UNCLASSIFIED

NRL Report 6179

Yankee Reactor Pressure Vessel Surveillance: Evaluation of Specimens Exposed During the Second Core

C. Z. SERPAN, JR., H. E. WATSON, J. R. HAWTHORNE, AND L. E. STEELE

Reactor Materials Branch
Metallurgy Division

November 24, 1964

U.S. NAVAL RESEARCH LABORATORY
Washington, D.C.

CONTENTS

ABSTRACT

Pressure vessel surveillance specimens from four capsules in accelerated irradiation positions of the Yankee Atomic Power Reactor have been tested by the U.S. Naval Research Laboratory. In spite of the fact that the four capsules were located in physically identical positions about the fuel core, they were subject to widely different neutron exposures (>1 Mev).

The Charpy-V transition temperature increase of the Yankee pressure vessel steel, which was irradiated together with a reference steel of the same nominal composition in the same capsules, was somewhat larger than the increase of the reference steel. The data from the reference steel followed closely the trend line of transition temperature increase versus total neutron exposure previously established by NRL for 540°F irradiations, but that for the Yankee vessel steel was displaced almost 100°F higher than the reference steel. Postirradiation annealing was beneficial for the three heat treatment conditions studied, and, in one case, essentially complete recovery of initial properties was observed.

The study demonstrated the usefulness of accurate dosimetry data for each surveillance specimen and the importance of measurements of the neutron dosage to which the monitored reactor component is exposed.

PROBLEM STATUS

This completes one phase of the radiation effects program under study. Other phases of the research problem are continuing.

AUTHORIZATION

NRL Problem M01-14
Projects PR 007-01-46-5409; SR 007-01-01, Task 0858;
AT(49-5)-2110; and USA-MIPR-ERG-5-64

Manuscript submitted September 18, 1964.

YANKEE REACTOR PRESSURE VESSEL SURVEILLANCE: EVALUATION OF SPECIMENS EXPOSED DURING THE SECOND CORE

INTRODUCTION

The significance and implications of the fast (>1 Mev) neutron-induced increase in the temperature of the nil-ductility transition point (NDT) of carbon and low-alloy pressure vessel steels have been the subject of a significant amount of research (1,2). Recognition of this behavior resulted in a joint decision by the operators and builders of the Yankee Atomic Power Reactor, the Yankee Atomic Electric Company, and the Westinghouse Electric Corporation respectively, to undertake a program for the in-core surveillance of the pressure vessel of the Yankee reactor. Details of this surveillance program have been reported by E. Landerman of the Westinghouse Atomic Power Division (3).

Surveillance capsules to monitor the neutron exposure and increase in transition temperature of the pressure vessel steel were inserted during the shutdown for the second core refueling. Prior to the end of the second core life, Yankee representatives indicated to the U.S. Atomic Energy Commission that surveillance capsules would be made available for evaluation by an AEC-sponsored organization. NRL was then asked by the AEC to accept responsibility for testing and evaluating the surveillance specimens from the second core. Subsequently, a meeting was held between Yankee, Westinghouse, and NRL personnel to determine the best possible approach to testing the capsules in order to gain the maximum amount of information from the surveillance specimens.

The locations of the capsules included in the surveillance program are shown in Fig. 1. As originally planned, four capsules were to be placed between the thermal shield and the pressure vessel in order to assess, as closely as possible, the true condition of the pressure vessel. Of these four, only two were actually inserted because of a misalignment of the access holes. Eight other identical capsules were placed inside the thermal shield adjacent to the fuel in accelerated exposure positions in order to determine in advance what might be the long-term condition of the pressure vessel. It was originally planned to remove the capsules over a period of several years in order to periodically assess the change in embrittlement to the pressure vessel. Some of the accelerated capsules were to be removed first, and during subsequent shutdowns the pressure vessel capsules were to be removed, since the exposure to these capsules would accumulate at a much slower rate and early removal of them would not yield as much information. At the time of removal of the capsules, only those from the four positions indicated in Fig. 1 remained. The other four accelerated capsules as well as the two pressure vessel capsules were missing from their positions. These six capsules had been broken off, presumably by action of the turbulent water flow inside the reactor. Further indications of the water flow turbulence are described in a later section of this report.

The four remaining capsules, in physically similar positions around the circumference of the fuel core, were removed from the reactor during the second-core shutdown. Because each capsule contained a limited number of specimens, it was deemed necessary to test the specimens of all four capsules in order to provide a meaningful analysis.

Each of the capsules contained Charpy V-notch impact and tension specimens made from a section of the Yankee pressure vessel steel (ASTM Type A302-B modified) as well as reference or correlation monitor specimens of a widely distributed and well-documented heat of A302-B steel (4). The latter material, which was furnished by the

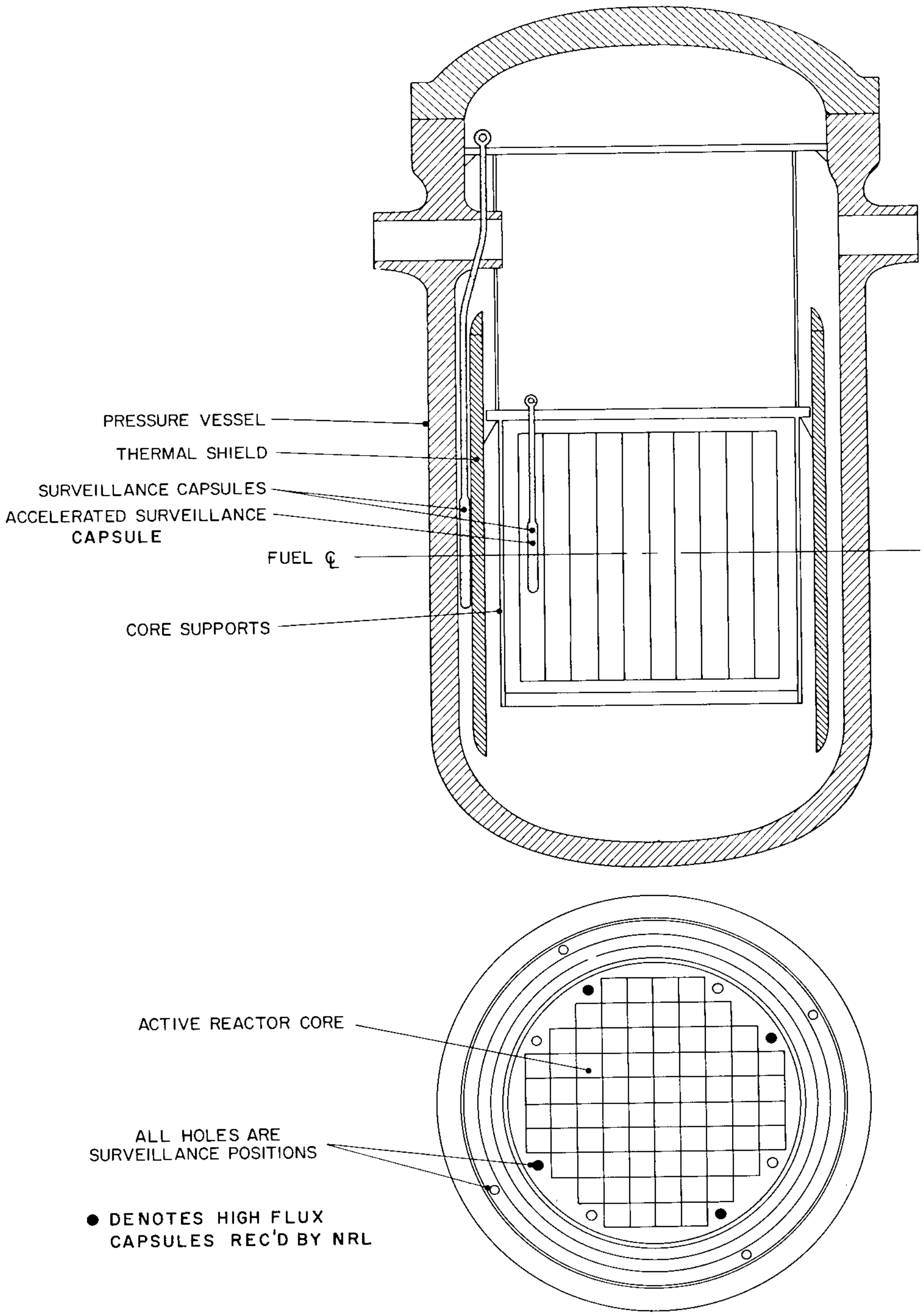

Fig. 1 - Schematic view of the Yankee Atomic Power Reactor showing surveillance positions and the locations of capsules received by NRL. (From Ref. 3.)

U.S. Steel Corporation, has been irradiated and evaluated by various laboratories including NRL. A sectional view of the surveillance capsule is shown in Fig. 2. Two of the capsules also contained special neutron dosimeter assemblies (Fig. 3) directly above the specimens. Neutron detectors included iron, nickel, and cobalt-aluminum, as well as cadmium-shielded nickel and cobalt-aluminum. The monitor wires were of the same material used by NRL and the Reactor Physics Group of the Materials Testing Reactor (MTR) for routine neutron flux measurements.

This report describes the recovery and testing of the Charpy V-notch specimens from the accelerated surveillance capsules, describes the recovery and analysis of the neutron flux monitors, and presents the results of testing of the specimens in both the as-irradiated and postirradiation annealed conditions with respect to neutron dose received. These results are also discussed with reference to previously obtained information on this steel (5) and to power reactor surveillance programs in general.

OPERATIONS AND TESTING PROCEDURES

Capsule disassembly, dosimetry sampling, and testing were all performed in the hot cell facilities at NRL. Specimens were removed from the 1/32-inch-thick stainless-steel-sheathed capsules after opening of the capsules by a remote milling machine equipped with a special slitting head (6). Charpy V-notch specimens were tested on a remotely operated impact machine which had been previously calibrated with Watertown Arsenal reference test specimens. Dosimetry counting and analysis was performed by the Phillips Petroleum Company, MTR Radiation Counting Laboratory, in Idaho.

Capsule Disassembly

All four capsules (designated Nos. 1, 2, 6, and 8) were opened in the machine shop hot cell and the specimens removed and sorted. Visual observations of the stainless steel sheath showed them to be almost black; the specimens were also quite dark but otherwise in good condition. The sheaths were apparently free of cracks or other such imperfections; however, the bottom portion of one sheath appeared to have a hole worn completely through it (Fig. 4). It was postulated that the water flow repeatedly forced this capsule against the thermal shield or some other fixed structural member with fluttering so that eventually a hole was worn through the sheath. This action even caused wear of one specimen. This water-turbulence-induced fluttering was also probably responsible for the shiny area on the capsule support disk as well as the long, indented section on the support tube, shown in Fig. 5. The support disk had a hook welded on to facilitate placement and removal of the capsule assembly. The fluttering apparently knocked off the hook, and the constant impact against a hold-down member was probably responsible for the shiny area.

Dosimetry Sampling

The neutron flux monitor assemblies were remotely freed from the stainless steel support tubes using a pipe cutter; the monitors themselves were removed from the assemblies in an out-of-cell, shielded glove box.

Sections of the neutron flux wires from the monitor assemblies were sent to the Radiation Counting Laboratory at the MTR for counting and analysis. Additionally, halves of four broken Charpy specimens of the reference material, one from each of the four capsules, were sent to the Chemical Processing Plant at the National Reactor Testing Station in Idaho Falls for extraction of the Mn^{54} isotope. Disintegration rate determinations and flux analyses of the extracted isotope were performed by the MTR group. As an aid in determining the vertical flux gradient in the reactor core region, a 1/2-inch section of

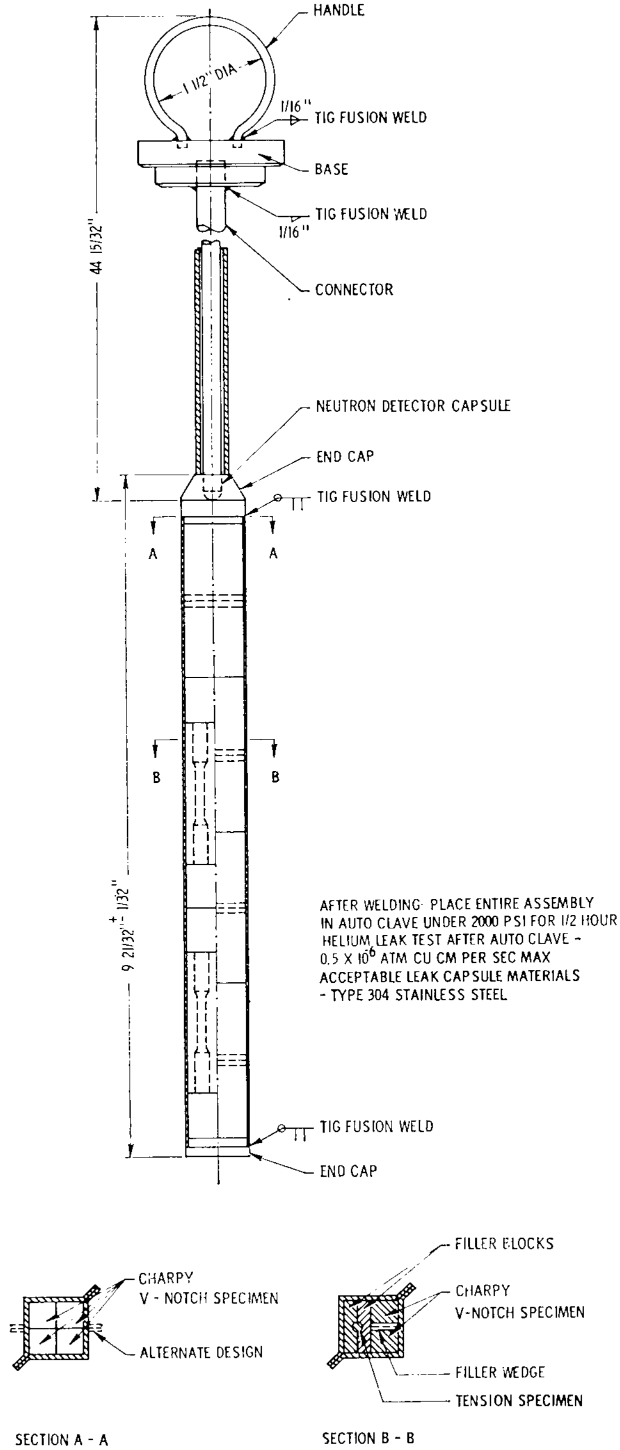

Fig. 2 - Yankee reactor vessel steel surveillance assembly showing construction details and position of specimens and dosimeters (from Ref. 3). The neutron detector capsule was contained in two of the assemblies.

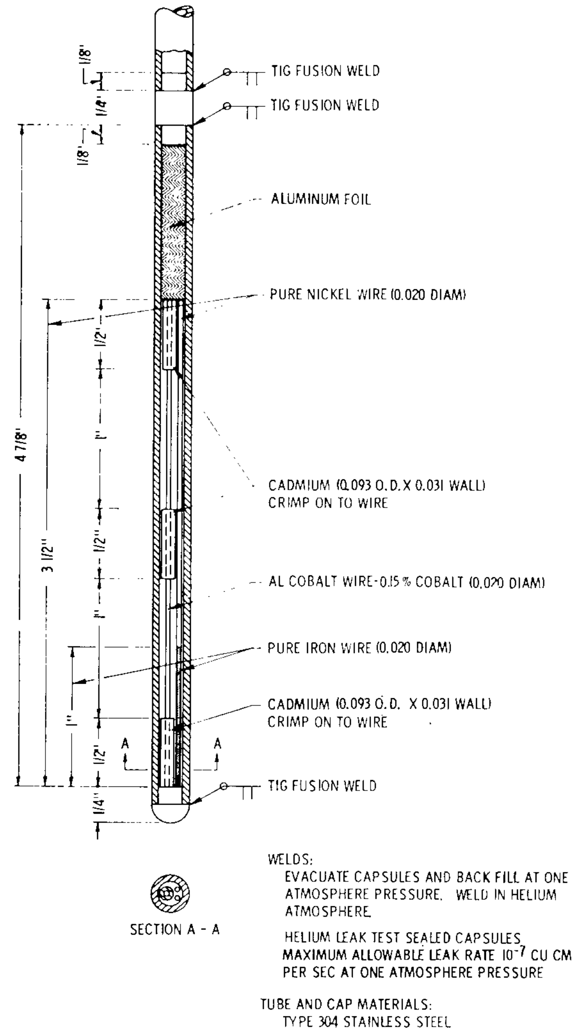

Fig. 3 - Neutron detector capsule as contained in two of the four surveillance assemblies (from Ref. 3)

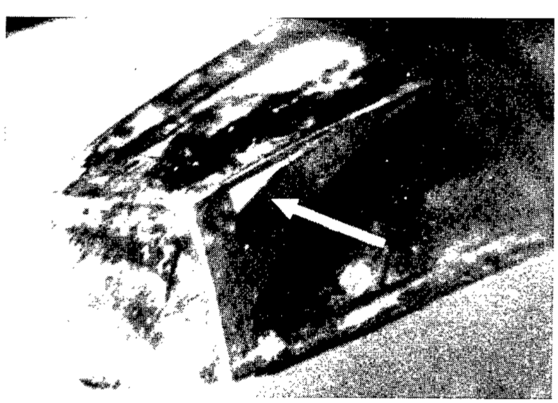

Fig. 4 - Surveillance capsule sheath showing hole (arrow) caused by fluttering against a fixed reactor member. (In-cell photo.)

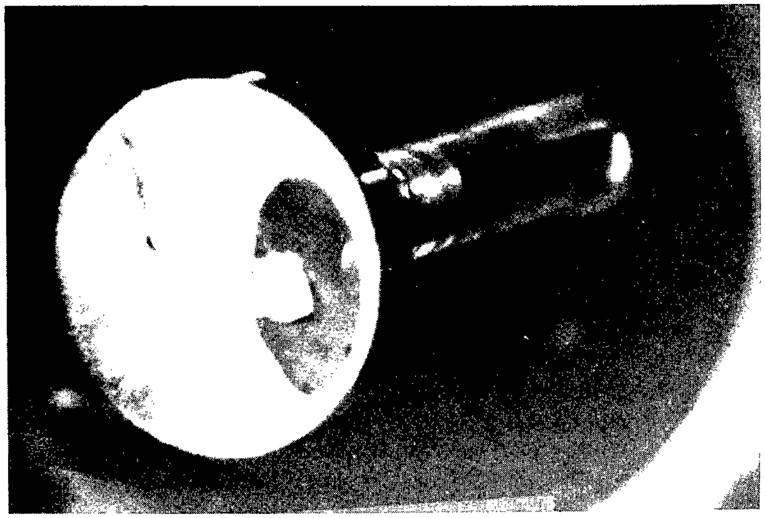

Fig. 5 - Capsule support disk and support tube. Water turbulence induced fluttering is thought to have been responsible for shiny area on the capsule support disk as well as the long indented section on the support tube. (In-cell photo.)

the stainless steel support tube located 3 inches above the specimen area of one of the dosimeter-containing capsules was also sent for analysis with the Charpy-specimen halves.

Specimen Testing

The placement of the irradiation capsules in the reactor suggested that all four would have duplicate exposures, and the testing program was planned upon that assumption. Shortly after the start of the testing, however, it was noted that the specimens from the four capsules did not exhibit similar properties. Consequently, a new testing program was devised. In this new program, all specimens of the Yankee vessel steel from capsule 8, as well as the reference A302-B specimens from all four capsules, were tested in the as-irradiated condition. Additionally, one Yankee specimen from capsule 6 was tested in the as-irradiated condition and gives some indication of the transition temperature increase for that steel in that capsule. Finally, the remaining Yankee vessel specimens from three capsules were annealed for 168 hours at three different temperatures (850, 750, and 640°F) in order to ascertain the possibilities of restoring the initial notch ductility properties of this material.

RESULTS

In viewing the results of the steel testing and neutron monitoring phases of the Yankee surveillance program, it should be recognized that the test capsules were all taken from locations of accelerated neutron exposure. Thus, the transition temperature increases and neutron exposure values measured and reported are several times greater than the actual conditions of the Yankee vessel.

In analyzing the surveillance results, it should be noted that, while the capsule irradiation temperature (reactor coolant temperature) was approximately 540°F for most of the second core life, there were variations in temperature. For example, there was a gradual significant drop in temperature (67°F) in the last three months of the second core life of

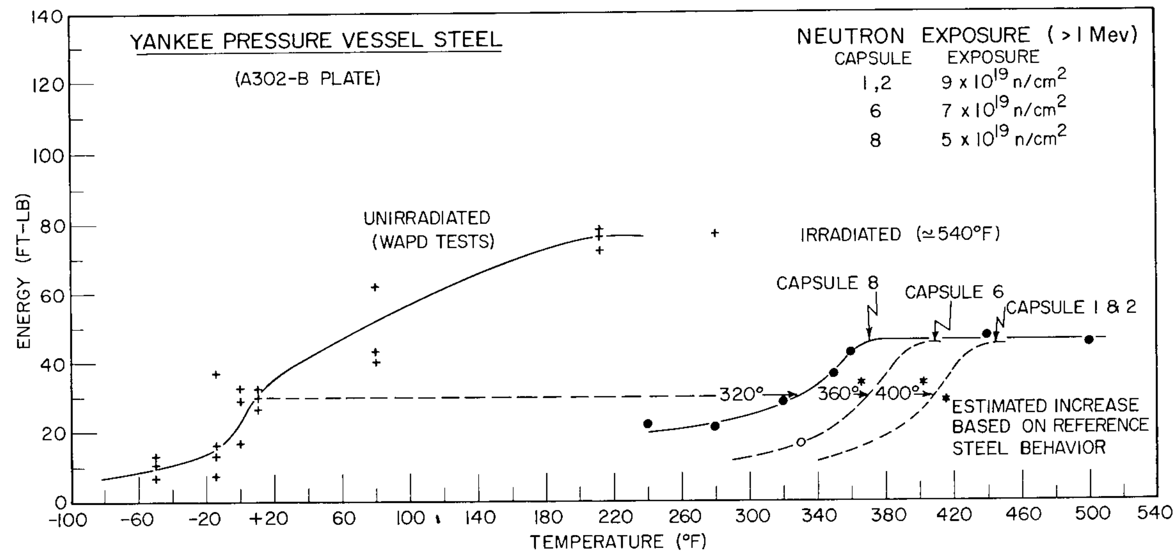

Fig. 6 - Irradiated notch ductility characteristics of the Yankee pressure vessel steel

the Yankee reactor. This variation does no harm to the analysis of results, however, since the temperature drop was small and was at a time of decreasing neutron exposure. Furthermore, all capsules underwent the same thermal history during exposure.

Charpy impact energy versus temperature curves for the Yankee material from the accelerated capsules are presented in Fig. 6. The unirradiated initial nil-ductility transition temperature (+10°F) has been estimated from Charpy V-notch tests conducted by Westinghouse. The transition temperature increase for capsule 8, was determined from a number of specimens. Visual ratings of fracture appearance indicated a range of ductile fracture from 25 to 100%. The curve shown for capsule 6 is an approximation based upon the data obtained for the reference steel in this capsule. The one point for the Yankee material adds validity to this approximation. Similarly, the dashed curve for capsules 1 and 2 indicates the approximate increase of the transition temperature.

Charpy curves for the reference steel from the accelerated capsules are shown in Fig. 7. The initial NDT of this plate in the unirradiated condition (indicated by the arrow) was determined by NRL from drop weight tests. Although a very limited number of specimens were available for the development of these curves, the data give a fair approximation of the Charpy-V 30-ft-lb level for comparison of transition temperature behavior. The specimens from capsules 1 and 2 had properties similar enough to be treated as representative of one exposure condition. These data gave the first indication of the variation in neutron exposure among the specimen capsules.

Results of annealing the remaining Yankee specimens at three different temperatures (640, 750, and 850°F) for 168 hours are shown in Fig. 8. The data curves, although developed with adequate numbers of specimens, only indicate the estimated magnitude of the recovery of properties of the specimens from capsules 1, 2, and 6, since the as-irradiated curves for these capsules are "best estimates." The notch ductility and annealing results shown in Figs. 6, 7, and 8 are summarized in Tables 1 and 2.

Instantaneous flux and integrated neutron exposure values (>1 Mev) are given in Table 3a as calculated from analysis of Charpy specimens and in Table 3b from the analysis of neutron flux monitors from the dosimeter capsules. The wide range of flux levels to which the capsules in otherwise duplicate positions were subjected is apparent. Westinghouse performed a neutron flux analysis on two Charpy specimens from capsule 8, the

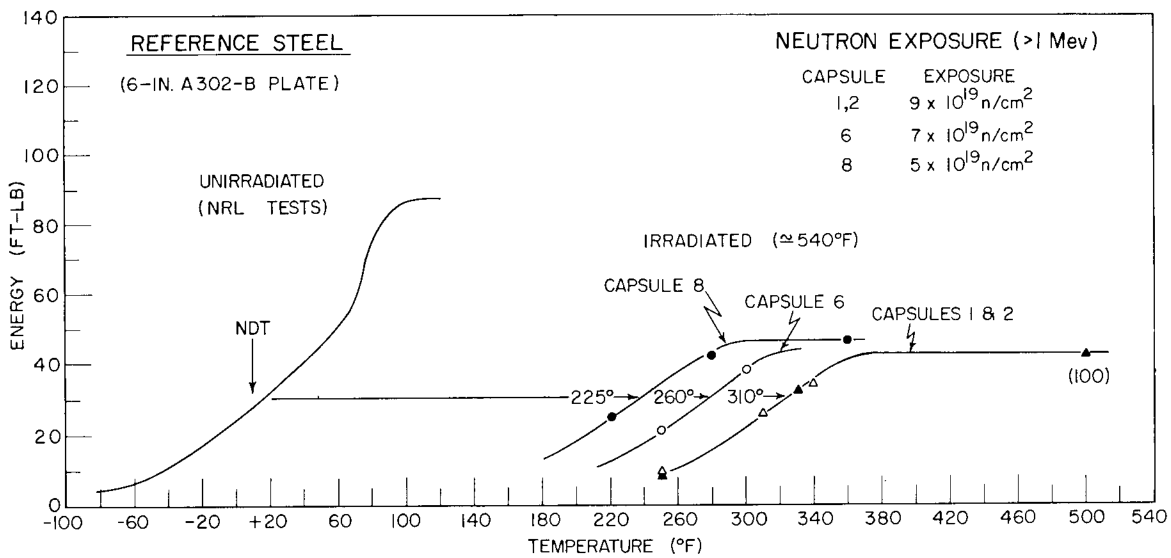

Fig. 7 - Irradiated notch ductility characteristics of the reference steel exposed in Yankee surveillance capsules. The (100) indicates 100% shear fracture appearance.

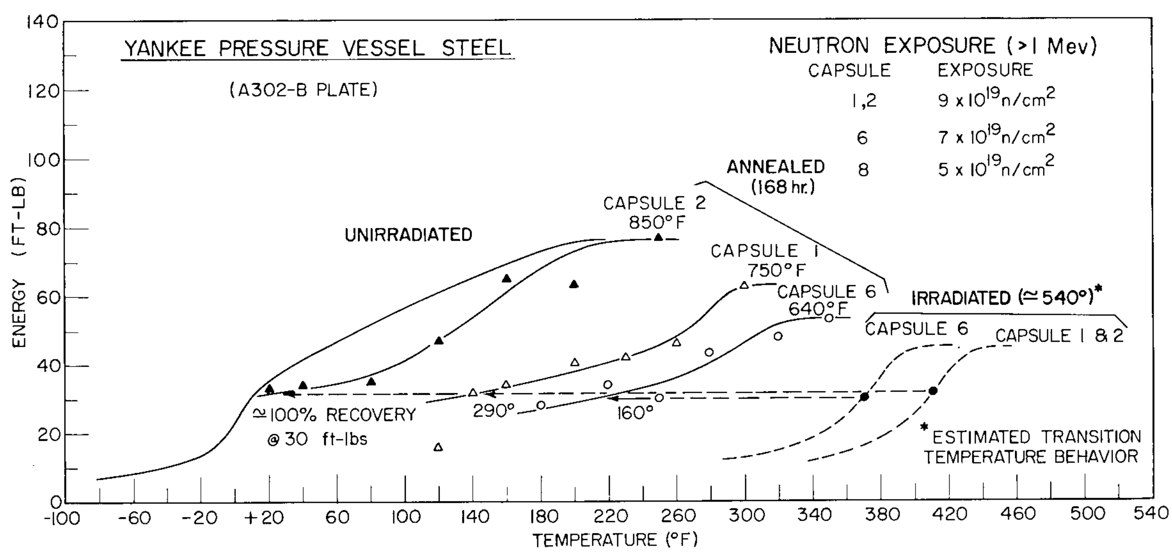

Fig. 8 - Effect of postirradiation heat treatment on the notch ductility characteristics of Yankee pressure vessel steel

results of which agreed very closely with data developed by the MTR physics group on two other Charpy specimens from the same capsule.

DISCUSSION

Neutron dosimetry proved to be the key to the meaningful analysis of the data from the Yankee second core surveillance testing program. Since all four capsules were in identical physical locations, even to the point of being adjacent to equivalent weights of

Table 1
The Effect of Irradiation on the Notch Ductility Properties of Yankee Surveillance Specimens

Capsule No.	Specimen Material	Neutron Exposure (n/cm^2 (>1 Mev))	30-ft-lb Transition (°F)			Energy Absorption at Full Shear (ft-lb)		
			Unirrad.	Irrad.	ΔT	Unirrad.	Irrad.	Δ ft-lb
1	Yankee Steel	9×10^{19}	10	~410	~400	76	~45	~31
	Reference Steel	9×10^{19}	15	325	310	87	42	45
2	Yankee Steel	9×10^{19}	10	~410	~400	76	~45	~31
	Reference Steel	9×10^{19}	15	325	310	87	42	45
6	Yankee Steel	7×10^{19}	10	~370	~360	76	~45	~31
	Reference Steel	7×10^{19}	15	275	260	87	44	43
8	Yankee Steel	5×10^{19}	10	330	320	76	46	30
	Reference Steel	5×10^{19}	15	240	225	87	46	41

Table 2
The Effect of Postirradiation Annealing on the Notch Ductility Properties of Yankee Reactor Surveillance Specimens (approximated from limited data)

Capsule No.	Annealed, 168 hr (°F)	30-ft-lb Transition (°F)			Percent Recovery	Energy Absorption at Full Shear (ft-lb)		
		Irrad.	Annealed	ΔT		Irrad.	Annealed	Δ ft-lb Recovery
2	850	410	10	400	100	45	76	31
1	750	410	120	290	72	45	64	19
6	640	370	210	160	45	45	53	8

UNCLASSIFIED

Table 3a
Neutron Flux and Integrated Exposure Values As Determined by Chemical Separation of Mn^{54} from Charpy Specimens

Capsule No.	$Fe^{54}(n,p)Mn^{54}$		Nominal Exposure*
	n/cm^2-sec (>1 Mev)	n/cm^2 (>1 Mev)	n/cm^2 (>1 Mev)
1	3.25×10^{12}	9.38×10^{19}	9×10^{19}
2	3.06	8.83	9
6	2.56	7.38	7
8	1.69	4.88	5

*A centrally located specimen was used to represent specimens in the capsule.

Table 3b
Neutron Flux and Integrated Exposure Values As Determined by Dosimetry Counting and Analysis of Neutron Flux Monitors

Capsule No.	Spec. No.	2200 m/sec		$Fe^{54}(n,p)Mn^{54}$		$Ni^{58}(n,p)Co^{58}$	
		n/cm^2-sec	n/cm^2	n/cm^2-sec (>1 Mev)	n/cm^2 (>1 Mev)	n/cm^2-sec (>1 Mev)	n/cm^2 (>1 Mev)
1	1	2.5×10^{13}	6.20×10^{20}	3.44×10^{12}	9.92×10^{19}		
1	1 Cd*					3.40×10^{12}	9.81×10^{19}
1	2			3.42	9.87		
1	2 Cd*					3.55	10.2
8	1	1.45	4.21	3.69	10.6	2.76	7.96
8	1 Cd*					3.10	8.94
8	2			3.67	10.6		

*0.040-inch cadmium shield.

fuel, the wide discrepancies in transition temperature increases between the capsules could only be traced to neutron exposure differences. These differences were apparently caused by the angle of suspension of the capsules, either toward or away from the fuel elements. Since the capsules were supported from the top only, it may have been possible for them to move as a pendulum under the action of the coolant water flow.

Two sets of dosimetry data for the capsules are shown in Tables 3a and 3b. However, the set of data resulting from analysis of the Mn^{54} isotope induced in the Charpy specimens (Table 3a) is the most significant set. This is simply because the test specimens themselves were analyzed for induced activity, and thus, were most accurately representative of the neutron exposure at that point. Conversely, the dosimeters located in the special dosimeter assemblies atop two of the capsules were somewhat displaced from the specimens and, in the case of capsule 8, showed a large difference in exposure level. No full explanation has been found for this observation. In this connection, however, the importance of incorporating neutron flux monitors in intimate contact with test specimens in any irradiation assembly cannot be overemphasized. For example, it would have been preferred to locate dosimetry wires in the notches of the Charpy-V specimens, thus eliminating the costly and time consuming operation of extraction of the induced Mn^{54} isotope from Charpy specimens themselves.

All neutron flux and total exposure values reported herein are taken to be neutrons per square centimeter greater than 1 Mev in energy. A fission spectrum was assumed for all calculations; cross sections used were computed as averaged over a fission spectrum. Cross sections used for the $Fe^{54}(n,p)Mn^{54}$ and $Ni^{58}(n,p)Co^{58}$ reactions were 68 and 95 millibarns respectively. Co^{58} burnout corrections were made using thermal flux values obtained from bare and cadmium-shielded cobalt dosimeters by the reaction $Co^{59}(n, \gamma)Co^{60}$, and the cross-section value of 36.3 barns.

From the Charpy curves for capsule 8 (Figs. 6 and 7), it is apparent that even within the same capsule the two groups of specimens of the same nominal composition and fabrication history behaved very differently in spite of a very similar exposure history. This is illustrated in Fig. 9, on which are plotted the two sets of data points developed from the Yankee and the reference material test specimens. The data points from the reference material follow the line established in previous irradiation experiments conducted by NRL at 540°F, parallel to the general ΔNDT trend band. The Yankee vessel steel data points also are parallel to the trend band, but are displaced upward by 90 to 95°F.

The reasons for the considerable discrepancy between transition temperature increases for the Yankee and reference A302-B steels are not fully understood but may be due to a combination of factors already recognized and under study by NRL and other laboratories. For example, Carpenter, Knopf, and Byron (7) of the Bettis Atomic Power Laboratory reported the existence of "sensitive" and "insensitive" heats of the same nominal composition of A302-B steel. These inconsistencies were manifested by large differences in transition temperature increase for the same neutron exposure under the same irradiation conditions. The Bettis investigators concluded that these differences in behavior were probably caused by differences in metallurgical structure developed by variations in heat treatment of the many plates used in their study.

NRL has recently reported the results of irradiations upon 1/2-inch plates of laboratory-produced heats of nominal A212-B steel (5). These results were then compared with irradiation results from a commercially prepared, 4-inch-thick plate of A212-B steel, an irradiation reference steel. The initial unirradiated NDT of the laboratory steel was 35°F less than that of the commercially prepared steel. After irradiation to 1.3×10^{19} n/cm^2 (>1 Mev), the NDT (based upon Charpy V-notch tests) of the laboratory steel was 105°F lower than the NDT of the commercial steel. Compositional differences in this instance may be cited as the possible cause for the wide variation in properties observed, but a combined effect of both metallurgical microstructure and composition has not been eliminated as the key to the observed discrepancy between steels after irradiation.

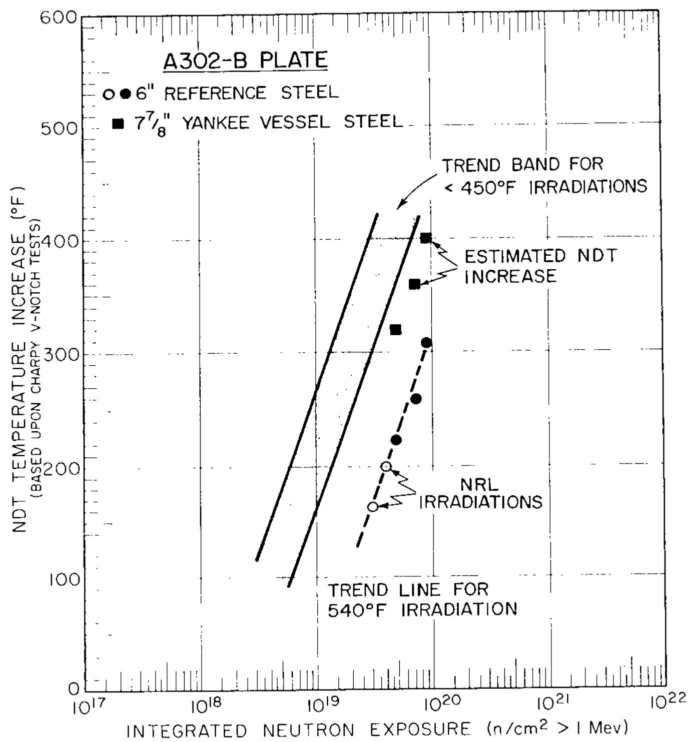

Fig. 9 - Trend line for 540°F irradiations of A302-B steel showing difference in neutron embrittlement between Yankee vessel and reference steels

The significance of the Yankee material data points in Fig. 9 is that the Yankee pressure vessel steel is more sensitive to radiation, showing a larger transition temperature increase for a given neutron exposure than that observed for a carefully produced heat of A302-B steel. On the other hand, the energy absorption at full shear fracture is almost the same for both steels after irradiation; in spite of the fact that the unirradiated value was somewhat higher for the reference steel. Possible reasons for the observed differences are being explored.

The annealing results from the Yankee material are much more encouraging. The specimens from capsule 2 which were annealed for 168 hours at 850°F (Fig. 8) showed essentially complete recovery of initial properties including energy to full shear fracture. Based upon the estimated increase due to irradiation, the magnitude of recovery was about 400°F. Annealing of capsule 1 specimens at 750°F for 168 hours resulted in a recovery of about 290°F, or about 72%, and high recovery of energy for full shear fracture. This compares favorably with a similar irradiation-annealing experiment in which the A302-B reference steel was irradiated at 540°F, then annealed at 750°F for 72 hours (8). Recovery of about 61% of initial properties in the latter experiment was effected, although the recovery in full shear energy was not as great as that developed in the Yankee vessel steel. The 168-hour, 640°F annealing of capsule 6 resulted in a recovery of 160°F, or about 45%, with significant benefit to shear energy absorption.

CONCLUSIONS

In analyzing the results of the Yankee reactor surveillance program, it should be noted that all the data were from capsules located in positions of accelerated neutron exposure.

The dose to the pressure vessel would be considerably reduced by the attenuating effect of the thermal shield and the intermediate water filled space. Nevertheless, certain meaningful conclusions are drawn from this study.

The steel used for the pressure vessel of the Yankee reactor may be classified as sensitive to irradiation embrittlement by fast neutrons (E > 1 Mev) when compared to results of the same irradiation on a reference plate of the same nominal composition. The cause of this sensitivity is not fully understood, but several hypotheses have been advanced, and research is being conducted to help solve the problem. The irradiation behavior of the reference steel included in the surveillance capsules was in excellent agreement with data from experimental studies, indicating no peculiarities in neutron flux or spectrum for the accelerated irradiation positions of the Yankee reactor.

The results of the annealing studies, although based upon estimated transition temperature increases due to irradiation, indicated very significant recovery of initial properties, especially with heat treatment at temperatures of 750 to 850°F.

The salient need for and usefulness of accurate neutron dosimetry data taken from the actual specimen area cannot be overstated. Without such information, the analysis of the Yankee surveillance specimens would have been impossible. The accuracy and potential of the Mn^{54} isotope for analysis of the neutron exposure for long-term irradiations has been well demonstrated in this surveillance program.

In addition to the need for care in determining the neutron exposure of surveillance specimens, it is extremely important that measurements be made of the neutron dosage to which the monitored reactor component is exposed. Without data of this sort no surveillance program, no matter how carefully planned and conducted, can produce data which can be applied with confidence.

The planning and design which go into a surveillance program must consider all possible hazards attendant upon the placement of materials in a nuclear reactor. For example, designs must be carefully drawn to preclude the breaking loose of components or their displacement from intended locations by turbulent coolant flow. In addition, complete records must be kept for future data analyses. The more important records include the steel processing history, from ladle through final fabrication and heat treatment, the exact location of every specimen in each surveillance capsule, and the history of the operation of the reactor; power output and coolant temperature are especially essential. Also, the surveillance program should include a fully documented reference steel along with the steel of direct concern. The inclusion of a reference steel, although requiring some additional effort, may be very rewarding as this case well demonstrates. Westinghouse and Yankee Atomic representatives deserve credit for providing a reference steel in this program.

It is apparent from the results of this study that carefully planned and conducted surveillance programs may be quite valuable in assessing radiation damage to reactor pressure vessels and more generally to the advancement of knowledge of radiation effects to reactor structural steels.

ACKNOWLEDGMENTS

The authors wish to acknowledge the discussions with E. Landerman and associates of the Westinghouse Atomic Power Division regarding the Yankee surveillance program as well as their helpful suggestions to this report. The efforts of the Phillips Petroleum Company in Idaho who provided the neutron dosimetry analysis are also appreciated. To John Kaslow of the Yankee Atomic Electric Company go particular thanks for many helpful discussions, for the provision of the reactor operations data, and for his suggestions to this report. The advice and support of the AEC, Fuels and Materials Development Branch, Division of Reactor Development, are also acknowledged with appreciation.

REFERENCES

1. Steele, L.E., and Hawthorne, J.R., "Neutron Embrittlement of Reactor Pressure Vessel Steels," NRL Report 5984, Oct. 1963, and "Materials and Fuels for High Temperature Nuclear Energy Applications," The MIT Press 1964

2. Berggren, R.G., "Critical Factors in the Interpretation of Radiation Effects on the Mechanical Properties of Structural Metals," Welding Research Council Bulletin 87, Apr. 1963, pp. 1-7

3. Landerman, E., "Surveillance Tests on Structural Materials in Nuclear Reactors," ASTM Symposium on Radiation Effects on Metals and Neutron Dosimetry, Los Angeles, California, Oct. 2-3, 1962, ASTM STP 341, 1963, pp. 233-252

4. Alger, J.F., and Porter, L.F., "Evaluation of Reference Pressure-Vessel Steels for Neutron-Irradiation Studies," U.S. Steel Applied Research Laboratory, June 18, 1964

5. Steele, L.E., Hawthorne, J.R., Serpan, C.Z., Jr., and Watson, H.E., "Irradiation Effects on Reactor Structural Materials, Quarterly Progress Report (1 Nov. 1963 - 31 Jan. 1964)," NRL Memorandum Report 1501, Feb. 1964

6. Hawthorne, J.R., and Steele, L.E., "Radiation Damage of Materials (Specialized Equipment for Disassembly of Highly Radioactive Reactor Experiments)," Report of NRL Progress, Mar. 1960, pp. 23-25

7. Carpenter, G.F., Knopf, N.R., and Byron, E.S., "Anomalous Embrittling Effects Observed During Irradiation Studies on Pressure Vessel Steels," Nuclear Science and Engineering 19:18-38 (1964)

8. Steele, L.E., Hawthorne, J.R., Serpan, C.Z., Jr., and Watson, H.E., "Irradiation Effects on Reactor Structural Materials, Quarterly Progress Report, 1 Feb. - 15 Apr. 1964," NRL Memorandum Report 1534, May 1964; also HW-82379

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* U.S. Naval Research Laboratory Washington, D.C.	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

YANKEE REACTOR PRESSURE VESSEL SURVEILLANCE: EVALUATION OF SPECIMENS EXPOSED DURING THE SECOND CORE

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final report on one phase of the problem

5. AUTHOR(S) *(Last name, first name, initial)*

Serpan, Charles Z., Jr., Watson, Henry E., Hawthorne, J. Russell, and Steele, Lendell E.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 24, 1964	18	8

8a. CONTRACT OR GRANT NO. NRL Problem M01-14 b. PROJECT NO. RR 007-01-46-5409 c. SR 007-01-01, Task 0858 AT(49-5)-2110 d. USA-MIPR-ERG-5-64	9a. ORIGINATOR'S REPORT NUMBER(S) NRL Report 6179 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES

Unlimited availability

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Dept. of the Navy (Office of Naval Research and Bureau of Ships) Dept. of the Army

13. ABSTRACT

Pressure vessel surveillance specimens from four capsules in accelerated irradiation positions of the Yankee Atomic Power Reactor have been tested by the U.S. Naval Research Laboratory. In spite of the fact that the four capsules were located in physically identical positions about the fuel core, they were subject to widely different neutron exposures (>1 Mev).

The Charpy-V transition temperature increase of the Yankee pressure vessel steel, which was irradiated together with a reference steel of the same nominal composition in the same capsules, was somewhat larger than the increase of the reference steel. The data from the reference steel followed closely the trend line of transition temperature increase versus total neutron exposure previously established by NRL for 540°F irradiations, but that for the Yankee vessel steel was displaced almost 100°F higher than the reference steel. Post-irradiation annealing was beneficial for the three heat treatment conditions studied, and, in one case, essentially complete recovery of initial properties was observed.

The study demonstrated the usefulness of accurate dosimetry data for each surveillance specimen and the importance of measurements of the neutron dosage to which the monitored reactor component is exposed.

DD FORM 1473 1 JAN 64

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Nuclear reactor						
Nuclear power plant						
Yankee Atomic Power Reactor						
Steel embrittlement						
Embrittlement sensitivity						
Neutron exposure						
Pressure vessel surveillance						
Surveillance program						
Nil-ductility transition						
Transition temperature increase						
Neutron flux measurements						
Neutron flux monitor assemblies						
Postirradiation annealing						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.