops to 14,000 gpm or lower, the reactor power must be reduced drastically so that flow instrumentation, by relay action, initiates a (fast, slow) scram. 17,000

— — — — — — —

73. Closely associated with the coolant flow is the pressure change across the core. If flow decreases, ΔP (increases, decreases) and, thus, can be used as a control parameter. At the ORR, a setback occurs if the ΔP decreases to about 21.4 psi. slow

— — — — — — —

74. The only other coolant-instrumentation control parameter is temperature. At the ORR, both the outlet temperature (from the core) and the Δt across the core are used as controls. Both recorders (Δt and outlet temperature) have switches to initiate setback, reverse, and _____-scram action if either becomes too high. decreases

— — — — — — —

75. The most accurate method of determining reactor power is the use of heat-transfer calculations. You will recall from your study of heat transfer that you need to know the flow rate of the coolant, Δt of the coolant, and the specific heat of the coolant in order to calculate the heat power. — slow

- - - - - - -

76. Thus, the control of these parameters, _____ flow rate and change in _____, is necessary in overall reactor control.

- - - - - - -

> Due to the size and inertia of the reactor coolant system, flow and pressure changes cannot be made instantaneously. Also, changes in temperature are secondary effects resulting from other changes such as coolant-flow changes or neutron-intensity changes. Generally speaking, process instruments exhibit appreciable delays (one second or more) in responding to changes in the parameters being monitored. On the other hand (at least in the power range), the response of nuclear instrumentation is essentially instantaneous.

coolant, temperature

- - - - - - -

77. The slowness of response of these instrument channels limits their control and protective assignments to those conditions or situations which can be handled by setbacks, reverses, or _____ scrams.

- - - - - - -

78. It is imperative that when fast action is needed the action must be initiated by electronic circuits and not by recorder switches and relays. Thus, the power-level safeties and reactor period circuits (nuclear instruments) initiate _____ scrams. — slow

- - - - - - -

4.5. Review of ORR Control Systems

79. The first stage of a reactor startup when reactivity increases must be kept small due to slow instrument response is called the _____ mode. The later, higher power stage when instrument safeguard response is fast is called the _____ mode. (Frame 1).

fast

- - - - - - -

80. Slow increase of reactivity during startups is accomplished by the use of a timer which causes _____ withdrawal of the control rods; this makes actual motor speed reduction unnecessary. (Frames 15-17)

start, run

- - - - - - -

81. Above about 0.001 N_L, "confidence" is said to have been established in the _____ channel and from this level through the power range it exercises its control functions. (Frames 85-87, Section V-3, and Frames 18 and 19, above)

intermittent

- - - - - - -

82. Control-rod withdrawal during the startup phase is inhibited when the reactor period is (more than, less than) 30 sec. (Frames 21-23)

log N

- - - - - - -

83. The same switch, on the control desk, that allows the operator to bypass the 30-sec period inhibit on rod withdrawal will produce a _____ if turned in the opposite direction. (Frame 28)

less than

- - - - - - -

84. Below 0.001 N_L, group control-rod withdrawal is limited to all rods (continuously, intermittently). (Frames 15-17) — reverse

- - - - - - -

85. One function of the 20-sec- and 10-sec-period inhibits is to provide _____ action in case the 30-sec-period inhibit fails. (Frame 26) — intermittently

- - - - - - -

86. A fast insertion of the control rods, either automatically or by the operator, to reduce the reactor power level is called a _____. (Frames 28-30) — backup

- - - - - - -

87. In the power range of reactor operation, the control of power level is assumed by an automatic system called the _____ system. (Frames 31 and 37) — reverse

- - - - - - -

88. The amount of reactivity change which can be made by servo action is (unlimited, limited). (Frame 59) — servo

- - - - - - -

89. Normally, the servo is operative only between _____ and N_F. (Frames 31 and 36) — limited

- - - - - - -

90. A setback is a servo-controlled (increase, reduction) of reactor power. One of the conditions which causes a setback is for the power-level-safety recorders to "see" a power level of _____ N_F. (Frame 51) — N_L

- - - - - - -

91. From the process instrumentation, you might expect a slow scram to be initiated by either low coolant _____ or high coolant _____. (Frames 70-74)	reduction, 1.1
92. Scrams initiated by the process instrumentation are called (slow, fast) scrams because of the response time of the instrument channels. (Frames 63-66)	flow, temperature
93. Control action, operating through switches and relays, causes reductions of the reactor power (when required) by _____, by _____, or by _____ scrams. (Frames 63-67)	slow
94. Scrams initiated by the safety instrumentation are called _____ scrams because they are accomplished electronically rather than by the slower action of _____ and _____. (Frames 67 and 78)	setbacks, reverses, slow

4.6. Startup Controls - HFIR

95. Operators who are interested only in the ORR control system may turn to Section V-5. Those who skipped the ORR information will start here.	fast, switches, relays

96. The HFIR has three startup and operating modes. Mode 1 is the normal startup mode when proceeding directly to the full-power level. Modes 2 and 3 are special modes to allow low-power operation with no coolant flow or low coolant flow. Only Mode 1 operation will be discussed in this work. Operations in Modes 2 and 3 will be left to on-the-job training.

97. As we mentioned earlier, there are some controls which may not be built into the instrumentation. We called these administrative controls because they are set according to _____ procedures.

- - - - - - -

98. Some of the checks on the startup checklist could be considered _____ controls. administrative

- - - - - - -

99. After the completion of the startup checklist, the operator should have confidence that the "wide-range counting channel" is ready for startup if: administrative

a. The counting-rate chambers are fully inserted and the counting rate is more than 10 counts/sec and less than 20,000 counts/sec.
b. The fission-chamber drive is set for "automatic" operation.
c. The pulse amplifier (pulse-height selector) is set on "operate".

This is usually referred to as having "counting-rate confidence".

- - - - - - -

100. If the pulse-height selector is properly set, the operator is confident that the channel is counting only neutrons and not both _____ and gammas.

- - - - - - -

101. If the counting rate is at least 10 counts/sec, the operator is also confident that the _____ chamber, from which the counting-rate meter (CRM) gets its signal, is positioned properly (fully inserted). neutrons

- - - - - - -

102. When the operator is assured that the CRM is reading properly, that the fission-chamber drive will operate automatically, and that the pulse amplifier is set on "operate", he is said to have "counting-rate ____" and is ready for reactor startup. — fission

\- - - - - - -

103. When startup is initiated, the shim plates are withdrawn simultaneously and continuously rather than intermittently as at some reactors. — confidence

\- - - - - - -

104. There is no timed sequence of intermittent withdrawal. The shim plates are withdrawn ____.

\- - - - - - -

105. As the plates are withdrawn, reactivity is increased, and the reading of the CRM ____. — continuously

\- - - - - - -

106. When the CRM reaches 10,000 counts/sec, the fission-chamber drive automatically begins to move the fission chamber farther from the core. The automatic drive then keeps the fission chamber positioned so that the CRM counting rate is maintained at 10,000 counts/sec. — increases

\- - - - - - -

107. The automatic fission-chamber drive, the counting-rate channel, and a special operational amplifier are components of what is called a "wide-range counting channel". These components work together to take the constant 10,000 counts/sec reading of the counting-rate meter and multiply this reading by a factor which represents the distance the fission chamber is from the core. From this product the reactor power can be determined.

- - - - - - -

108. The fission-chamber drive must operate automatically to move the chamber away from the core when the counting rate reaches _____.

- - - - - - -

109. As the fission chamber moves away from the core, it "sees" a smaller percentage of the total _____ population.

10,000 counts/sec

- - - - - - -

110. This distance factor and the 10,000 counts/sec recorded by the CRM are combined by an electronic instrument to give an output reading in units of reactor _____ over a wide range of power levels.

neutron

- - - - - - -

> The "distance factor" was first determined by calibrating the distance the fission chambers were withdrawn against the actual reactor power calculated from the heat output. This was done during the initial startup tests of the reactor and is updated as necessary.

power

- - - - - - -

111. The counting channels at the HFIR make satisfactory measurements of reactor flux over the whole startup and power range of the reactor. This is the reason for calling them the _____ _____ counting channels.

\- - - - - - -

112. The wide-range counting channels are most relied upon during startup; i.e., to 10 Mw. However, since they are reliable to 100 Mw, they are used as the power-level recorders at full power. wide-range

\- - - - - - -

113. The wide-range counting channel is used to compute the reactor power automatically throughout the startup range and up to _____ Mw.

\- - - - - - -

114. For each wide-range counting channel there is an associated counting-rate period channel. These three period channels get their signals from the three _____ chambers. 100

\- - - - - - -

115. Instrumentation of the greatest reliability is necessary for the high-performance HFIR. For this reason, three independent wide-range counting channels were included. Actually, only two are considered necessary; but, with only two installed, the chances of having to shut down because of a failure of one are higher than the designers liked. With three channels installed and operating, the chance of two failing during a run is so small that the desired reliability is achieved. fission

\- - - - - - -

116. In most cases of electronic control at the HFIR, a control action is initiated only when at least two of three instrument channels recognize, at the same time, the need for control action. These systems are called "two-of-three (or two-out-of-three) coincidence" systems.

– – – – – – –

117. This method of control, wherein two channels must recognize the need for control before any action is taken, is called _____ _____.

– – – – – – –

two-of-three coincidence

118. There are three startup instrument channels which measure and record the reactor period and flux, but their control actions do not depend on coincidence in all cases.

– – – – – – –

119. These instruments are similar, in most respects, to period instruments of other ORNL reactors. They record the time interval during which the neutron population increases by a factor of e. This time interval is called the reactor _____.

– – – – – – –

period

120. These instrument channels are equipped with electrical switches to inhibit control-plate withdrawal if the period becomes too short.

– – – – – – –

121. During startup, if any period channel indicates a period less than 30 sec control-plate withdrawal is inhibited.

– – – – – – –

122. This action (is, is not) considered to be two-out-of-three coincidence.

- - - - - - -

123. All control-plate withdrawal (shim plates and regulating cylinder) is inhibited if (all three, any two, any one) period channel indicates a period of (less than, more than) 30 sec. — is not

- - - - - - -

124. This inhibit holds only as long as the period is less than 30 sec. When the period becomes longer than _____, control-plate withdrawal may continue. — any one, less than

- - - - - - -

125. If a sudden increase in reactivity should cause at least two period recorders to see periods as short as 5 sec, all control-plate drives would insert the plates at full speed. This is called a "reverse". — 30 sec

- - - - - - -

126. When the instrumentation causes all control plates to be inserted, the action is called a _____.

- - - - - - -

127. A reverse at the HFIR, during startup, will be initiated if at least two period channels "see" a period of less than _____. — reverse

- - - - - - -

128. Reverse action, initiated by a period of 5 sec or less, is an example of action caused by the coincidence of at least _____ instrument signals out of _____. — 5 sec

- - - - - - -

129. When startup of the reactor is initiated, it usually continues uninterrupted to a power level of 10-Mw (this is N_L at the HFIR), at which level the power is held constant until all systems are checked. — two, three

\- - - - - - -

130. At the end of the startup range at N_L, an automatic control system (the servo system) which operates the center control cylinder (the regulating cylinder) assumes control and holds the power level constant at _____ Mw.

\- - - - - - -

131. The reactor power is held at 10 Mw by the _____ control system until all systems are checked and the reactor is ready to go to full power. — 10

\- - - - - - -

132. When the reactor is considered ready for full-power operation, the operator increases the "demand" signal to the servo which then adjusts the reactor power to match the power level represented by the selected "demand" signal. — servo

\- - - - - - -

4.7. The HFIR Servo System (see Figure V-54)

133. The servo system is used to control the movement of the regulating cylinder automatically in order to increase or decrease the reactivity as needed to keep the power level constant. It is also used to increase the power from 10 Mw to 100 Mw (full power). The power increase is accomplished by increasing the servo "demand".

\- - - - - - -

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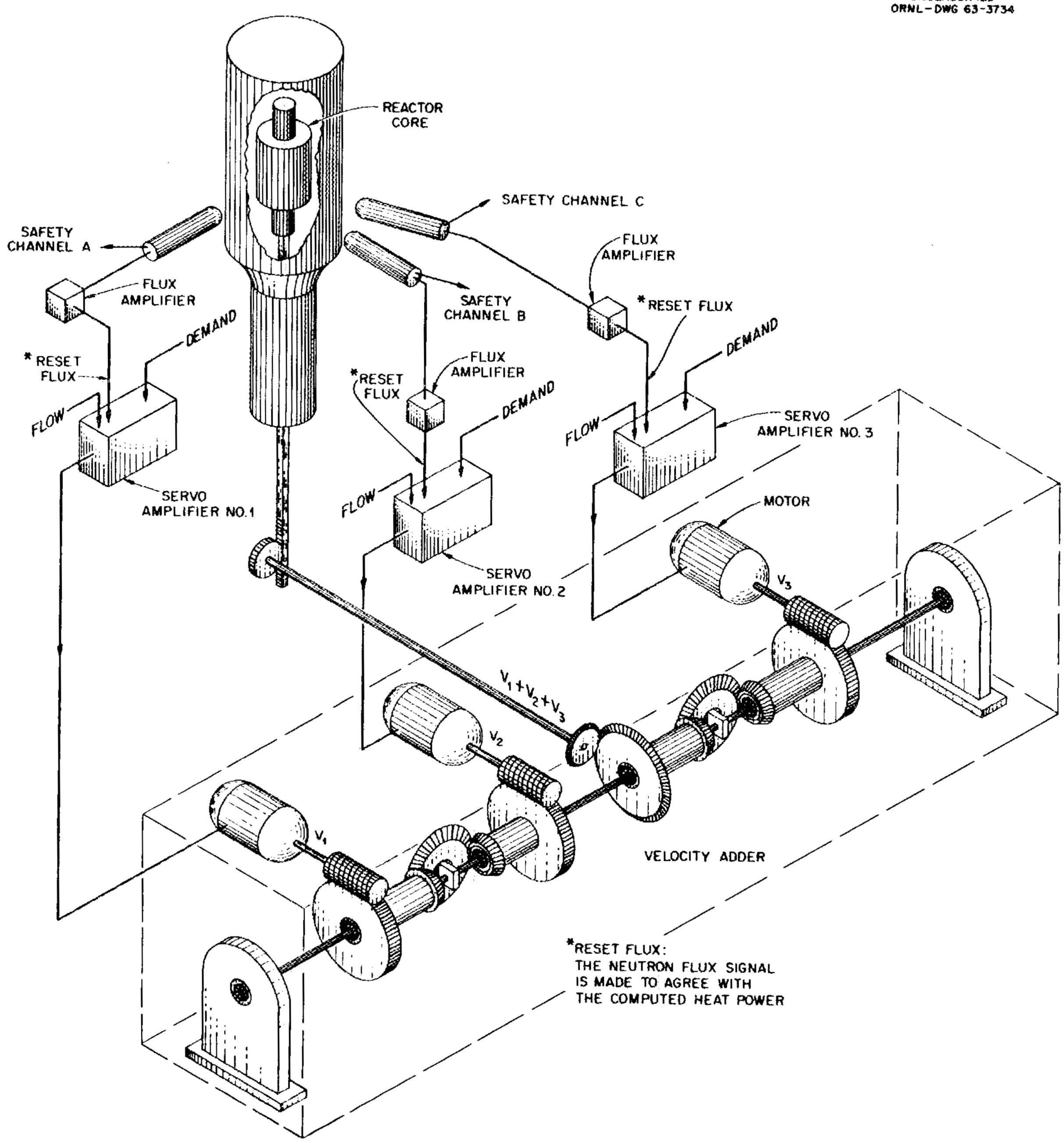

Fig. V-54. HFIR Servo System

134. The servo system, then, is a system for automatically controlling changes in the _____ of the reactor.

— — — — — — —

135. In order to change the reactivity of the _____ safely as needed, the servo system must be able to monitor the _____ flux of the core. reactivity

— — — — — — —

136. Signals to the three channels of the servo system are initiated by three ionization chambers which monitor the _____ flux. reactor, neutron

— — — — — — —

137. Each of the three ionization chambers produces a voltage signal which eventually controls one of the three motors of the system. The electronic equipment which is the signal path from ionization chamber to servo motor is called the servo channel. neutron

— — — — — — —

138. A servo channel is the instrument channel which converts the very weak chamber signal into one large enough to control a _____ motor.

— — — — — — —

139. The servo signal is initiated by an _____ _____ near the reactor core. servo

— — — — — — —

140. As noted in Figure V-54, this raw signal is first amplified by the flux amplifier. ionization chamber

— — — — — — —

141. The flux amplifier also compares the strength of the signal with the computed heat power and adjusts the signal strength to agree with the actual power level indicated by the heat power.

- - - - - - -

> The true power level of the reactor as indicated by the amount of heat being removed from the reactor by the coolant can be determined only by correlating coolant-flow and temperature measurements. The correlating process is too slow for the so-called "heat power" to be used for direct control action. Therefore, the neutron intensity as measured by ionization chambers must be used to initiate control action. This is the customary procedure in all nuclear reactors. In the HFIR, the neutron signal is automatically and continuously calibrated against the output of the heat-power monitor. In other reactors, calibration is done by the operator repositioning ionization chambers or adjusting the value of the ionization-chamber readouts.

- - - - - - -

142. This revision or reset of the flux signal is made because the power-level determined by the slower heat-power calculation is the only correct indication of the actual power level over the full life of a core.

- - - - - - -

143. Thus, the output of the flux amplifier is the revised signal called the _____ flux.

- - - - - - -

144. This reset flux signal is sent to the servo amplifier, where it is compared with signals from both the coolant flow monitor and the power-level demand. reset

- - - - - - -

145. The servo amplifier does two jobs. It amplifies and it _____ signals from three sources.

\- - - - - - -

146. From this comparison comes a voltage-difference signal called an error signal. compares

\- - - - - - -

147. When the servo amplifier compares the reset flux with the servo demand and the coolant-flow information, it produces an output called an _____ signal.

\- - - - - - -

148. The design of the HFIR servo system is different from that of the system installed in the ORR. It is identified as a "proportional" servo because the speed at which the servo motor runs is proportional to the size of the error between the demanded and measured reactor power levels. If the error is small, correction is made slowly; but, if it is large, the correction begins rapidly, slowing down as zero error is approached. As in the case of other servos, the direction of motor rotation is determined by the sign (+ or –) of the error signal. error

\- - - - - - -

149. The error signal causes the electrical power supplied to each servo motor to vary in voltage and polarity, plus or minus, and these variables determine the direction of rotation and also the _____ with which the motor turns.

\- - - - - - -

150. The direction and the speed with which the servo motor rotates are determined by the polarity and size of the signal that comes from the _____ amplifier. — speed

\- - - - - - -

151. If the demand signal to a servo amplifier is higher than the reset flux signal, the servo motor will move the regulating cylinder so as to (increase, decrease) the reactivity. — servo

\- - - - - - -

152. The action of a servo channel is always to change the reactivity in such a direction that the error signal will become zero. — increase

\- - - - - - -

153. In the above-mentioned case, the servo channel will temporarily increase the reactivity until the reset flux is the same as the demand signal and the error-signal voltage becomes _____.

\- - - - - - -

154. The other two servo channels also produce error signals which regulate the power to their _____ in the same manner. — zero

\- - - - - - -

155. As noted in Figure V-54 the three motors are attached to the drive mechanism of the regulating cylinder through a system of differential gears which make up a "velocity adder". — motors

\- - - - - - -

156. Each motor tries to position the regulating cylinder through this system of differential gears called a ______ ______.

- - - - - - -

157. The velocity adder works in such a way that when any two motors turn in the same direction they overpower an opposite motion of the third and drive the regulating cylinder in the correct direction to (increase, decrease) their error signal. velocity adder

- - - - - - -

158. The triple servo is not an example of a two-of-three coincidence system but, like the three counting channels, makes for increased reliability of operation. A coincident servo system is necessary to match the coincident safety system. (True, False). decrease

- - - - - - -

159. As long as any two servo channels are operating properly there will be no apparent or real degradation in the performance of the servo system. Any single channel (may, may not) be taken out of service for repair during reactor operation. false

- - - - - - -

160. In fact, two channels of the servo system may fail simultaneously in a number of ways and the remaining channel will continue to control the reactor satisfactorily. The three-channel servo system (is, is not) a higher performance system than the single-channel type. may

- - - - - - -

161. If some perturbation should cause the neutron flux in the vicinity of one servo chamber to increase, the signal from that chamber will be (smaller, larger) than the signals from the other two servo chambers. — is

- - - - - - -

162. The error signal would be such as to make this channel of the servo try to (increase, decrease) the reactivity by moving the regulating rod. — larger

- - - - - - -

163. The other two servo channels detecting the beginning of a decrease in reactor power would promptly bring the power back toward the demand point by (inserting, withdrawing) the regulating rod as needed. — decrease

- - - - - - -

> Before the servo system can act, it must detect an error between the actual and demanded power level. Of course, in the triple servo system in which each channel is independent, any error detected by one channel will cause it to act whether the error resulted from real or spurious conditions. The other two channels, which would not be affected by the same spurious conditions, would begin counteracting the real error introduced by the one channel as soon as that error was detected. The net perturbation in the flux would be appreciably smaller, however, than that which would have occurred had there been only a single servo system.

withdrawing

- - - - - - -

164. When the reactor power reaches 10 Mw during startup, the servo system assumes control and stops the power from increasing further by inserting the regulating cylinder as needed to (lower, raise, hold constant) the power level.

- - - - - - -

165. At this time the heat power is allowed to reach equilibrium, and instruments are again checked before raising the power level to N_F, which is _____ _____. — hold constant

- - - - - - -

166. When all checks are complete, the "run" button is pushed and the operator raises the servo demand to increase the power level. — full power

- - - - - - -

167. The rate at which reactivity can be increased by servo control is limited by the speed of the servo motors. The motor speeds normally limit the power change to a rate-of-rise of 1.5 Mw/sec.

- - - - - - -

168. The servo system operates only the regulating cylinder, and the rate that the reactivity can be increased is controlled by the _____ of the servo motors.

- - - - - - -

169. The servo motors normally limit the power rate-of-rise to _____ Mw/sec if the shim plates are not moved. — speed

- - - - - - -

170. The total amount of reactivity that the servo system is allowed to control is the reactivity worth of one linear inch of the regulating cylinder. — 1.5

- - - - - - -

171. Mechanical stops are placed so that the servo system can increase reactivity only by an amount equal to the reactivity worth of _____ _____ of the regulating cylinder.

- - - - - - -

172. When one of these stops is reached, the shim plates are adjusted by the operator to increase or decrease reactivity, as needed, in order that the servo system will move the regulating cylinder back to the center of its operating range when it compensates for the change made by the shim plates. — one inch

\- - - - - - -

173. When the servo system adjusts the regulating cylinder to compensate for the reactivity change caused by moving the shim plates, it moves away from the stop; and once again the servo is able to _____ the power level automatically.

\- - - - - - -

174. By withdrawing both the shim plates and the regulating cylinder, the reactivity can be increased fast enough to be a hazard. So, the rate-of-rise of the power level by group automatic-shim withdrawal is limited by a "group-withdraw inhibit" which is initiated if any two of the three servo channels see a rate-of-rise greater than 5 Mw/sec. — control or adjust

\- - - - - - -

175. If the reactivity should suddenly be increased enough to cause a power rate-of-rise (less, greater) than 5 Mw/sec as determined by the servo channels, withdrawal of all control plates would be inhibited.

\- - - - - - -

4.8. Control at Full Power

176. The control of the reactor neutron-flux level in the power range is the job of the _____ system. There are, however, limits placed on operation by other instrument channels. — greater

\- - - - - - -

177. Because the buildup of xenon and samarium poisons is relatively high in the HFIR, a restart following a scram is, at the least, difficult to achieve and may be impossible, even if attempted immediately. servo

\- - - - - - -

178. It is of (more, less, equal) importance to avoid scrams in the HFIR than in other ORNL reactors.

\- - - - - - -

179. At full power, the HFIR is running much nearer core burnout conditions than are other ORNL reactors. A relatively small increase in neutron flux or decrease in coolant flow could result in burnout (breach of fuel cladding by melting). more

\- - - - - - -

180. The HFIR (will, will not) tolerate a considerable increase in flux or decrease in coolant flow while operating at full power.

\- - - - - - -

In the HFIR it is advantageous to continue operation at a power level consistent with the available coolant flow rather than to scram. This is so because of the rapid buildup of xenon and the subsequent buildup of stable samarium (poisons). Coolant flow must continue in order to avoid core meltdown from afterheat. If afterheat is not removed, a scram can do little more than postpone a meltdown. To avoid unnecessary scrams, when most of the coolant flow is lost but afterheat coolant flow is still available, the power of the reactor is automatically reduced under servo control to a value corresponding to the reduced flow. The safety system, meanwhile, re-adjusts itself to protect the reactor against power increases above that corresponding to the heat-removal rate provided with the coolant flow available. will not

\- - - - - - -

181. Scramming the HFIR (is, is not) the most desirable corrective measure for an excessively high power level.

\- - - - - - -

182. Scramming the HFIR (is, is not) always desirable or necessary following loss of electrical power to the primary coolant pumps. — is not

\- - - - - - -

183. Within the designed operating range of the HFIR, the allowable power level is determined by the coolant flow rate. The controlling instrument signal is called the flux-to-flow ratio. The permissible operating power level of the HFIR is determined by the _____ of reactor flux to coolant flow at that particular time. — is not

\- - - - - - -

184. The power level at which the HFIR automatically scrams (does, does not) depend on the coolant-flow rate at the time. — ratio

\- - - - - - -

4.9. Power-Level Safety

185. Unlike other ORNL reactor systems, the HFIR system does not use the power-level safety recorders as the principal power recording instruments. Each of the three recorders does, however, take its signal from a separate ionization chamber; but the chamber signal has first been corrected to a power corresponding to the existing heat power. (No control actions originate from signals from these recorders.) — does

\- - - - - - -

186. As at the other ORNL reactors, there are _____ power-level safety channels at the HFIR.

\- - - - - - -

> The same instruments are referred to both as "flux-level" and as "power-level" safety instruments.

three

\- - - - - - -

187. The power-level safety channels give the operator information as to the power level above approximately 10 Mw.

\- - - - - - -

188. The linear recorders of the safety channels read the reset flux level (or value) from about 5 Mw to more than _____ Mw, which is full power.

\- - - - - - -

189. The "fast trip comparators" (FTC's) of the flux-level safety channels are electronic devices that monitor the reset flux and trip at 1.1 N_F (110 Mw) to initiate a reverse, thus reducing reactor power if it should tend to rise too high for any reason.

100

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190. At least two of the three FTC's in the flux-level safety channels must detect a power level of 1.1 N_F in order for the reverse to be initiated. The _____ coincidence arrangement ensures that spurious actions of one instrument or channel will not interfere with reactor operations; but, and more importantly, the coincidence system permits on-line testing and maintenance of the equipment.

\- - - - - - -

191. If something should happen to cause the power level to surge to 1.3 N_F (_____ Mw), the safety channels would cut off the current to the control-rod-drive magnets, causing the rods to drop in what is called a "fast scram." two-of-three or two-out-of-three

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> The HFIR shim-safety plates are supported on the drive rods by ball latches which are operated by shafts that extend down to electromagnets located in the subpile room. When energized, these electromagnets hold the latch shaft in the clutch position and prevent the shim-safety plates from dropping. If as much as two-thirds of the current to the electromagnets is lost, they allow the latch shaft to release the shim-safety plates so that the plates drop and cause a scram. Each of the electromagnets is equipped with three energizing coils--each coil controlled by only one of the "fast-trip comparators" in the safety system. Thus, if two FTC's reduce the current in the coils they control, a scram will occur. If, however, only one FTC reduces the current in its coil, no scram will result.

130

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192. Again, the two-of-three coincidence prevails so that in order for the reactor to be shut down with a fast scram at least _____ power-level safety channels would have to "see" a power level of _____ Mw.

\- - - - - - -

193. A power surge to 130 Mw is not the only cause of a fast scram. Information from seven different sources per channel is fed into individual FTC's, as shown in Figure V-55. Each of these instruments compares the composite signal from its sources with a reference voltage and sends the difference or "error signal" to the "OR" circuit, which either allows magnet current to flow when all conditions are normal or does not allow magnet current to flow when any one condition changes beyond tolerance. — two, 130

- - - - - - -

194. Each of the three safety channels has an "OR" network which accepts signals from any of the seven _____-_____ comparators.

- - - - - - -

195. Normally, the "OR" circuit receives a 10-volt signal from the fast-trip comparator. If the "OR" network in any channel receives a zero error voltage (condition beyond tolerance), which means that a fast scram request has come from one of the seven comparators, it turns off the magnet current that it controls. — fast-trip

- - - - - - -

196. Then, if two of three "OR" networks both cut off the _____ current they control, the rods drop and shut down the reactor.

- - - - - - -

197. The two-of-three _____ arrangement is used in the control channels as well as in the safety channels to keep spurious signals from interfering with reactor operation and to permit on-line testing. — magnet

- - - - - - -

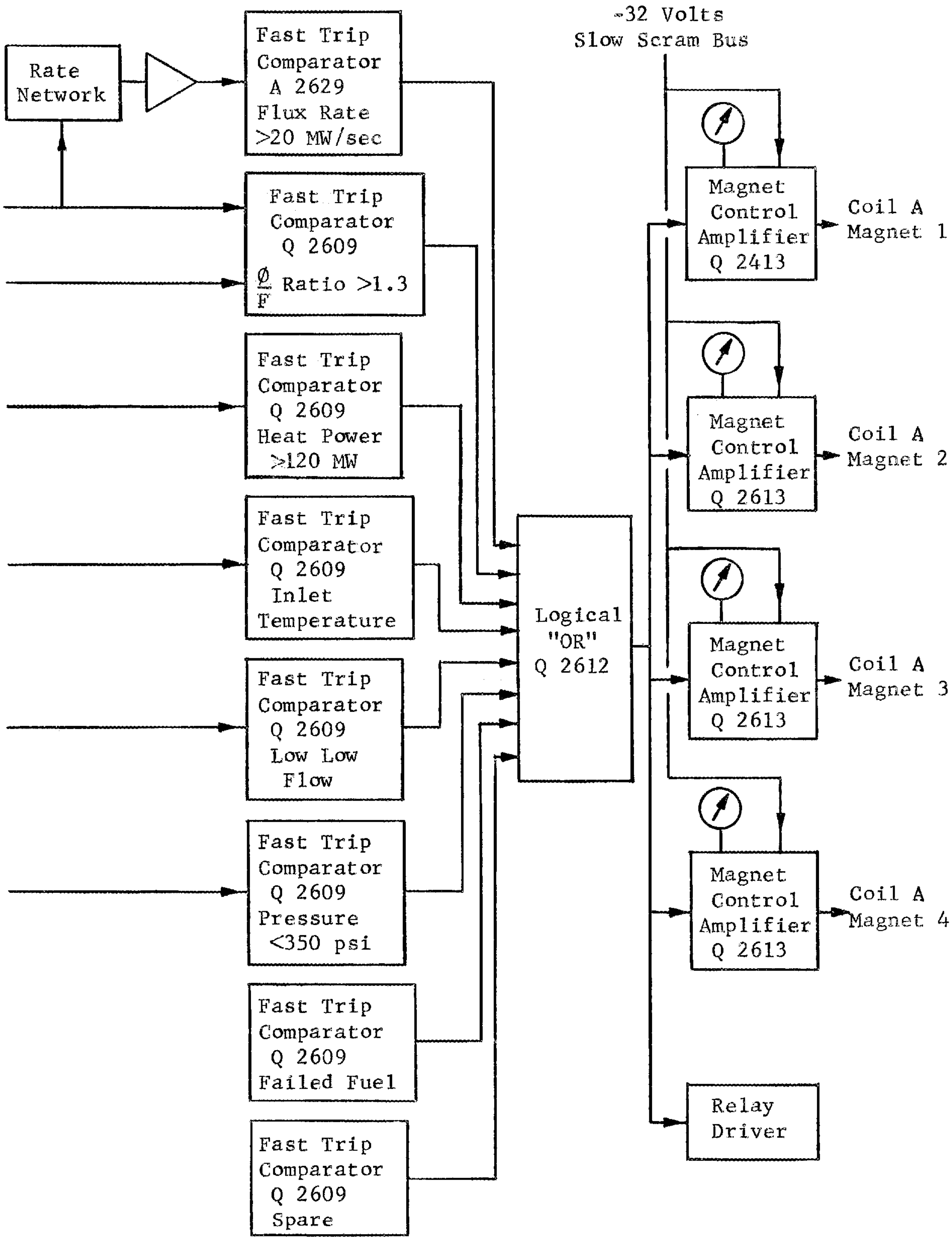

Fig. V-55. Block Diagram of Fast-Trip Comparators and OR Circuits

4.10. Review of HFIR Control Systems

198.	The HFIR has _____ operating modes. (Frame 96)	coincidence
199.	When the operator at the HFIR is assured that the CRM is reading properly, that the fission-chamber drive will operate automatically, and that the pulse amplifier is ready to operate, he is said to have "counting-rate _____" and is ready for reactor startup. (Frames 99-102)	three
200.	At the HFIR, the control plates are withdrawn (intermittently, continuously) during startup. (Frames 103 and 104)	confidence
201.	The automatic fission-chamber drive keeps the fission chamber positioned so that the CRM count is maintained at _____ counts/sec. (Frame 106)	continuously
202.	The power level, during startup, is calculated and displayed by the _____-_____ counting channel. (Frames 107-110)	10,000
203.	In most cases of electronic control at the HFIR, a control action is initiated only when _____ instrumentation channels recognize, at the same time, the need for control action. (Frames 115 and 116)	wide-range

204. When at least two signals are required from a group of three instruments to produce a control or safety action, the action is called _____ _____. (Frames 115-117) — two

- - - - - - -

205. The 30-sec-period inhibit during startup is a case in which two-of-three coincidence (is, is not) used. (Frames 118-122) — two-of-three coincidence

- - - - - - -

206. During startup when the power reaches _____, an automatic control system called the _____ system assumes control of the reactor and will hold the power _____ at any selected level within the allowable range. (Frames 130-132) — is not

- - - - - - -

207. The servo system (does, does not) use the two-of-three coincidence system for its controlling actions. (Frames 157-160) — 10 Mw, servo constant

- - - - - - -

208. The neutron-flux signal to the flux amplifier of the servo system is automatically revised to be the same as the _____-_____ measure of power level. This revised signal is called the _____ flux signal. (Frames 141-144) — does not

- - - - - - -

209. The corrective action of a servo channel is always in a direction that will produce a zero _____ signal. (Frames 150-152) — heat-power, reset

- - - - - - -

210. The servo normally limits a power change to a rate-of-rise of _____ Mw/sec. (Frame 167) error

- - - - - - -

211. Power increases, resulting from group automatic-shim-withdrawal are stopped by a "group-withdraw-inhibit" which is initiated if two flux-level safety channels "see" a rate-of-rise greater than _____ Mw/sec. (Frames 174 and 175) 1.5

- - - - - - -

212. The flux-level safety recorders are (logarithmic, linear) instruments. (Frame 188) 5

- - - - - - -

213. If two out of the three flux-level safety channels "see" a power level of 110 Mw, a _____ is initiated. (Frames 189-190) linear

- - - - - - -

214. Dropping of the shim-safety plates caused by a signal from the safety channels is called a "fast" _____. (Frame 191) reverse

- - - - - - -

215. The safety channels initiate a fast scram if two out of the three sense a power level of _____ Mw. (Frame 191) scram

- - - - - - -

V-5. INSTRUMENT BEHAVIOR DURING AN ORDERLY REACTOR STARTUP

The purpose of this section is to describe an orderly reactor startup. We shall list the sequence of events from the beginning of the startup until full power is attained and explain events that have not already been explained. Briefly, an orderly reactor startup consists of withdrawing the control rods slowly until the reactor is critical, withdrawing the rods a little more to make the reactor slightly supercritical so that the power increases, stopping the increase at N_L (from 1% to 10% of full power, depending on which reactor) when the servo assumes control, checking that all systems are functioning properly, and, finally, increasing the power level to 100% of the operating level by raising the servo demand. The discussion here will primarily be slanted toward instrumentation behavior during the startup.

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5.1. Prestartup Information Review

1. In order for the fission chain reaction to begin in a reactor, neutrons must be present to be captured by the fuel atoms and cause _____ of the fuel atoms.

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2. Some fissions take place in a new subcritical reactor core (called a cold, clean core) due to small numbers of neutrons being produced by cosmic radiation reacting with atoms and due to the spontaneous fissioning of ^{238}U. Depending on neutrons produced in these ways to start a reactor is unsatisfactory for a number of reasons. For example, there would be no way of predicting when a reactor would start, a situation not conducive to orderly operation. Measurement shows that the low, naturally occurring neutron flux fluctuates unpredictably in spite of all efforts to control it. — fissioning

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3. Control of a reactor during startup requires having a stable neutron source which produces an appreciable quantity of neutrons. The strength of the source is selected, among other things, to produce a sufficient neutron flux to be easily measurable with ordinary rather than laboratory-type instrumentation. Further, the flux is made high enough to be monitorable even when there is no fuel in the reactor so that the effects of the addition of each unit of fuel can be observed.

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4. Proper control of a reactor during startup requires a (larger, smaller) quantity of neutrons than can be supplied by cosmic radiation or the spontaneous fissioning of ^{238}U so that the neutron flux can be _____ at all times.

- - - - - - -

5. An adequate source of neutrons for reactor startup is supplied from either of two sources: (1) photoneutrons from high-energy gamma radiation reacting with structural materials, moderator, and reflector in an "old" reactor; and (2) a special "nonfission" neutron source in a "new" reactor.

larger, monitored

- - - - - - -

In the frame above, the term "old" reactor refers to any reactor that has recently been operated at an appreciable power level for an appreciable length of time. Such a reactor will contain radioactive nuclei in its structural materials and in its fuel elements. Some of these radioactive atoms emit gamma rays (photons) that are energetic enough that when they strike certain other atoms normally in the reactor they cause neutrons to be expelled. A "new" reactor would naturally not contain such radioactive atoms--neither would an "old" reactor which had not been recently operated.

- - - - - - -

6. High-energy gamma photons in an "old" water-moderated reactor core produce "photoneutrons" from their collisions with the naturally occurring deuterium in the water. There may be enough of these _____ that a special nonfission neutron source is not necessary.

- - - - - - -

7. When a reactor is new, a neutron source is kept near the core to provide, as a minimum, a readily detectable number of neutrons per second. Such a neutron source may be made of a small beryllium shell filled with radioactive antimony. photoneutrons

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8. In new reactors, beryllium and radioactive antimony are often used as a nonfission source of _____.

- - - - - - -

9. One reason for starting with a detectable neutron flux is that only then are we able to measure, with assurance, the increase in neutron flux caused by the fissioning of fuel atoms as the reactor is made more nearly critical. Only then can proper control be exercised. (Each fission returns two or three neutrons for each neutron absorbed.) neutrons

- - - - - - -

10. The factor by which the neutron flux increases above source level as a result of the fissioning of fuel atoms (when fuel is present) is called the neutron multiplication.

- - - - - - -

11. If we know the neutron flux due to the source only and can measure the increase in neutron multiplication at any time during startup, we can calculate how nearly _____ the reactor is as either more fuel is added or as the control rods are withdrawn.

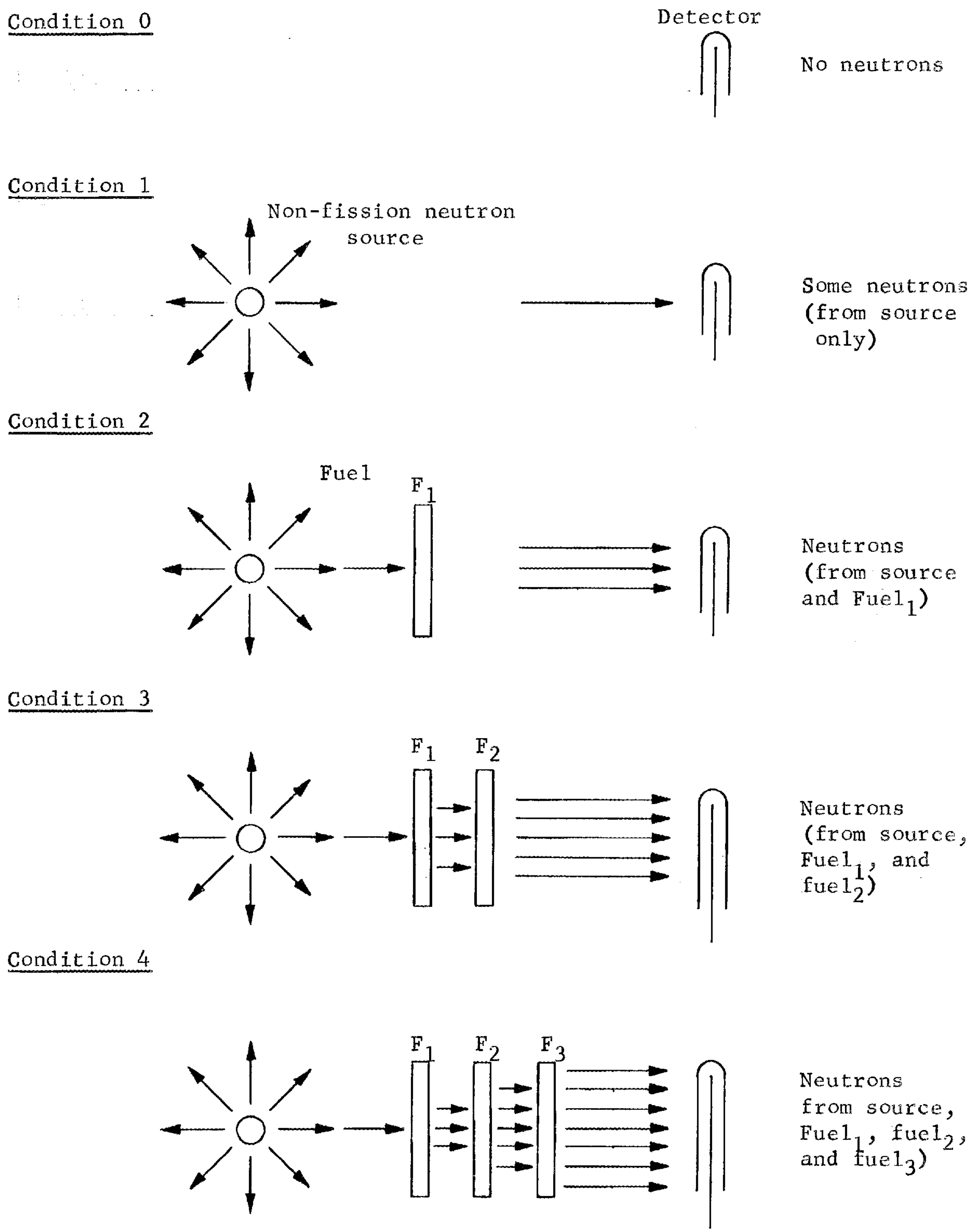
- - - - - - -

12. Each condition shown in Figure V-56 is a steady-state condition. The increase in neutrons above source level seen by the detector and caused by the presence of fuel is the neutron _____. critical

- - - - - - -

13. From the detector's point of view, the fuel amplifies the number of neutrons released by the nonfission neutron source. multiplication

- - - - - - -


Condition 0
Detector
No neutrons
Condition 1
Non-fission neutron source
Some neutrons (from source only)
Condition 2
Fuel
F1
Neutrons (from source and Fuel1)
Condition 3
F1
F2
Neutrons (from source, Fuel1, and fuel2)
Condition 4
F1
F2
F3
Neutrons from source, Fuel1, fuel2, and fuel3)

14. As more fuel is added to the core or as neutron poison is removed from the core, the neutron flux _____. A comparison of the neutron flux with no fuel present to the neutron flux when fuel is present allows us to compute the neutron _____ that the fissioning of fuel causes.

- - - - - - -

15. As more fuel is added or as more neutron poison is removed, the neutron multiplication rate increases. | increases, multiplication

- - - - - - -

16. As the reactor nears criticality due to fuel additions or due to poison removal, the neutron multiplication rate becomes very large and its reciprocal approaches zero. Thus, a graph of the reciprocal of the multiplication rate versus feul content of the core can be used to predict the total amount of fuel required to make the reactor critical.

- - - - - - -

17. In order for a reactor to achieve a self-sustaining chain reaction independent of the nonfission neutron source, the core must contain a critical mass of _____.

- - - - - - -

18. The critical _____ is the smallest amount of fuel in a given reactor core of a certain size and shape in which a self-sustaining fission chain reaction will occur. | fuel

- - - - - - -

19. The smallest amount of fuel which will support a self-sustaining fission chain reaction in a reactor core is called the _____ mass. | mass

- - - - - - -

20. If, however, we started operating the reactor with exactly a critical mass, the chain reaction could not be sustained long because the fissioning of the atoms of ^{235}U would soon reduce the amount of ^{235}U to below the critical mass. — critical

- - - - - - -

21. Thus, in order for a reactor to achieve and sustain an appreciable level of power production, the reactor must have more fuel than just the _____ _____.

- - - - - - -

22. Instead of discussing this excess amount of fuel in terms of kilograms or pounds, we relate the excess to the number of fissions it can produce and speak of the reactor's excess k. The control rods are used to "cancel" this _____ _____ until it is needed. — critical mass

- - - - - - -

> You will recall that "k" stands for the ratio of the number of fissions caused by neutrons in one generation to the number of fissions caused by the preceding generation of neutrons.

excess k

- - - - - - -

23. If a reactor has more than enough fuel to make it critical, it is said to have _____ k.

- - - - - - -

24. A reactor with excess k must also have a method of controlling the use of that excess. The usual method of control is to place neutron absorbers (poisons) in the form of control rods within the fuel configuration so that excess neutrons are absorbed and are not available to cause _____. — excess

- - - - - - -

25. To keep the reactor at a given power level, the ____ rods are adjusted so that they absorb just enough neutrons to make the fissions caused by one generation of neutrons equal to the number caused by the preceding generation of neutrons. — fission

- - - - - - -

26. When each generation of neutrons is equal in number to the last generation, the reactor is _____. — control

- - - - - - -

27. When a reactor is critical, k = 1 and the ratio of fissions caused by one generation of neutrons to the fissions caused by the next generation is _____. — critical

- - - - - - -

28. In order to control the excess k, neutron absorbers are placed close to the fuel to nullify the effect of the excess k. These absorbers are usually called _____ rods. — 1:1 or one-to-one

- - - - - - -

29. These control rods are such strong neutron _____ that, when they are fully inserted into the core, a self-sustained chain reaction is not possible. In this condition the reactor is said to be subcritical. — control

- - - - - - -

30. When the control rods are withdrawn (poison is removed), the k of the reactor (increases, decreases, remains the same). — absorbers

- - - - - - -

31. When the control rods are inserted (poison is added), the excess k of the reactor is (increased, decreased). — increases

- - - - - - -

5.2. Startup

32. With the foregoing review for background, let us describe an orderly startup with first emphasis on the conditions in the reactor, as described by the instrumentation, from shutdown condition to criticality, the condition at which a fission chain reaction is self-_____.

decreased

- - - - - - -

33. Prior to startup and attaining the condition called criticality, we describe the reactor's condition as being _____. However, we shall assume that it already contains sufficient fuel to become supercritical when the control rods are withdrawn sufficiently.

sustaining

- - - - - - -

34. During startup, the control rods are being moved (usually being withdrawn--poison is being removed) so as to (increase, decrease) the k of the core.

subcritical

- - - - - - -

35. As _____ increases, the number of neutrons being detected by the counting-rate meter _____.

increase

- - - - - - -

36. Since the neutron source is producing neutrons at a constant rate, a continuously increasing count on the counting-rate meter indicates that the neutron _____ is increasing.

k,
increases

- - - - - - -

37. Before criticality is attained, the reactor is referred to as being subcritical, and so the neutron multiplication is called _____ neutron multiplication.

multiplication

- - - - - - -

38. During the time when the reactor is subcritical, the operator looks to two types of instruments for information. These are the counting-rate meters and the counting-rate reactor-period meters, both being readouts of the counting-rate channels. subcritical

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> Perhaps it should be mentioned that while we use the expression "counting-rate meters", we could also add "and recorders" because they are both used; and, after all, a recorder is a recording meter. We hope there will be no confusion if, at times, we use the terms interchangeably.

\- - - - - - -

39. As the control rods are withdrawn during an orderly startup, the counting rate will _____ steadily until the counting-rate meter indicates an increase of about four decades. (In the HFIR, the counting rate reaches and remains at 10,000 cps because the chamber position adjusts to keep this value once it is attained.)

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40. You will recall that the counting-rate meter usually can count accurately over a range of about four decades. Except for the HFIR installation, ORNL counting-rate recorders read from 1 count/sec to 10,000 counts/sec. increase

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41. As the counting rate increases beyond 10,000 per sec, the statistical fluctuations in the neutron flux begin to affect the counting _____.

\- - - - - - -

42. You will recall that once the counting channel has reached the end of its operating range during reactor startup the fission chamber is withdrawn to a region of much weaker flux thus placing the channel back into its operating range. At the beginning of a startup, the fission chamber must be returned to a position near the core where it can detect the small number of _____ due to the source. — accuracy

----

43. In some ORNL counting systems, when the neutron count reaches about 10,000 counts/sec control-rod withdrawal is stopped and the chamber is withdrawn to a position where the neutron flux is lower and the chamber detects only a few _____ per sec once more. — neutrons

----

44. When the fission chamber has been repositioned, control-rod _____ may be continued if other conditions permit. — neutrons

----

45. At some moment during this startup, the neutron population will have grown enough and the k of the core will be great enough (k = 1) that the chain reaction becomes self-sustaining. We say that at this moment the reactor is _____. — withdrawal

----

46. Although source-neutron multiplication still exists after the reactor is critical, the percentage of neutrons contributed by the _____ becomes insignificant; and we describe the condition of the reactor in terms of its self-sustained neutron flux. — critical

----

47. The <u>moment</u> of criticality <u>may not be long</u>, for as soon as k is <u>increased further</u> to _____ the power level, the reactor becomes <u>supercritical</u>. — source

- - - - - - -

48. When the reactor is <u>supercritical</u>, the counting-rate recorder will show a <u>continuous increase</u> in the counting rate <u>even after</u> the <u>withdrawal</u> of the control rods <u>has been stopped</u>. Also, the reactor-<u>period recorder</u> will indicate a <u>sustained positive</u> period. — raise or increase

- - - - - - -

49. You will recall that the <u>reactor period</u> is the <u>length</u> of time during which the neutron <u>flux changes</u> by a <u>factor of</u> _____.

- - - - - - -

50. When the <u>neutron flux</u> is <u>increasing</u>, the reactor period is (negative, positive). When the <u>neutron flux</u> is <u>decreasing</u>, the period is _____. — e

- - - - - - -

51. Until <u>criticality</u> is <u>reached</u>, the period is <u>infinite</u> <u>except</u> while k is <u>being</u> increased by <u>control rod</u> _____. — positive, negative

- - - - - - -

52. <u>Each</u> increase in k causes a <u>momentary positive</u> period even while the reactor is <u>still subcritical</u>; however, if the reactor is <u>still subcritical</u>, the period meter soon returns to an _____-period reading if control-rod motion is stopped because the neutron flux <u>remains constant</u> at the higher multiplication level until the <u>next k increase</u> is made. — withdrawal

- - - - - - -

53. When the reactor becomes critical, a further increase in k will cause the period meter to indicate a _____-period "spike" as before; but instead of returning to an infinite period, it will show a sustained positive period, indicating that the reactor is supercritical. — infinite

- - - - - - -

54. When the period meter shows a sustained positive period, the reactor is _____. — positive

- - - - - - -

55. Any increase in k above criticality (when k = 1) causes the reactor to become _____. In this condition, each generation of neutrons is larger than the preceding one and the neutron flux continues to _____, even when there is no additional increase in k. — supercritical

- - - - - - -

56. During this early part of an orderly startup, the operator depends entirely on the counting-rate meters and the counting-rate period meters for reactor flux information. — supercritical, increase

- - - - - - -

57. The meters that give the operator information about the neutron flux level are the _____-_____ meters or indicators.

- - - - - - -

58. The meters that indicate the time lapse during which the neutron flux changes by a given amount are the counting-rate _____ meters. — counting-rate

- - - - - - -

59. After the reactor becomes <u>supercritical</u>, the operator notes that without a further increase in k the reactor period remains (negative, infinite, positive), showing that the chain reaction is <u>definitely self-sustaining</u>. — period

- - - - - - -

60. As the power level <u>increases</u>, effects such as the <u>negative temperature coefficient</u> and the <u>buildup</u> of <u>xenon-135</u> in the fuel tend to <u>reduce</u> the excess k so that the power-increase <u>rate</u> usually <u>diminishes</u>. — positive

- - - - - - -

61. In order to achieve a higher power level, the operator usually must <u>continue</u> to increase the k in <u>small increments</u> to overcome the _____ and _____-poisoning effects so that the period <u>remains positive</u> and the power level <u>continues to rise</u>.

- - - - - - -

62. As the neutron flux gets <u>higher</u>, the operator can <u>begin</u> to shift his attention to another instrument that is often used in the <u>upper startup</u> or <u>intermediate</u> range of reactor operation. This is the <u>log-N channel</u> which supplies information readout on the <u>log-N</u> and the <u>log-N period</u> meters or indicators; therefore, the <u>upper startup range</u> is sometimes referred to as the <u>log-N range</u>. The log-N meter is so named because its <u>output varies</u> with the <u>logarithm</u> of its <u>input signal</u>. — temperature, xenon

- - - - - - -

63. The nuclear instrument of the <u>upper startup</u> or _____ range of operation <u>supplies information</u> by readouts on the _____ meter and the log-N _____ meter.

- - - - - - -

64. At reactors in which the power level is referred to in terms of N_L (0.01 N_F) and N_F (full power), the intermediate range begins at about 0.001 N_L, about _____ decades below N_L.

intermediate or log-N, log-N, period

- - - - - - -

65. The log-N channel is normally used as a controlling instrument throughout only 4 decades of neutron flux level. However, the information is useful through 5 decades or more or from 0.001 N_L to beyond 100 N_L (100 N_L is also called _____).

3

- - - - - - -

66. One of the reasons for not using the log-N meters alone for operating in the power range is that, since the readout scale is logarithmic, it is too difficult to read the power level precisely at the upper end of a logarithmic scale (from 10% N_F to 100% N_F).

N_F

- - - - - - -

67. The log-N channel is most useful for power measurements up to a power level of _____.

- - - - - - -

68. As the startup progresses through the intermediate range, the operator reads the power level in percent of full power on the _____-_____ meter.

N_L

- - - - - - -

69. When the power level reaches N_L (which may be either 1% or 10% N_F, depending on the reactor), an automatic control system called the servo assumes control and inserts a regulating rod to stop the reactor power increase at N_L. The servo then holds the power at this level by making small adjustments with the regulating rod as needed. log-N

\- - - - - - -

70. The instrumentation discussed thus far has been related to two ranges--the lower startup range and the upper startup range. The upper startup range is also called the intermediate or _____-_____ range.

\- - - - - - -

71. The two startup ranges are often combined and simply called the startup range. log-N

\- - - - - - -

72. The two startup ranges include, at most ORNL reactors, operation up to _____.

\- - - - - - -

73. Startup instrumentation at the HFIR is different from that at many reactors, but the theory of operation is much the same as that discussed in the above frames. N_L

\- - - - - - -

74. The startup range at the HFIR is up to 10 Mw, which is 10% of the full 100-Mw power level. In this case, N_L is _____ N_F rather than 0.01 N_F as at other ORNL reactors.

\- - - - - - -

75. At the HFIR, the startup range is from zero power to _____ Mw. 0.1

- - - - - - -

76. The reason the counting-rate meter (CRM) of the HFIR may be used through the intermediate range is that when the CRM reaches 10,000 counts/sec the fission chamber is automatically moved farther and farther from the core so that it is kept in a neutron flux that causes a counting rate of _____ counts/sec. This feature allows these same instruments to be used all the way from zero to full power. 10

- - - - - - -

77. As the _____ _____ is automatically moved away from the core, the distance from the core at which 10,000 counts/sec occurs is a measure of the reactor power. This distance is indicated on the power meter in units of percent of full power. 10,000

- - - - - - -

78. This instrument system is called the "wide-range counting channel" because it covers about 10 decades of power. fission chamber

- - - - - - -

79. High accuracy is not extremely important in a counting channel as long as its counting error is known. It is, therefore, entirely satisfactory to operate the HFIR counting channels at a constant 10,000-counts/sec rate. The counting rate is kept at this value in the wide-range counting channels during startups and at full-power operation by automatically repositioning the _____ _____ as needed.

- - - - - - -

80. At the HFIR the startup instruments, the _____-_____ counting channels, supply power-level information from source level to _____.

fission chambers

\- - - - - - -

81. During an orderly startup, there is usually no break in the procedure from the beginning of startup to N_L.

wide-range, N_F or full power

\- - - - - - -

82. Below N_L nuclear heating is generally not an important consideration, but above N_L forced-convection cooling of the reactor core is usually a necessity.

\- - - - - - -

83. During the pause at N_L, the power level is kept constant by the automatic control system, called the _____.

\- - - - - - -

84. The instruments which record the temperature changes in the reactor respond more slowly to a power-level change than do the nuclear instruments. Thus, a power-level increase may be noted on a nuclear instrument (before, only after) it is displayed on a heat-measuring instrument.

servo

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85. When all checks have been made and the reactor is ready for the power level to be increased above N_L, the operator uses the servo system to raise the power level. The servo system is an (automatic, manual) power-level controlling system that was discussed in Section V-4.

before

\- - - - - - -

86. The operator increases the power level by increasing the demand to the servo system. The servo system uses the regulating rod to make the power level match the _____. automatic

- - - - - - -

87. Before raising the power level all the way to N_F, a "heat balance" (heat-production determination) may be made at some intermediate power level, such as 0.6 N_F or 0.75 N_F. This is done by stopping the power increase at, say, 0.6 N_F and waiting until the coolant temperature reaches equilibrium at a fixed flow rate. From the heat output of the core, the true power level is calculated. demand

- - - - - - -

88. Before increasing the reactor power-level demand to N_F, the heat-power level may be checked by measuring the _____ output of the core at a power level between N_L and N_F.

- - - - - - -

89. If the heat-power level matches the power level indicated by the neutron-detecting instruments, the power is increased to N_F. heat

- - - - - - -

90. If the heat-power level differs appreciably from the power level indicated by the _____-_____ instruments, the instruments usually are adjusted so that their readouts match the heat power level before the power is raised to N_F. Wide variations should be looked on with suspicion since they may be indicative of an abnormal condition.

- - - - - - -

91. Before the power level is raised to N_F, the readouts on the instruments must be made to match the _____ power level.

neutron-detecting

\- - - - - - -

92. The "true" power level of the reactor is calculated from the _____ output of the core.

heat or "true"

\- - - - - - -

93. In the power range, instruments with linear scales are used because they can be read with greater precision than those having _____ scales.

heat

\- - - - - - -

94. The instruments with _____ scales used in the power range are often called the "safety" instruments or just "safeties". This, of course, is not because of the scales but because their inputs come from the safety instrument channels.

logarithmic

\- - - - - - -

95. The nuclear instruments on which the operator will be most dependent while the reactor power is between N_L and N_F are the _____.

linear

\- - - - - - -

96. After the power level indicated by the safety instruments has been shown to agree with the calculated heat power, the operator increases the power level to N_F by raising the _____ to the servo.

safeties

\- - - - - - -

97. When the reactor reaches full power, the _____ system holds the power level constant by adjusting the regulating-rod position.

demand

\- - - - - - -

5.3. Self-Test

98. To help ensure safe and orderly reactor startups, a neutron _____ of suitable strength must be present at, or within, the core. "Suitable" strength is that which produces a _____ flux that is readily detectable by the reactor startup instrumentation without benefit of the _____ afforded by the fuel. (Frames 2-5, 10, and 11) — servo

- - - - - - -

99. In order to make orderly measurements of changes in neutron multiplication, a _____ _____ is used which produces a measurable neutron flux. (Frames 9-11) — source, neutron, multiplication

- - - - - - -

100. A comparison of the neutron flux with no fuel in the core to the neutron flux when fuel is present allows us to compute the neutron _____ that the fissioning fuel causes. (Frame 14) — neutron source

- - - - - - -

101. A reactor must have more fuel than just a critical mass in order to have _____ k. (Frames 16-19) — multiplication

- - - - - - -

102. Prior to startup and attaining the condition called criticality, we describe a reactor as being _____. (Frame 29) — excess

- - - - - - -

103. In the startup range, the instrument that indicates the neutron-flux level is the _____-_____ meter. (Frames 34-42) — subcritical

- - - - - - -

104. When the fission chain reaction is just self-sustained in a reactor, the reactor is said to be _____. (Frame 45) — counting-rate

- - - - - - -

105. The _____ meter indicates the time required for the neutron flux to change by a factor of e. (Frames 48 and 49) — critical

- - - - - - -

106. The instrumentation often used in the upper startup range is the log-N channel which supplies information by way of readouts on the log-N meter and the log-N _____ meter. (Frames 62-65) — period

- - - - - - -

107. The intermediate startup range is also called the _____ range because the neutron instrument in use displays the neutron level on a logarithmic scale. (Frames 62-66) — period

- - - - - - -

108. Ordinarily, the log-N instrumentation is given relatively little attention above _____. (Frames 64-66) — log-N

- - - - - - -

109. The HFIR uses an instrument system called the _____-_____ counting channel for power level and period information from startup to full power. (Frames 73-80) — N_L

- - - - - - -

110. The instruments which record the temperature changes in a reactor respond (more quickly, more slowly) than the nuclear instruments. (Frame 84) — wide-range

- - - - - - -

111. In the power range of operation, most reactor operators prefer to use instruments with _____ scales. These instruments often get their signals from the _____ channels. (Frames 93 and 94)

more slowly

- - - - - - -

112. During normal full-power operation of a reactor, an automatic control system called a _____ keeps the power level constant. (Frame 97)

linear, safety

- - - - - - -

servo

SECTION V-6. PROCESS INSTRUMENTATION

6.1. Introduction

Process instruments are those instruments which measure specific parameters in a manufacturing process. For example, if we were manufacturing steam in a coal-fired plant, we would want to know the water level in the boilers, the steam pressure, etc. The instruments used to measure and/or maintain control of a process would be called process instruments.

In the business of operating nuclear reactors, this definition is modified just a little bit. We think of process instruments as those instruments which measure and/or control parameters having to do with all processes other than nuclear processes.

In this section, we shall discuss the principal methods of measuring the parameters of interest in such areas as the coolant loops, waste systems, containment, and radiation control. Much of the process information is read out either locally, remotely in the control room, or both on electrical or pneumatic indicators or recorders. However, in the case of the liquid level in a tank, the local instrument may be a sight glass and the remote indicator may be a light and/or an alarm actuated by some other type monitor. We shall not be as interested in the circuitry and method of display of information as we are in the instrument that originates the signal. Let us begin with a discussion of various ways of measuring pressure, flow, and temperature.

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6.2. Pressure Sensors

1. We shall discuss pressure instruments first since, quite often, flow is determined by pressure difference.

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2. Two common pressure-measuring instruments are the manometer and the Bourdon gauge. The manometer is merely a U-shaped tube filled with a liquid as shown in Figure V-57.

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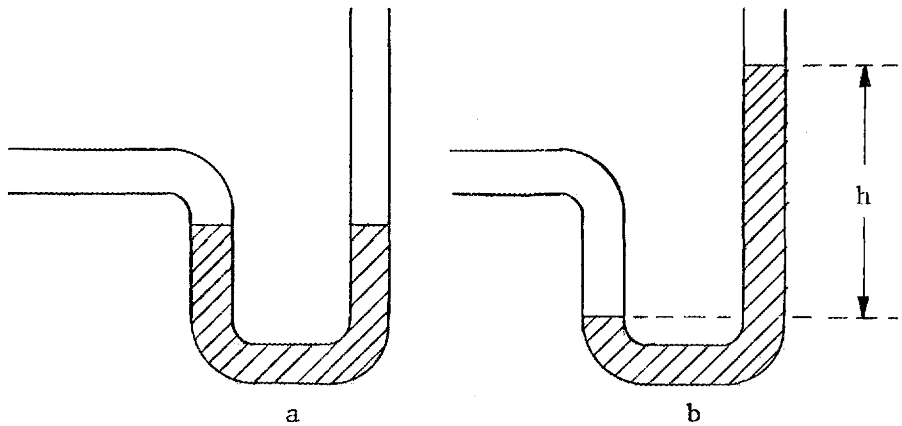

Fig. V-57. The Manometer

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3. In part a of the figure, the liquid level is the same in both legs of the tube. This would be the case when there is little, if any, pressure difference between the two legs.

\- - - - - - -

4. In part b of the figure, there is more pressure on the liquid in the left leg than on the liquid in the right leg. This added _____ in the left leg forces the liquid to a higher level in the right leg.

\- - - - - - -

5. The difference in the heights of the liquid levels in the two legs is caused by the difference in _____ exerted on the liquids in the two legs. pressure

\- - - - - - -

6. To use this instrument to measure pressure, we must know the liquid used (so we can determine its density) and the difference in the _____ of the liquid in the two legs. — pressure

— — — — — — —

7. A 1-ft column of water exerts a pressure of 0.433 lb/in.^{2}; so, if the liquid in the manometer is water and the difference in liquid level, h, is 2 ft, the manometer is measuring a pressure of $0.433 \frac{\text{lb}}{\text{in.}^2 \times \text{ft}} \times 2 \text{ ft} =$ _____ psi. — height

— — — — — — —

8. If the liquid in a manometer is mercury (a 1-ft column of mercury exerts a pressure of 5.9 psi) and h is 2 ft, the manometer is measuring a pressure of $5.9 \frac{\text{lb}}{\text{in.}^2 \times \text{ft}} \times 2 \text{ ft} =$ _____ psi. — 0.866

— — — — — — —

9. In order to calculate how much pressure is exerted on the liquid in one leg of a manometer as related to the pressure on the liquid in the other leg, the operator must know the liquid in the manometer and the difference in the (density, height, cross section) of the liquid in the two manometer legs. — 11.8

— — — — — — —

10. It is often unnecessary to know a pressure difference in pounds per square inch. In many cases a pressure may be stated merely as a certain number of inches of water or centimeters of mercury. — height

— — — — — — —

11. A mercury barometer is a special type of manometer. We are accustomed to hearing atmospheric pressure expressed as a certain number of centimeters or inches of mercury.

— — — — — — —

12. A pressure-measuring device that uses the difference in the heights of two liquid columns is commonly called a _____.

— — — — — — —

13. Some reactor buildings use dynamic containment. At the ORR, for example, the building containment system seeks to keep the pressure inside the building about 0.3 in. of water less than the pressure outside. Often, the instruments used to check this pressure difference are the type mentioned above, _____, filled with water and placed in a slanted position to make them easier to read with precision. Slanting the tube causes the liquid to move along a greater distance of the tube for any given change in the height of the liquid column. manometer

— — — — — — —

14. The Bourdon pressure gauge is used extensively as a direct reading gauge. It makes use of a partially coiled tube as shown in Figure V-58. manometers

— — — — — — —

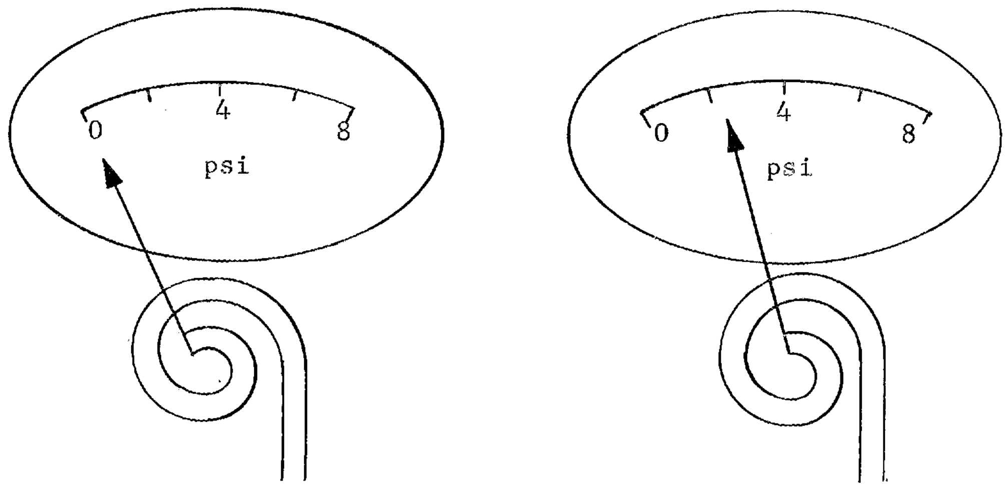

Fig. V-58. Bourdon Gauge

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15. When a fluid pressure is exerted in the tube, it begins to uncoil and moves a needle along a scale calibrated to read psi directly.

- - - - - - -

16. A Bourdon gauge is usually calibrated to read pressure in units of _____.

- - - - - - -

17. Although pressures are often given in units of pounds per $in.^2$, a valid reading of pressure from a manometer could be _____ of water. — psi or $lb/in.^2$

- - - - - - -

18. Our discussion thus far has been concerned with two types of "sensors" which would probably be used as local indicators. Although the _____ and _____ gauge could probably be equipped with electrical contacts, more complicated devices are usually necessary when remote readouts are required. — inches

- - - - - - -

19. Figure V-59 is a block diagram of a typical circuit for remote display (such as in the control room) of process information.

manometer, Bourdon

- - - - - - -

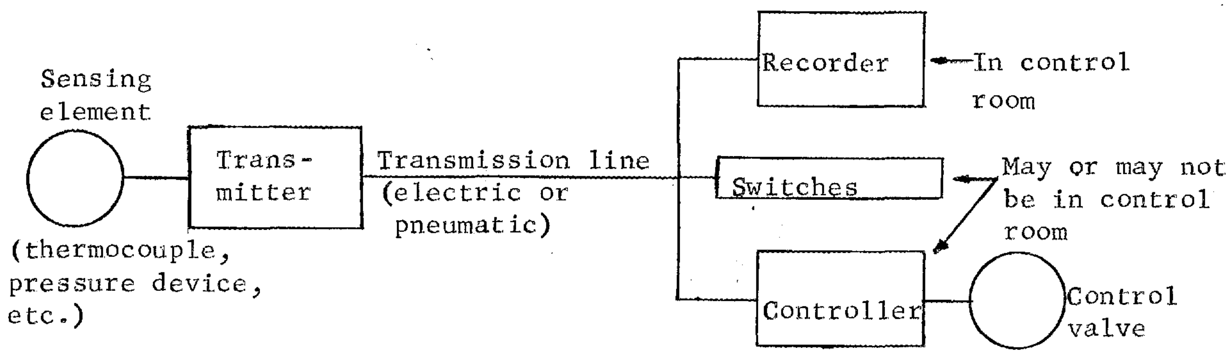

Fig. V-59. Block Diagram of a Process Instrument Channel

- - - - - - -

20. A sensing element, often called just a "sensor", is the instrument that does the monitoring of a parameter and can be equipped to furnish a signal for remote recording or readout.

- - - - - - -

21. The _____ element provides a signal (which may be electrical, hydraulic, or pneumatic) for a transmitter. The transmitted signal then may be used to drive a recorder or possibly a controller for another system.

- - - - - - -

22. The instrument which detects the condition of, and/or changes in the condition of, a parameter is called a _____ element or _____. This instrument can be equipped to provide a signal to a _____ which can, in turn, send a signal to a remote readout instrument or a control device.

sensing

- - - - - - -

6.3. Flow Systems

23. Fluid flow is often determined by measuring pressure differences along a pipe or across an orifice in a pipe. Let us look at Figure V-60 to see how this might be done. The lines indicate the fluid-flow path.

sensing, sensor, transmitter

- - - - - - -

Generally speaking, an orifice is just an opening or vent. Our use of the term is a little more specific in that we mean a vent of precisely determined size through which the fluid in a pipe flows.

- - - - - - -

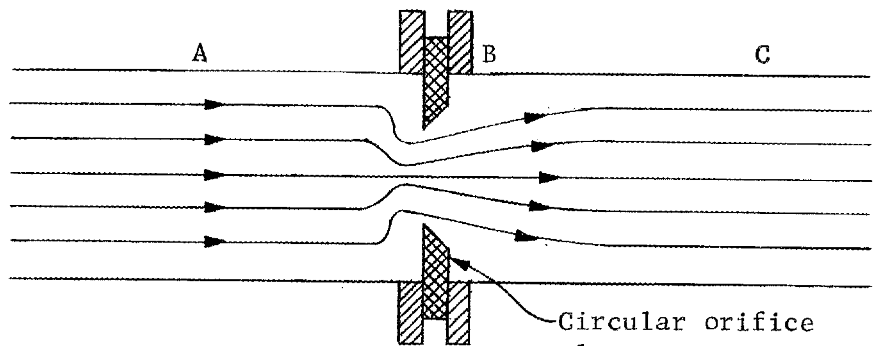

Fig. V-60. Longitudinal Section of a Pipe Showing an Orifice Between Two Flanges at a Pipe Joint

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24. You may recall from your study of heat transfer and fluid flow that, in a constricted pipe, at the place where the fluid velocity is greatest the pressure at right angles to the flow is least. Note in Figure V-60 the resemblance of an orifice to a constriction in a pipe. At A, the velocity is low so a pressure gauge at A would read (higher, lower) than a gauge at B where the velocity is higher.

- - - - - - -

25. A manometer at B would indicate a (lower, higher) pressure than one at either A or C. — higher

- - - - - - -

26. So, with a manometer at A reading a higher pressure than a manometer at B, it is possible to take the difference between the two readings and calculate the flow. The formula used is — lower

$$F = C\sqrt{\Delta h}$$

where F is the flow rate, Δh is the pressure difference (or difference in heights of the liquid in the manometer), and C is a constant determined by the type of fluid, the size of the pipe, and the size of the orifice.

- - - - - - -

27. Now, instead of using two manometers, let us connect one manometer tube as shown in Figure V-61 and the Δh can be read directly. Since Δh is really a pressure difference in this case, let us use a more common symbol, Δp. Our equation is now

$$F = C\sqrt{\_\_\_\_\_}\ .$$

- - - - - - -

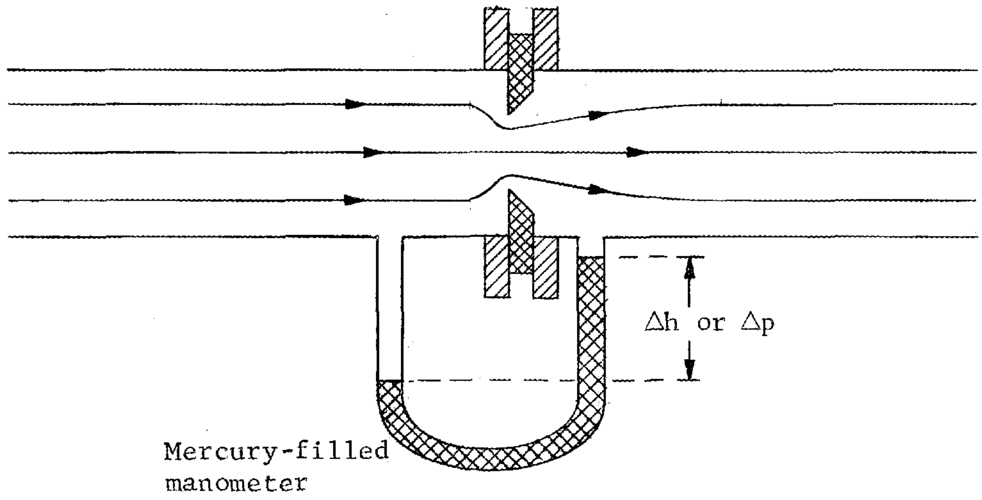

Fig. V-61. Orifice-Type Flow Measuring Device

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28. When there is a difference in fluid velocity along a pipe, a difference in _____ can be measured. Δp

- - - - - - -

29. If a pressure difference can be measured across an orifice, the fluid _____ _____ can be calculated from this information. pressure

- - - - - - -

30. The rate of flow of a fluid can be calculated by measuring the pressure drop across an _____. flow rate

- - - - - - -

31. Another flow element that depends upon the pressure drop across the instrument to measure flow is the "venturi". You will note from Figure V-62 that the venturi looks, even more than the orifice, like just a constriction in a pipe. orifice

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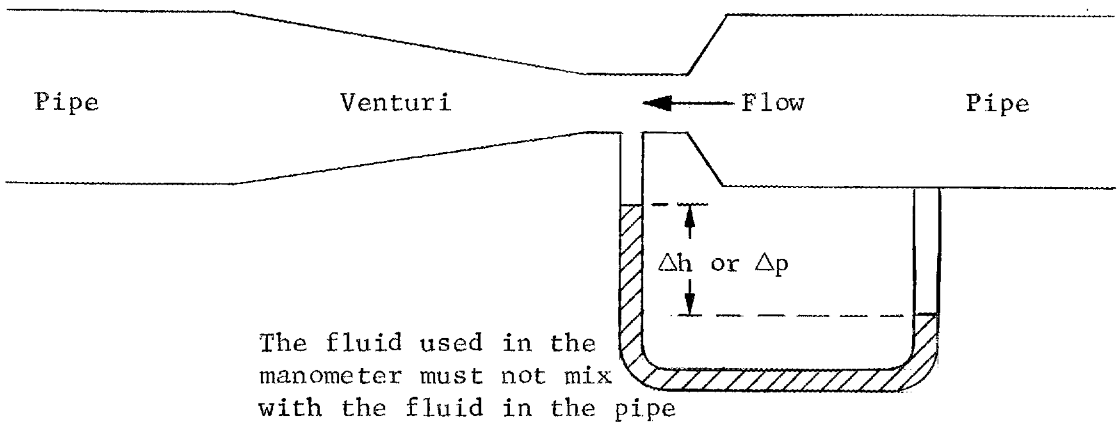

Fig. V-62. Venturi Flow Meter

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The fluid used in the manometers of both the orifice flow meter and the venturi flow meter must be such that it is not affected either chemically or physically by the fluid in the pipe. For example, if the fluid in the pipe is water, mercury would be a good liquid for the manometer (for some systems).

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32. When using the venturi, flow is calculated by the same equation that was used when we took Δp readings across the _____.

\- - - - - - -

33. The venturi allows smoother flow than the orifice allows and, for this reason, pumping power (to drive the fluid through the orifice) is less. Thus, a venturi is often used in a system where using an orifice as a flow detector would require a more powerful pump. orifice

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34. When using either an orifice or a venturi, flow measurements are dependent on a difference in _____.

— — — — — — —

35. In a venturi, where the velocity of the fluid is greatest, the sidewise pressure is (greatest, least, the same). pressure

— — — — — — —

36. Two instruments that are often used for flow measurements are the _____ and the _____. least

— — — — — — —

37. If a pressure difference can be measured in a fluid stream, a _____ rate can be calculated. orifice, venturi

— — — — — — —

In the foregoing discussion, simple manometers were used in conjunction with an orifice and a venturi to give a good visual illustration of the pressure difference developed by flowing fluids. Although manometers are actually used in simple systems when only local readings are required, remote readouts are necessary in reactor systems since the coolant fluid may be radioactive. Complex pneumatic or electric instruments are installed in place of the manometers to detect the pressure difference and translate it into pneumatic or electrical signals for the remote readouts. The readout meters are usually calibrated directly in units of flow. flow

— — — — — — —

38. The last flow instrument we will describe is the rotameter. This versatile little instrument is widely used as a local, direct-reading sensor for both liquids and gases; but it can also be designed to transmit a signal to a remote readout instrument.

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39. Very simply, the rotameter is an "in-line" instrument with a vertical section of transparent tubing tapered slightly outward from bottom to top (Figure V-63). Inside the tapered section is a weighted plummet or bob which is lifted by the force of the fluid moving up in the tube. As the plummet is carried up, the outward taper of the tube allows more fluid to flow around it. For a given fluid flow, the plummet is raised until its weight is equal to the force exerted by the moving fluid on the plummet. For local readout, etched calibration marks on the transparent tube allow a direct reading of flow.

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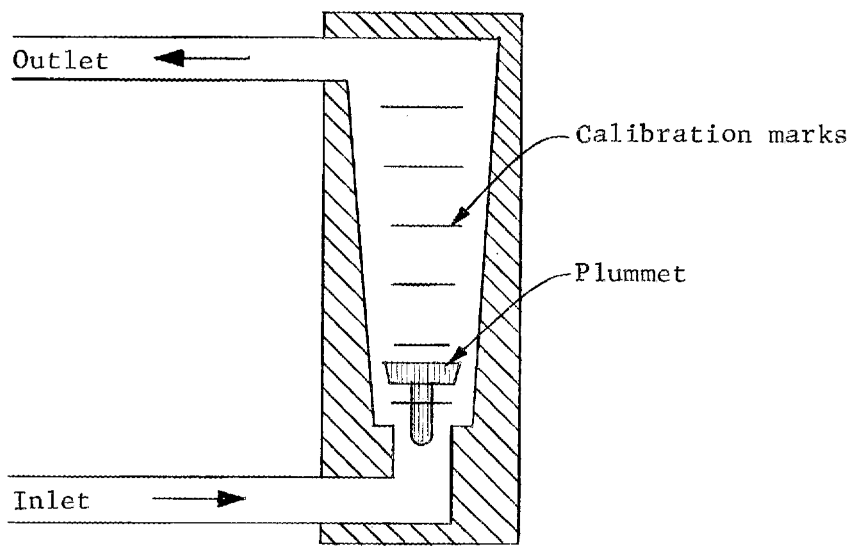

Fig. V-63. Rotameter

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40. For low fluid flow, the plummet will be near the (top, bottom) of the calibrated tube.

- - - - - - -

41. The rotameter balances the force exerted by the fluid against the (size, weight) of the plummet. | bottom

- - - - - - -

42. The rotameter can be designed to measure the flow rate of either a liquid or a _____ | weight

- - - - - - -

43. Around the HFIR and ORR, rotameters are normally used only for local readouts. | gas

- - - - - - -

44. The orifice, venturi, and rotameter are instruments used to measure _____ _____ _____.

- - - - - - -

6.4. Temperature Sensors

45. We have discussed some pressure-sensing and flow-sensing devices. Now, let us look at a number of devices used to measure temperatures. | fluid flow rate

- - - - - - -

46. A thermometer is probably the least complicated and best known of all temperature-measuring devices. However, its use around a reactor is quite limited; so a variety of other types of temperature-sensing devices must be used.

- - - - - - -

47. A more versatile sensor is the thermocouple which, in principle, operates as shown in Figure V-64. A potential difference is developed at each junction and is proportional to the temperature at the junction. The potential developed at the cold junction is less than that at the hot junction. Because the voltages (emf's) are in series but of opposite polarity, there will be a current in the circuit due to the difference of the emf's.

\- - - - - - -

A thermocouple "junction" is the point at which the two wires, made of different materials, are joined.

\- - - - - - -

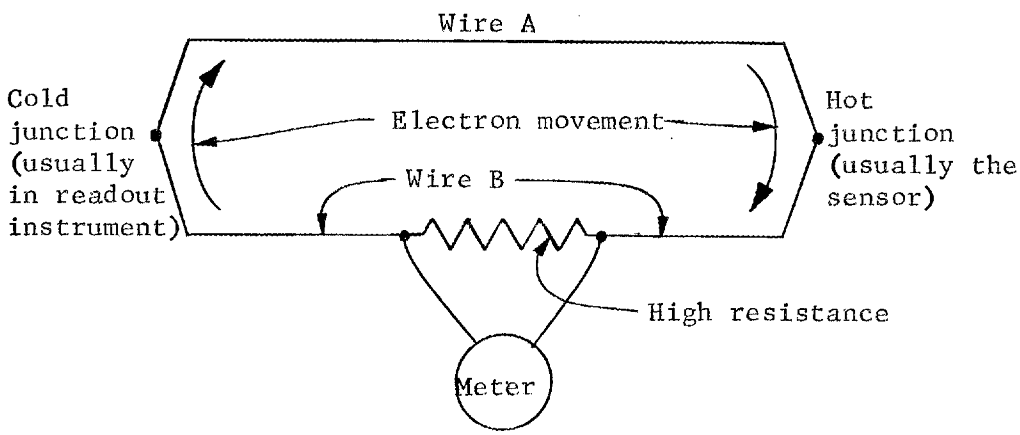

Fig. V-64. Thermocouple Circuit

\- - - - - - -

48. If two wires of different materials (Chromel and Alumel are commonly used as thermocouple materials) are joined to form a continuous loop and one connection is heated while the other connection is kept cool, electron movement takes place from one wire to the other producing a potential difference across a series-connected high resistance, which can be measured by a suitable instrument.

\- - - - - - -

49. The amount of voltage measured varies directly with the temperature difference between the cold and hot junctions or couples. If the temperature difference increases, the voltage increases; if the temperature decreases, the voltage _____.

- - - - - - -

50. As the temperature difference (Δt between the two junctions) increases, the meter reading _____. decreases

- - - - - - -

51. If the cold junction is kept at a constant temperature and the temperature of the hot junction increases 50°, the Δt will increase _____ degrees and the meter reading will _____ a proportional amount. increases

- - - - - - -

52. Now, all we need to do is to calibrate the meter in degrees of temperature rather than in volts or amperes. 50, increase

- - - - - - -

53. The thermocouple principle is: if you "couple" the ends of two wires made of different materials and make one couple hot and the other cold, an _____ current will flow in the wires.

- - - - - - -

54. The current produced, and thus the voltage drop across R (Figure V-64), depends on the difference in _____ between the two couples. electric

- - - - - - -

55. If the hot junction (or couple) is in the reactor and the cold junction is in the control room, the meter reading will increase as the reactor temperature (decreases, increases). — temperature

- - - - - - -

56. The output of a thermocouple system is not a direct temperature measurement; it is an electrical potential. — increases

- - - - - - -

57. However, the voltage output changes with temperature. So, if we measure the output with a sensitive voltmeter, the meter needle will show an (increased, decreased) voltage as the temperature goes up and (increased, decreased) voltage as the temperature goes down.

- - - - - - -

58. Thus, we can calibrate the meter to read degrees of temperature rather than millivolts of electricity. — increased, decreased

- - - - - - -

59. Although the output of a thermocouple is an electrical signal, the meter readout is normally calibrated to read _____ in either Fahrenheit or Centigrade degrees.

- - - - - - -

60. Another instrument which produces an electrical signal variation that is linear over a wide temperature range is the resistance thermometer. It is a long length of insulated fine wire wound on a spool. — temperature

- - - - - - -

61. A resistance thermometer operates because the resistance of a metal increases as its temperature increases. It, then, is a resistor whose resistance will increase nearly linearly as its temperature ____.

\- - - - - - -

62. If a given resistance thermometer has a resistance of 100 ohms when the temperature is 50°F and 200 ohms when the temperature is 100°F, its resistance will be about 300 ohms when the temperature is ____ °F. — increases

\- - - - - - -

63. Nickel, copper, and platinum are the most common materials used for the resistance wire in resistance thermometers. — 150°F

\- - - - - - -

64. The approximately linear temperature range for nickel is from –150°F to +300°F, well within the range of many reactor coolant temperatures.

\- - - - - - -

65. One metal that might be used in a resistance thermometer for measuring a reactor coolant temperature is ____.

\- - - - - - -

66. For better precision in measuring as well as for measurement of higher temperatures (up to 1000°F), platinum is used as the resistor wire. — nickel

\- - - - - - -

67. When precision is of prime importance, the resistance thermometer is used rather than thermocouples or other temperature-measuring devices. From this one would expect that a (thermocouple, resistance thermometer) would be required for making the coolant temperature measurements for a reactor.

\- - - - - - -

68. We should discuss one other temperature-measuring device--the gas-filled bulb. At the HFIR, gas-filled bulbs are used to measure the inlet and exit primary coolant temperatures of the reactor for use by the servo system.

resistance thermometer

\- - - - - - -

69. Gas-filled bulbs may be used as temperature-measuring devices because when a gas is placed in a closed container the pressure it exerts on the walls of the container varies at a known rate with temperature changes.

\- - - - - - -

70. If, at the HFIR, the gas pressure in the gas-filled bulb increases, it is an indication that the primary coolant _____ has increased.

\- - - - - - -

71. This pressure change may be used to drive a pneumatic transmitter for remote display of the _____.

temperature

\- - - - - - -

72. In the early portion of this section, we stated that information concerning coolant flow and temperature is necessary for calculating heat power. These, however, are not the only parameters that need to be monitored.

temperature

\- - - - - - -

73. We need process information of many kinds, for example, pump-bearing temperatures and liquid levels in storage tanks. Instruments for monitoring various temperatures may be the same, fundamentally, as those already discussed. The measurement of liquid levels will be discussed next.

- - - - - - -

6.5. Liquid Level

74. One of the simplest instruments for measuring liquid levels in tanks is the sight glass, used as shown below (Figure V-65).

- - - - - - -

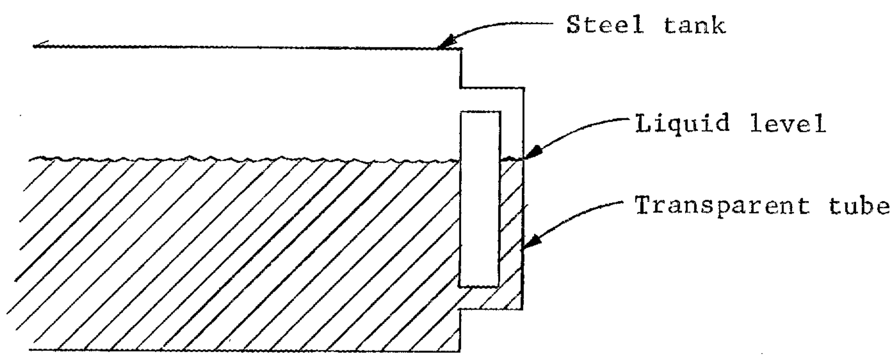

Fig. V-65. Liquid Level Measure by Sight Glass

- - - - - - -

75. Normally, this type of instrument would be used only to display information locally.

- - - - - -

76. For a liquid-level indicator, a sight glass is suitable for (local, remote) readout.

- - - - - - -

77. Another common type of indicator makes use of a float arrangement, such as that shown below (Figure V-66), for local readout. local

- - - - - - -

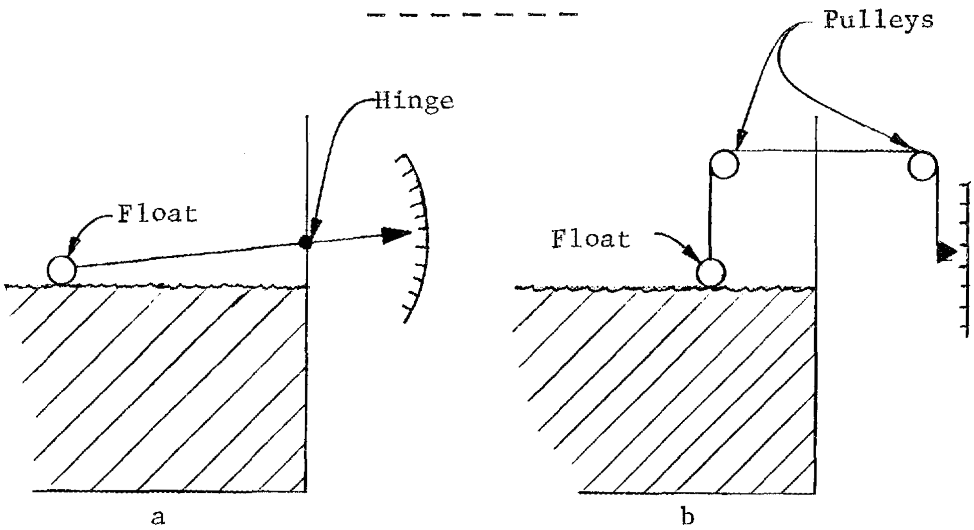

Fig. V-66. Float-Type Local Indicators

- - - - - - -

78. Figure V-66 has been simplified for our purpose, but it does represent two methods of using a float to measure the _____ _____ in a tank.

- - - - - - -

79. The drawings in Figure V-66 show the use of float mechanisms for (remote, local, electrical) display of liquid-level information. liquid level

- - - - - - -

80. A float may also be used in another way to measure liquid level. This method is sometimes called the displacement-force balance. The float is essentially fixed in position and the height of the liquid above the float determines the amount of upward force on the float. local

- - - - - - -

81. You have probably noticed that a float (inner tube, plastic float, empty oil drum, etc.) may be pushed down into the water if enough force is exerted. The deeper the float is pushed, the _____ the force necessary.

— — — — — — —

82. The amount of force the water exerts on the float is proportional to the amount of water displaced by the float and to the depth of water above the part of the float which is submerged. — greater

— — — — — — —

83. So, if you had a long vertical float in a fixed position in a tank, the depth of the liquid would determine not only how much liquid was displaced by the float, but also how much force was exerted upward on the float by the liquid. The force exerted on the float would be called the displacement _____.

— — — — — — —

84. If it should take a small force to balance the displacement force, you would suspect a (high, low) liquid level in the tank. — force

— — — — — — —

85. The magnitude of the balance force would indicate the _____ of the liquid in the tank. — low

— — — — — — —

86. It may not be obvious at this time but, while there seems to be little difference in the quality or quantity of information displayed locally by the sight glass and the float indicator, it is much simpler to adapt the float mechanism for a remote readout of tank level. — level or height

— — — — — — —

87. You may recall our discussion of the potentiometer (frequently abbreviated "pot."). To refresh your memory, it looks like this schematically (Figure V-67).

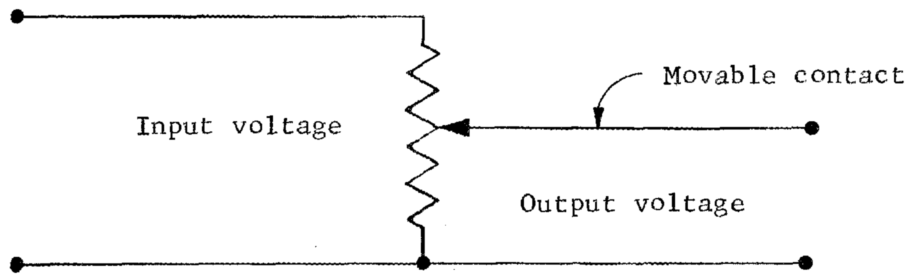

Fig. V-67. Potentiometer

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88. The potentiometer is a potential or voltage (divider, generator, amplifier).

\- - - - - - -

89. If the input voltage to the potentiometer is 10 volts, the output voltage may be anywhere between _____ volts and _____ volts, depending on the position of the movable contact. — divider

\- - - - - - -

90. The preceding frame was inserted here merely to check to see if you remembered. If you did not answer correctly, you may want to review Section V-1.1.1, Frames 97 through 108. — zero, 10

\- - - - - - -

91. Now attach the potentiometer to the float mechanism so that the float moves the sliding contact of the _____. Figure V-68 is a simplified drawing of how this could be done.

\- - - - - - -

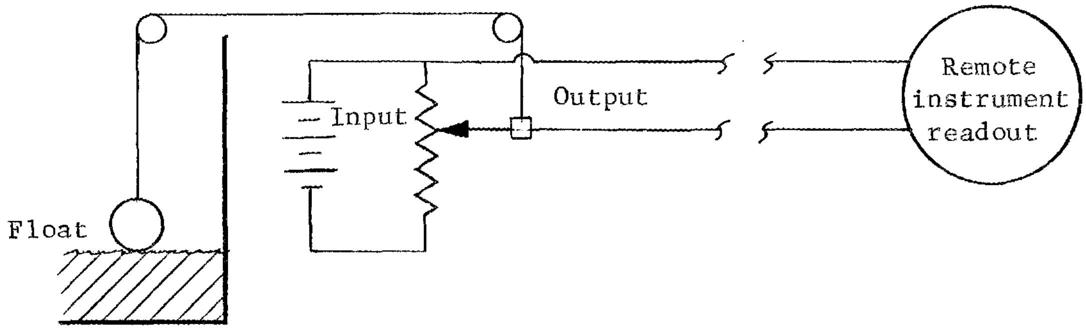

Fig. V-68. Simplified Liquid Level Instrument with Remote Readout

- - - - - - -

92. In looking at Figure V-68 you will note that as the liquid level decreases the voltage output from the potentiometer also _____.   potentiometer

- - - - - - -

93. As the liquid level increases, the signal voltage to the instrument (increases, decreases, remains the same).   decreases

- - - - - - -

94. By designing the system correctly, the voltage to the instrument can be made to be proportional to the _____ _____ in the tank, thus allowing a continuous display of liquid-level information.   increases

- - - - - - -

95. The float-indicator mechanism may also be designed to control the liquid level.   liquid level

- - - - - - -

96. In order to control over a range having both high-level and low-level limits, the float could be attached to switches which would energize a fill pump at a designated low level and de-energize the pump at a designated high level. Thus, _____ of both high and low levels could be achieved.

\- - - - - - -

97. One other liquid-level-measuring and liquid-level-controlling device measures the level of a liquid by the pressure it exerts at a chosen depth. control

\- - - - - - -

98. You may recall that the pressure exerted by a liquid depends only on its density and depth. This means that if you have a tank of fuel oil (density 0.7 gm/cm^3) and a tank of water (density 1.0 gm/cm^3) of the same depth the (water, fuel oil) will exert the most pressure on the bottom of the tank.

\- - - - - - -

99. Another illustration is two tanks of fuel oil, same density, with the depth of the oil in one tank at 10 ft while the depth of the oil in the other tank is only 5 ft. If the pressure is proportional only to the depth, the 10-ft depth of oil will exert (one-half, twice, four times) as much pressure on the bottom as the 5-ft depth. water

\- - - - - - -

100. The name engineers have given this pressure is hydrostatic pressure. Hydro refers to the fact that it is a liquid, and static means it is not caused by motion of the fluid. twice

\- - - - - - -

101. So, we can measure the liquid level above a certain depth in a tank by measuring its _____ pressure at that depth.

- - - - - - -

102. In a very simplified situation, we could say that the higher the liquid level, the _____ the hydrostatic pressure. — hydrostatic

- - - - - - -

103. A simple pressure gauge, calibrated to read in liquid-level units (inches, feet, gallons, etc.) would be adequate for a (local, remote) readout. — higher

- - - - - - -

104. For remote display of information or for liquid-level control, pressure-actuated switches would be used to initiate the information signal or control action. More sophisticated instruments can give a direct readout of pressure which can be transmitted to remote instruments. — local

- - - - - - -

6.6. Water Purity

105. It is very important--for reactors that use water for moderating, cooling, or shielding--that the purity of the water be maintained at a high level. By high purity, we mean that microbiological growths and the amount of dissolved solids must be kept at a minimum level, and the pH must be maintained at a prescribed level. The meaning and significance of pH will be discussed.

- - - - - - -

106. The growth of biological organisms is usually inhibited by the addition of bactericides according to a pattern set by administrative action. In some systems, the chemicals are added by operators; in others, the chemicals are added by metering pumps. In either case, there is no need for instruments that have not already been discussed.

\- - - - - - -

107. Usually, the primary coolant system of a reactor is a closed system; and there is small chance of growth of micro-organisms. Secondary coolant systems, with their cooling towers and accessory equipment, are very susceptible to such growths; and so it is in these systems that _____ are most often used.

\- - - - - - -

108. Bactericides are most often needed in coolant systems that are (closed, open). — bactericides

\- - - - - - -

109. Primary coolant systems usually depend on demineralization to keep the purity of the water at a high level. Demineralization serves both to remove unwanted ions and to keep the resistivity of the water high. — open

\- - - - - - -

110. The only instrument used for water purity control that is different from instruments already mentioned is the meter that measures the pH of the water.

\- - - - - - -

111. For our purposes, we can think of pH as a numbered scale from 1 to 14 in which the numbers from 7 down to 1 represent increasing acidity of the water and numbers from 7 up to 14 represent increasing alkalinity of the water.

- - - - - - -

112. Thus, water that is neither alkaline nor acidic (perfectly neutral) will have a pH of (1, 7, 14).

- - - - - - -

113. Water with a pH of 7.5 is (more, less) alkaline than water with a pH of 9.0. 7

- - - - - - -

114. Water with a pH of 4.5 is more _____ than water with a pH of 6.0. less

- - - - - - -

115. Meters used for pH measurements make use of a special electrode which is placed in the solution (water) to be checked. acidic

- - - - - - -

116. The voltage produced at this electrode is compared with a constant reference voltage in the instrument.

- - - - - - -

117. The very sensitive voltmeter that indicates the difference voltage in this comparison is calibrated, not in volts but in pH units from 1 to 14.

- - - - - - -

118. If the meter indicates a number such as 5.5, the sample solution is (alkaline, acidic, neutral) because 5.5 is less than 7.

- - - - - - -

119.	If the meter indicates a pH of 7, the solution is (alkaline, acidic, neutral).	acidic

\- - - - - - -

120.	If the meter indicates a pH of 9.3, the solution is (alkaline, acidic, neutral).	neutral

\- - - - - - -

121.	Although the pH meter is usually used for analysis of individual samples, it can be adapted to give a continuous analysis for either local or remote display by placing the electrode for the unknown sample in a special container through which a sample stream of water flows.	alkaline

\- - - - - - -

122. You may wonder why we need to monitor the pH continuously. The prescribed pH for a system is determined by the structural components of the system and the changes that may take place in the water because of its dissolved mineral content. If the pH is either too low or too high, corrosion of structural materials may be accelerated.

\- - - - - - -

123. For example, the water in a secondary coolant system is usually kept about neutral (pH at the ORR is 7 to 7.5; at the HFIR it is 6.6). One reason for the slightly greater acidity at the HFIR is that the rate of water evaporation is such that the calcium concentration in the water builds up faster. The extra acidity is to prevent certain calcium salts from forming and depositing inside the pipes.

\- - - - - - -

124. It is important to keep the pH of a water coolant system at a given level to prevent such things as (nitrogen, calcium, hydrogen) deposits in the pipes. This would be true especially in an open system in which water evaporation from a cooling tower is appreciable.

- - - - - - -

125. The controlling pH meters initiate signals which cause the strokes of acid-metering pumps to be adjusted to keep the pH of the system at a constant value. Longer strokes would increase the acid fed to the system; shorter strokes would decrease the amount of acid fed to the system. The signal can also be used to control the pumping speed of a variable speed pump, when this is the method of determining the rate of acid addition to a system. calcium

- - - - - - -

126. If the pH of the HFIR secondary coolant becomes greater than 6.6, let us say 7.0, the system needs (more, less) acid.

- - - - - - -

127. The signal from the pH meter is converted to an error signal which causes the stroke of the acid-metering pump to become (longer, shorter) to put more acid into the system. more

- - - - - - -

128. Lest we leave the impression that the calcium content of the secondary water is the all-important reason for determining pH, we should mention that there are other important considerations including the fact that there is an optimum pH for the bactericides used to protect the structural parts of the cooling towers. longer

- - - - - - -

129. Experiments have shown that, at high temperatures, corrosion of aluminum fuel cladding is least when the pH of the primary coolant water is kept at about 5.0.

- - - - - - -

130. Since the fuel elements at both the HFIR and the ORR are clad with aluminum, the pH of the primary coolant water is kept at about _____.

- - - - - - -

131. If the fuel elements were clad with stainless steel rather than aluminum, the _____ of the coolant system might need to be different. 5.0

- - - - - - -

6.7. Radiation Monitoring

132. The last instruments we shall consider are not exactly process instruments and are not exactly in the nuclear instrumentation category. They are the radiation-detection instruments which monitor the radioactivity of the coolant systems and the containment and ventilation systems, as well as those portable instruments used for general radiation monitoring. pH

- - - - - - -

133. Normally, radiation-detection instruments for general monitoring are portable; and those that monitor specific systems, such as coolant or ventilation, are stationary so that their outputs can be tied into an alarm or safety system.

- - - - - - -

134. From all of the portable instruments available, we shall pick for discussion only the G-M survey meter and the cutie-pie because they are most often used for general monitoring.

\- - - - - - -

135. The G-M survey meter uses for a detector an argon-filled ionization chamber which has a potential difference across its electrodes of from 800 v to 1500 v. An applied voltage in this range (you may recall that this voltage range is called the Geiger range) produces a strong output pulse that needs little electronic amplification in order for it to be detected by either earphones or a sensitive voltmeter (discussed in Section V-2, Frames 32-40 and 55-73).

\- - - - - - -

> You will recall that the radiation detector used by this meter is called a Geiger-Mueller tube in honor of the men who developed it. From the combination Geiger-Mueller, we get the G-M for the name of the survey meter.

\- - - - - - -

136. The G-M survey meter uses an argon-filled _____ _____ for a radiation detector.

\- - - - - - -

137. In the "Geiger region", the applied voltage across the ionization chamber is _____ to _____ volts.

ionization chamber

\- - - - - - -

138. The strength of the output pulse of the G-M tube is such that (much, little) electronic amplification is needed to display the signal. 800 to 1500

\- - - - - - -

139. The G-M survey meter is used for beta and gamma radiation detection and measurement in relatively low intensities of radiation where a very precise measure of dose rate is not essential. little

\- - - - - - -

140. The cutie pie, normally needed for the detection and measurement of higher intensities of gamma radiation, uses an air-filled ionization chamber for a detector. At ORNL, the cutie pie's ionization chamber has a cut out section in the detector housing which has been replaced with a thin film. This allows the meter to be used to detect high-energy beta particles as well as _____ radiation.

\- - - - - - -

141. The cutie pie is normally used to measure (higher, lower) radiation dose rates than those for which the G-M survey meter is applicable. gamma

\- - - - - - -

142. The radiation detector of the cutie pie is an air-filled _____ _____ (discussed in Section V-2, Frames 1-25, 45-55, and 65-70). higher

\- - - - - - -

143. The cutie pie is used for relatively intense gamma radiation; and, if it has a very thin-wall window, it can be used to detect high-energy _____ particles. ionization chamber

\- - - - - - -

144. The ionization-chamber-type radiation detectors we have just discussed, especially the Geiger-Mueller tube, are widely used in both portable and stationary instruments.

beta

\- - - - - - -

145. There is another detector which, due to its convenience, efficiency, and reliability at high counting rates, is used for measuring the radiation from such things as water samples and the smear papers used for contamination detection. This is the scintillation counter.

\- - - - - - -

Certain materials called phosphors emit light (scintillations) when they are exposed to radiation. When the light from such a material falls on a photocathode (a material which will emit photoelectrons when struck by light), electrons are emitted to an amplifier called a photomultiplier which has, for its output, a relatively large electrical pulse (see Figure V-69).

\- - - - - - -

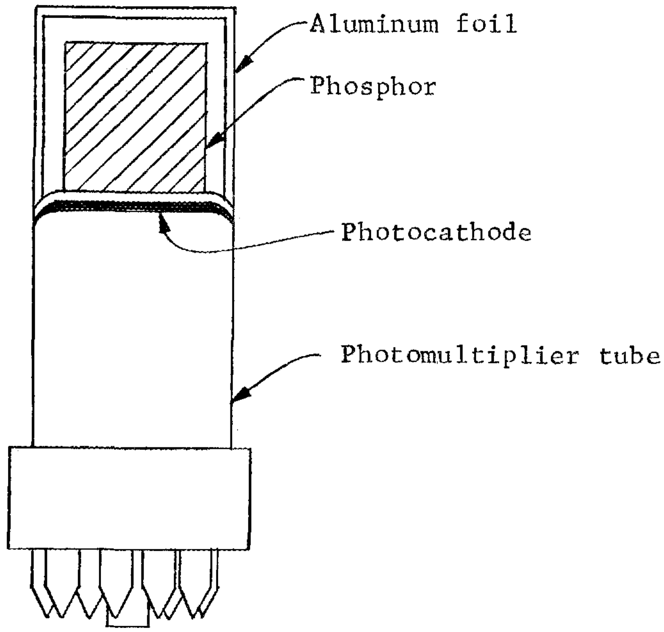

Fig. V-69. Diagram of the Detector Tube of a Scintillation Counter

- - - - - - -

146. This type of detector is called a <u>scintillation counter</u> because when a <u>pulse</u> of <u>radiation</u> enters the <u>phosphor</u> (often a sodium iodide crystal) the crystal emits a flash of _____.

- - - - - - -

147. The <u>flash of light</u> is intense enough to remove (electrons, protons, neutrons) from a material called a <u>photocathode</u>. — light

- - - - - - -

148. <u>Electrons</u> are emitted when a <u>flash of light</u> from the <u>phosphor</u> strikes a material called a _____ — electrons

- - - - - - -

149. The electrons from the photocathode are attracted to the plates of a photomultiplier where the number of electrons is increased when they collide with a series of plates and knock more electrons loose with each collision. One type of photomultiplier operates as shown in Figure V-70. photocathode

- - - - - - -

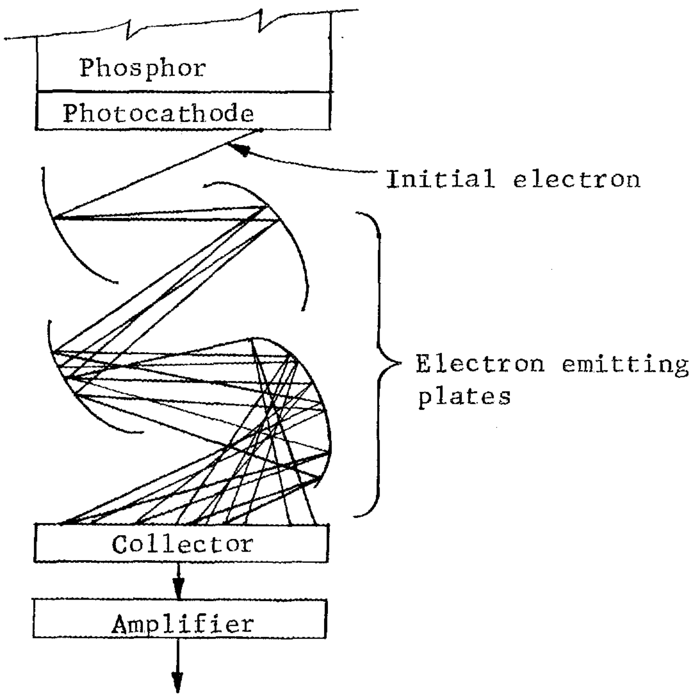

Fig. V-70. Photomultiplier

- - - - - - -

150. Many photomultipliers have a multiplication factor of a million or more. Thus, each time radiation produces a scintillation in the phosphor, the photomultiplier tube produces a relatively (strong, weak) electrical pulse in the output of the tube.

- - - - - - -

151. When a radioactivity analysis is needed in which greater efficiency is desired than can be achieved with a G-M probe, the _____ counter is often used. — strong

\- - - - - - -

152. When samples of reactor coolant water are taken to determine, for instance, the decontamination factor of the demineralizer system, they are usually counted with a _____ counter. — scintillation

\- - - - - - -

153. The beta-gamma and alpha counters, used by health physicists to count "smear" samples, use detectors of the scintillation type. This is because the scintillation-type detectors are more efficient and give greater (resolving time, precision, tolerance) in the determination of the dose rate. — scintillation

\- - - - - - -

154. Since all of the detectors we have discussed produce an electrical pulse or current as an output, any of them may be used, with suitable instrumentation, for either local or remote readout. However, G-M tubes are the detectors most often used to monitor coolant systems and liquid waste systems. Because the radiation levels are usually low, the probes may be decontaminated easily, the associated instrumentation is not complicated, and the higher efficiency of the scintillation counter is not necessary. — precision

\- - - - - - -

155. Geiger-Mueller probes are also used to monitor gaseous waste systems and ventilation systems. The instrument most often used to monitor the airborne radioactivity in the work areas of the reactor building is the continuous air monitor, called a CAM. It is called continuous because it monitors continuously, as opposed to a monitor which will monitor a sample of air periodically.

\- - - - - - -

156. The CAM continuously draws a sample of air through a filter-paper tape and uses a G-M tube to analyze the radioactivity of the airborne particulate matter which is caught by the _____. The airstream then flows past the G-M tube so that the nonfilterable gaseous radioactivity can also be detected.

\- - - - - - -

157. The air in work areas, such as the reactor bay and experiment rooms, is continuously analyzed for radioactivity by instruments called _____ _____ _____, abbreviated CAM's. — filter

\- - - - - - -

158. Continuous air monitors monitor air for both radioactive particulate matter and radioactive _____ matter. — continuous air monitors

\- - - - - - -

159. The CAM uses a _____ _____ as a detector. — gaseous

\- - - - - - -

160. The CAM analyzes the air by continuously drawing a sample of the air through a filter which stops much of the _____ matter. — G-M tube

\- - - - - - -

161. Radioactive particulate matter which is caught by the filter paper is analyzed for _____ and _____ radiation by the G-M tube. — particulate

\- - - - - - -

162. Gaseous matter, which is not stopped by the filter, is analyzed for beta and gamma _____ as the gaseous material flows past the detector. — beta, gamma

\- - - - - - -

163. The "Monitron" is a type of stationary instrument placed in work areas to detect gamma radiation and to sound an alarm when radiation exceeds a given level. These instruments use ionization chambers as detectors. — radioactivity

\- - - - - - -

164. Monitrons use ionization-chambers to monitor work areas for _____ radiation.

\- - - - - - -

165. Work areas around a reactor are continuously checked for gamma radiation by instruments called _____. — gamma

\- - - - - - -

166. Monitrons use (G-M tubes, ionization chambers, scintillation counters) to determine the intensity of _____ in the reactor work areas. — Monitrons

\- - - - - - -

6.8. Self Test

167. A device that indicates a pressure difference (ΔP) by the difference in the liquid levels in the two arms of a U-tube is called a _____. (Frames 2-6) — ionization chambers, radiation

\- - - - - - -

168. Flow meters often make use of the difference in _____ across an orifice or venturi for measuring flow. (Frames 23-36) — manometer

– – – – – – –

169. The rate of flow of a fluid is often determined by measuring the pressure drop across an _____ or _____. (Frames 23-36). — pressure

– – – – – – –

170. A rotameter is an instrument that gives a direct reading of _____ rate. (Frames 38-44) — orifice, venturi

– – – – – – –

171. A temperature-measuring device that utilizes a hot junction and a cold junction of two different materials (wires) is called a _____. (Frames 47-59). — flow

– – – – – – –

172. Chromel and Alumel are conductors commonly used in _____. (Frame 48) — thermocouple

– – – – – – –

173. A resistance thermometer relates change in temperature to a change in _____. (Frames 60-67) — thermocouples

– – – – – – –

174. The three metals most commonly used in resistance thermometers are nickel, copper, and _____. (Frame 63) — resistance

– – – – – – –

175. Sight glasses and float arrangements are used to measure _____ _____ in tanks. (Frames 73-79) — platinum

– – – – – – –

176. Liquid levels in tanks can also be measured by gauges which read the hydrostatic _____. (Frames 97-104) | liquid levels

- - - - - - -

177. The number read on a pH meter is an indication of whether a solution is neutral, _____ or _____. (Frames 111-120) | pressure

- - - - - - -

178. If the pH of a solution is 8.5, the solution is (acidic, alkaline, neutral). (Frames 111-120) | acidic, alkaline

- - - - - - -

179. If the pH of a solution is 7, the solution is (acidic, alkaline, neutral). (Frames 111-112) | alkaline

- - - - - - -

180. A G-M survey meter is used to detect and measure _____ and _____ radiation. (Frame 139) | neutral

- - - - - - -

181. A cutie pie is normally used to measure beta and gamma radiation levels which are (lower, higher) than those normally measured with a G-M survey meter. (Frame 140) | beta, gamma

- - - - - - -

182. Airborne radioactivity may be detected by instruments called _____. (Frames 155-160) | higher

- - - - - - -

183. Monitrons determine the intensity of _____ in the work areas around a reactor. (Frames 163-166) | continuous air monitors or CAM's

- - - - - - -

radiation

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