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Nuclear Steam Supply Systems

PERFORMANCE TEST CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
345 East 47th Street New York, N.Y. 10017

Nuclear Steam Supply Systems

PERFORMANCE TEST CODES

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ASME PERFORMANCE TEST CODES
Test Code for
NUCLEAR STEAM SUPPLY SYSTEMS

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FIGURES

Figure 1 - Nuclear Steam Supply System Diagram, Pressurized Water Reactor

Figure 2 - Energy Balance of Nuclear Steam Supply System, Pressurized Water Reactor

Figure 3 - Nuclear Steam Supply System Diagram, Boiling Water Reactor

Figure 4 - Energy Balance of Nuclear Steam Supply System, Boiling Water Reactor

SECTION 0, INTRODUCTION

0.1 This Code contains instructions for the performance testing of nuclear steam supply systems. These systems are defined as nuclear reactors that have been designed for the generation of thermal energy, together with the steam generating and other equipment required to transfer energy from the nuclear fuel to the working fluid of the power cycle.

0.2 This Code is limited to the testing of light water systems using pressurized water reactors (PWR) and boiling water reactors (BWR). This Code will be supplemented as other types of reactors come into general use.

0.3 It is intended that in using this Code a detailed examination will be made of the Code on General Instructions, PTC 1, and all other codes herein referred to, before starting preparations for the tests. Such an examination is for the purpose of assuring an orderly and thorough testing procedure, since it provides the user with an over-all understanding of the ASME Performance Test Codes requirements and enables him to understand readily the interrelationship of the various codes. The latest revisions of the individual codes should be used.

0.4 While Section 2 of this Code is concerned with symbols and their descriptions that apply specifically to the testing of nuclear steam supply systems, the user is referred to the Code of Definitions and Values, PTC 2, for a more complete discussion of the items that will be encountered.

0.5 The Supplements on Instruments and Apparatus, PTC 19, referred to herein, should be applied because the value of the test results depends on the selection and calibration of the instruments and the accuracy of the readings.

0.6 Advanced instrument systems, such as those using electronic devices or mass flow measurement techniques, may, by mutual agreement, be used as alternates to the Code instrument requirements, provided that the application of such instruments has demonstrated accuracy equivalent to that required by this Code.

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SECTION 1, OBJECT AND SCOPE

1.01 The purpose of this Code is to establish procedures for conducting tests to determine the thermal performance of a nuclear steam supply system as a unit. These tests include capacity, reactor power level, efficiency, and other related operating characteristics such as steam pressure, moisture content, and solids in the steam. (See Section 4.)

1.02 A determination of any or all of the performance items specified above may be necessary for purposes such as:

1.02.1 Checking the actual performance against guarantee.
1.02.2 Comparing these items with some standard of performance.
1.02.3 Comparing performance at different operating conditions.
1.02.4 Checking performance after new reactor fuel is loaded.
1.02.5 Determining the effects of changes to equipment.
1.02.6 Periodic verification of the means employed to monitor reactor power level.

1.03 The rules and instructions given in this Code apply to the equipment defined in the introduction. Testing of auxiliary apparatus shall be governed by the Performance Test Code applying specifically to the auxiliary apparatus in question.

1.04 Since there is no accurate, direct method of measuring the energy released by the nuclear fuel, the only method used for calculating the energy balance is the direct measurement of the energy output, losses and credits. This is referred to hereinafter as the energy loss method.

1.04.1 The output is defined as the energy absorbed by the working fluid or fluids within the envelope boundary. The working fluid is the steam and water substance through which means the nuclear steam supply system delivers energy.

1.04.2 The input is defined as the energy released by the nuclear fuel plus energy credits added to the working fluid or fluids, air, gas, and other fluid circuits that cross the envelope boundary, as shown in Figure 1 for pressurized water reactors (PWR) and in Figure 3 for boiling water reactors (BWR). The envelope boundary encompasses the equipment to be included in the designation "nuclear steam supply system." The input is equal to the output plus losses.

1.04.3 Energy credits are defined as those amounts of energy added to the envelope of the nuclear steam supply system other than the nuclear energy released by the fuel. These credits include quantities such as pumping energy.

1.04.4 Losses are defined as energy lost from the envelope of the nuclear steam supply system.

1.04.5 For a better understanding of the relationships between input, output, credits, and losses, refer to Figures 2 (PWR) or 4 (BWR).

1.05 The capacity of a nuclear steam supply system is defined as the actual evaporation rate of steam in pounds per hour delivered at specified conditions of the working fluid.

1.06 The reactor power level is defined as the rate of energy release in the reactor core in units of megawatts.

1.07 The efficiency of a nuclear steam supply system, as determined within the scope of this Code, is defined as the ratio of energy absorbed by the working fluid or fluids to energy

input as defined in Par. 1.04.2. This definition disregards the energy supplied to the auxiliary apparatus external to the envelope. (See Figures 1 and 3.)

Efficiency is expressed by the following equation:

$$\text{Efficiency (per cent)} = 100 \times \frac{\text{Output}}{\text{Output + Losses}}$$

1.08 The determination of data of a research nature or other special data is not covered by this Code.

1.09 It is recommended that a report be prepared for each test, giving complete details of the conditions under which the test has been made, including a record of test procedures and all data in a form suitable for demonstrating that the objectives of the test have been attained.

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SECTION 2, SYMBOLS AND THEIR DESCRIPTIONS

2.01

SYMBOL	DESCRIPTION	UNIT
A	Surface area of containment	ft^2
B_b	Energy (rate) in blowdown	Btu/hr
B_c	Energy (rate) crèdits to steam supply system	Btu/hr
B_{ci}	Energy (rate) in reactor inlet cleanup flow	Btu/hr
B_{co}	Energy (rate) in reactor outlet cleanup flow	Btu/hr
B_{cr}	Energy (rate) in control rod drive water	Btu/hr
B_{cs}	Energy (rate) loss in the reactor cleanup system	Btu/hr
B_{cw}	Energy (rate) to cooling water	Btu/hr
B_f	Energy (rate) in feedwater	Btu/hr
B_l	Energy (rate) loss from steam supply system	Btu/hr
B_{ld}	Energy (rate) in letdown from reactor coolant system	Btu/hr
B_m	Energy (rate) in makeup to reactor coolant system	Btu/hr
B_{rl}	Energy (rate) loss from energy envelope by radiation or convection	Btu/hr
B_s	Energy (rate) in steam	Btu/hr
B_{sw}	Energy (rate) in seal water	Btu/hr
B_w	Energy (rate) absorbed by working fluid	Btu/hr
C	System energy capacity	Mw hr/F
h_b	Enthalpy of blowdown	Btu/lb
h_{cr}	Enthalpy of control rod drive water	Btu/lb
h_f	Enthalpy of feedwater	Btu/lb
h_i	Enthalpy of cooling water to cooling system	Btu/lb
h_{ld}	Enthalpy of reactor coolant letdown	Btu/lb
h_m	Enthalpy of reactor coolant makeup	Btu/lb
h_o	Enthalpy of cooling water from cooling system	Btu/lb
h_s	Enthalpy of steam at steam supply system outlet	Btu/lb
h_{swi}	Enthalpy of seal water inlet	Btu/lb
η	Nuclear steam supply system efficiency	%
P_{me}	Average electrical power input to miscellaneous electrical equipment inside energy envelope	kw
P_{pe}	Average electrical power input to reactor coolant circulating pump driver	kw
P_{pre}	Average electrical power input to pressurizer heaters	kw
P_r	Reactor power level	Mw
P_s	Pressure of steam at steam supply system outlet	psia
t_f	Feedwater temperature	F
t_i	Containment (ambient) temperature	F
t_o	Outside air temperature	F
t_s	Steam temperature at steam supply system outlet	F
t_{swi}	Temperature of inlet seal water	F
U	Calculated heat transfer coefficient	Btu/hr-ft^2-F
W_b	Blowdown flow	lb/hr
W_{cr}	Water flow to control rod drives	lb/hr
W_{cs}	Cleanup system cooling water flow	lb/hr
W_{cw}	Cooling water flow	lb/hr
W_f	Feedwater flow	lb/hr
W_{ld}	Reactor coolant letdown flow	lb/hr
W_m	Reactor coolant makeup flow	lb/hr
W_s	Steam flow from nuclear steam supply system	lb/hr
W_{swi}	Water flow to seals	lb/hr
W_{swo}	Water flow from seals	lb/hr

x	Steam quality at steam supply system outlet	mass per cent
Δh_{cs}	Change in enthalpy in cleanup system cooling water	Btu/lb
Δt	Time rate of change of reactor coolant temperature	F/hr

2.02 Test and Run. Throughout this Code the word "test" is applied only to the entire investigation, and the word "run" to a subdivision. A run consists of a complete set of observations made for a period of time with one or more of the independent variables maintained virtually constant.

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SECTION 3, GUIDING PRINCIPLES

3.01 Items on Which Agreement Shall Be Reached. In order to achieve the objectives of the test, the parties to the test must reach agreement on the following pertinent items:

3.01.1 Envelope Boundary. This Code is based on the use of the loss method for determining the energy balance. Energy credits and losses are determined with reference to an envelope boundary, such as shown in Figures 1 and 3 for the PWR and BWR, respectively. The space within the envelope boundary represents the region of energy release within the nuclear steam supply system to which certain credits are added and from which certain losses are subtracted. The envelope boundary need not necessarily represent any particular physical boundary, such as the containment vessel or the reactor coolant system. The definition of the envelope boundary shall be established by mutual agreement to include or exclude certain pieces of equipment where this is appropriate.

3.01.2 Capacity determination – defined in Par. 1.05.

3.01.3 Energy credits to be measured.

3.01.4 Energy credits to be assigned where not measured.

3.01.5 Energy losses to be measured.

3.01.6 Energy losses to be assigned where not measured.

3.01.7 Permissible deviation from specified operating conditions between duplicate runs.

3.01.8 Power level determination – defined in Par. 1.06.

3.01.9 Efficiency determination – defined in Par. 1.07.

3.01.10 Other related operating characteristics – Pars. 4.02 and 4.03.

3.01.11 Allocation of responsibility for all performance and operating conditions which affect the test.

3.01.12 Selection of test personnel to conduct the test.

3.01.13 Establishment of acceptable operational conditions such as control rod positions, fluid temperatures and pressures, water level in steam drums, reference system arrangement, chemical additions to incoming feed, leakage rates, etc.

3.01.14 Cleanliness of the system initially and during the test.

3.01.15 The source of thermodynamic properties to be used. The latest edition of the ASME Steam Tables is recommended.

3.01.16 Establishment of number and duration of runs, number of load points, observations and readings to be taken to comply with the object or objectives of the test, procedures to be followed, and basis for rejection of runs.

3.01.17 Instruments, calibration of instruments, methods of measurement, and equipment to be used in testing the unit. The Performance Test Code Supplements on Instruments and Apparatus should be used when applicable.

3.01.18 Corrections to be made for deviations from specified operating conditions.

3.02 Selection of Personnel. To insure obtaining reliable results, all personnel participating in the test shall be fully qualified to perform their particular function.

3.03 Tolerances and Limits of Error. This Code does not include consideration of over-all tolerances or margins on performance guarantees. The test results shall be reported as computed from test observations, with proper corrections for calibrations.

3.03.1 Allowances for errors of measurement and sampling are permissible provided they are agreed upon in advance by the parties to the test and clearly stated in the test report.

3.03.2 Whenever allowances for probable errors of measurement and sampling are to be taken into consideration, the reported test results shall be qualified by the statement that the error in the results may be considered not to exceed a given plus or minus percentage.

3.04 Acceptance Test. An acceptance test shall be undertaken only when the parties to the test certify that the unit is operational and ready for test.

3.04.1 Parties to the test should designate a person to direct the test, and may designate an arbiter in the event of disputes as to the accuracy of observations and conditions or methods of operation.

3.04.2 After a preliminary run has been made, it may be declared an acceptable run if agreed to, provided that all the requirements of a regular run have been met.

3.04.3 At least two runs shall be made to demonstrate the attainment of capacity or reactor power level. If the results exceed the previously agreed upon deviation between runs, then the conditions of each test should be analyzed to determine whether there is reason to reject either or both tests by mutual agreement. The permissible deviation should also be re-evaluated to determine whether there is reason to change the permissible deviation by mutual agreement. If this examination does not result in mutual agreement that the two tests are acceptable and the deviation is acceptable, additional runs shall be made until at least two runs fall within the agreed permissible deviation. Acceptance shall be based upon the average of these two runs.

3.05 Preparation for All Tests

3.05.1 The entire system shall be checked for leakage and, where necessary, appropriate corrective actions shall be undertaken.

3.05.2 Any departures from standard or previously specified conditions in the physical state of equipment, cleanliness, or operating conditions shall be corrected if practicable. Otherwise, such departures shall be described clearly in the report of the test.

3.06 A preliminary run shall be made for the purpose of:

3.06.1 Determining that the nuclear steam supply system is in a suitable condition for conducting the test.

3.06.2 Checking operation of all instruments and test apparatus.

3.06.3 Training the test personnel.

3.07 Constancy of Test Conditions

3.07.1 Preparatory to any test run, the nuclear steam supply system shall be operated for a sufficient time to show that steady operating conditions have been attained. The parties to the test shall agree as to when these conditions have been attained.

3.07.2 Special means, as appropriate, may be employed for securing constant load.

3.07.3 Feedwater flow, water levels, and all controllable temperatures and pressures shall remain, as nearly as possible, unchanged throughout the run. Any other conditions in which variations might significantly affect the results of the test, shall also be held as constant as possible throughout the test.

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3.07.4 Every effort shall be made to conduct tests under the specified conditions such as output, pressures, and temperatures, or as close to the specified conditions as possible in order to minimize the application of corrections to the test results. For each variable, the parties to the test shall agree to the maximum permissible deviation of the average test value from the specified condition.

3.07.5 Should serious inconsistencies in the observed data be detected, the run shall be rejected completely, or in part if the affected part is at the beginning or end of the run.

3.08 Duration of Runs

3.08.1 When determining the energy balance, each run should be preferably of not less than four hours duration.

3.08.2 The actual duration of all runs from which the final data are derived shall be clearly stated in the test report.

3.09 Frequency and Consistency of Readings. Except for quantity measurements, it is recommended that the readings be taken at 10-minute intervals. If, however, there are significant fluctuations, the readings shall be taken at such frequency as may be necessary to determine a representative average. In this case, the parties to the test shall agree to the reading frequency to be used.

3.09.1 Where the amount of feedwater is determined from integrating instruments, a reading shall be taken every hour. When indicating flowmeters or manometers are used with venturi tubes, flow nozzles, flow tubes, or orifice plates for subsequently determining quantity measurements, the flow indicating element shall be read at intervals not exceeding five minutes. Readings shall be taken at intervals as short as one minute when deemed necessary by the parties to the test.

3.09.2 It is suggested that, insofar as feasible, pertinent data of the run be plotted continuously, as the run progresses, on coordinate paper of suitable scale arrangements to permit a complete review of the conduct of the run at least hourly.

3.10 Records and Test Reports. All observations, measurements, and instrument readings necessary for the objective of the test shall be recorded as observed. Corrections and corrected values shall be entered separately in the test record. Erasures in this record shall be prohibited. If deviations from standard or previously specified conditions are accepted by parties to the tests, they should be described in the test report.

3.11 Instruments and Methods of Measurement. The necessary instruments and procedures for making measurements are prescribed herein and should be used in conjunction with the following ASME Performance Test Codes Supplements on Instruments and Apparatus, and other publications for detailed specifications on apparatus and procedures involved in the testing. In all cases, care shall be exercised to apply the latest revision of the document concerned.

3.11.1 ASME Performance Test Codes:

General Instructions, PTC 1
Definitions and Values, PTC 2
Steam Generating Units, PTC 4.1
Steam Turbines, PTC 6

3.11.2 Supplements on Instruments and Apparatus, PTC 19:

Part 1 – General Considerations, PTC 19.1
Part 2 – Pressure Measurement, PTC 19.2
Part 3 – Temperature Measurement, PTC 19.3
Part 5 – Measurement of Quantity of Materials, PTC 19.5
Part 6 – Electrical Measurements in Power Circuits, PTC 19.6
Part 11 – Methods for Determination of Quality and Purity of Steam, PTC 19.11
Part 21 – Leak Detection and Leakage Measurement, PTC 19.21

3.11.3 ASME Research Publications:
Fluid Meters: Their Theory and Application

3.11.4 ASTM Standards, Part 23:
D-1066 – Method of Sampling Steam
D-1125 – Methods of Test for Electrical Conductivity of Industrial Water and Industrial Waste Water
D-1428 – Methods of Test for Sodium and Potassium in Industrial Water and Water-Formed Deposits by Flame Photometry
D-2186 – Methods of Test for Deposit-Forming Impurities in Steam