Detection Probability Assessment

for

Visual Inspection of Ships

Laura A. Demsetz
Assistant Professor
Civil and Environmental Engineering
University of California, Berkeley

Juan Cabrera
formerly
Graduate Student
Naval Architecture and Offshore Engineering
University of California, Berkeley

FINAL REPORT
SR-1375

April 30, 1999

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the Maritime Administration and the Ship Structure Committee. We thank the Project Technical Committee for their guidance in carrying out this work, and for their review of this report. We are particularly grateful to Committee members Rong Huang of Chevron Shipping for his guidance throughout the project and his careful review of the final report.

The work described in this project was carried out in a timely fashion consistent with the original proposal and subsequent quarterly reports. However, the first author was unacceptably late in delivering both the draft final report to the Maritime Administration. The responsibility for this delay lies entirely with the first author. The patience of those involved in administering this project is gratefully appreciated.

CONTENTS

List of Tables

List of Figures

1. Introduction

The work described in this report is part of an ongoing effort to determine the probability of detection (POD) in marine structural inspections. An understanding of POD can help ensure safe, cost-effective lifecycle operation of marine structures, allowing the appropriate combination of design assumptions and scheduled inspections. Work to date at U.C. Berkeley has focused on the inspection of oil tankers.

In a previous project, a preliminary model of the factors affecting POD in tanker inspection was developed, and is shown in Figure 1. Reviews of literature and interviews with inspectors indicated that the factors associated with an inspector, in particular, experience, would likely be important determinants of POD, along with factors such as access and lighting. Several approaches for evaluating POD were identified, with benchmarked inspection data (a comparison of two inspections of the same structure that take place within a relatively short time) and in situ experiments (a comparison of the performance of multiple inspectors inspecting the same structure under controlled conditions) considered to be the most promising. An application of the benchmarked inspection data approach to historical survey data for two ships highlighted the importance of several factors: prior knowledge of the history of a particular vessel and sister ships, the purpose of the inspection, and factors such as lighting, access, and cleanliness that may be different for different tanks on the same ship. The POD factor model and selected data from the benchmarked inspection case study can be found in [Demsetz et al. 1996b]. The full literature review, model development, and case study results can be found in [Demsetz et al. 1996a]

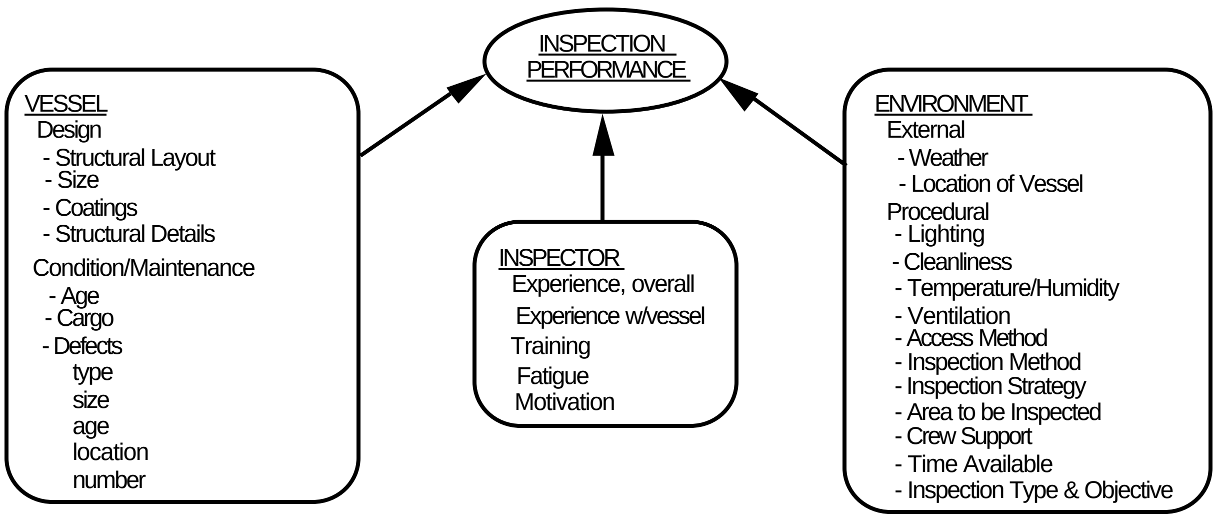

Figure 1. Factors affecting probability of detection.

In the work described here, in situ experiments are used as a means of obtaining POD information. The rationale for the use of in situ experiments is first described, along with the advantages and disadvantages of these experiments with respect to other means of obtaining POD information. Results of an initial in situ experiment, conducted in Portland, Oregon, in September, 1995, are then presented. Based on these results, the experimental protocol was revised. Using the revised protocol, a second experiment was conducted in Port Arthur, Texas, in July, 1996. Results of this experiment are presented as well. Conclusions regarding POD in tanker inspection and regarding the in situ inspection method are drawn in the final section of this report. The data from the two experiments are summarized in Appendices B and C.

1.1 In Situ Experiments

Previous studies have suggested several means of acquiring POD information, including solicitation of expert opinion, laboratory experiments, benchmarked historical data, and in situ experiments [Ayyub and White 1992, Demsetz et al. 1996a]. These methods and their relative advantages and disadvantages are summarized in Table 1. In manufacturing industries, POD curves are generated using test samples and recording the results of inspections under controlled conditions [Rummel 1989]. In dealing with larger structures, the aviation industry has used controlled experiments on specimens representing a portion of the structure [Berens 1989] and a comparison of the results of inspections of differing levels of rigor (similar to the benchmarked historical data approach) [Dinkeloo 1978]. Recent work on POD in offshore structures has involved controlled laboratory experiments on full scale samples that represent a portion of an offshore structure [Rudlin 1992].

Approach	Advantages	Disadvantages
Solicitation of Experts: ask experts to estimate POD for a variety of circumstances.	low cost; few time constraints; few resources required; easy data management	some experts are unable or unwilling to provide an estimate of POD; experts in tank inspection may not accurately estimate POD
Laboratory Experiments: carry out inspections in a controlled environment on test specimens constructed to contain the range of defects of interest.	ability to control test conditions; knowledge of true condition; fewer time constraints than *in situ* experiments	difficulty in recreating field environment; costly if large specimens used
Benchmarked Inspection Data: comparison of results of subsequent inspections, specifically an underway inspection with a drydock inspection shortly thereafter	low cost; few resource requirements;	little or no control over factor conditions; no guarantee that drydock inspection yields "true" condition of tank; few examples of usable historical data
In-Situ Experiments: experiments carried out on an in-service or temporarily out-of-service vessel	ability to replicate field environment;	high cost, especially of keeping vessel out of service; chance that too few defects exist to provide meaningful results (unless markers used as to "simulate" defects)

Table 1. Methods of Determining Probability of Detection.

The in situ tank inspection experiments described in this report were carried out in "real" structures: tankers that, while temporarily out of service, provide an experimental environment that comes as close as possible to duplicating the actual field condition of an underway inspection. The major advantage of an in situ experiment is this close replication of actual field conditions. Although each inspectors' motivation during the experiment may differ from that in his or her normal job practice, other inspector factors and the vessel and environmental factors are true to life. Thus, in situ experiments provide an opportunity to assess overall POD and to investigate the impact of inspector factors on POD. In the experiments described here, inspectors carried out an equivalent of an underway (or voyage) inspection, rather than the more thorough inspection done during a periodic overhaul in a shipyard (where a better environment, one more "friendl" to inspection, is available).

There are, however, disadvantages to in situ experiments. The resource requirements are significant; a vessel and a group of inspectors must be brought to the same place at the same time. Associated costs include the cost of the inspectors and, most significantly, the cost of keeping the vessel out of service for several days. In the experiments described in this report, the vessels were temporarily out of service for other reasons. This made the experiments economically feasible. A major disadvantage of in situ experiments is that the condition of the vessel is unknown before the experiment starts. It may turn out that the vessel has few defects of interest, and that the experiment, while executed correctly, yields no useful data regarding probability of detection. To guarantee that at least some data were obtained from the experiments described here, markers that were roughly as difficult to detect as real defects were placed in portions of the vessels.

1.2 Pre-experiment Planning

At the time this research project was awarded, it was anticipated that one experiment would be carried out during the first year of the project, on a vessel to be determined, and that a second experiment would be carried out during a possible second year of the project. Shortly after the project started, a vessel that was to be laid up at dockside for an unknown length of time was identified. The owner of the ship agreed to let it be used as the site for the experiment. Because there was a significant chance that the ship would be placed back in active service shortly, the experiment was planned and carried out as quickly as possible. Planning issues regarding the ship, the inspectors, and the preparation of the tanks prior to the experiment are described in this section.

1.2.1 General Plan

The general plan for the experiment called for three types of inspection. The first, a standard visual inspection, was carried out independently by each of several inspectors. After the inspection, each inspector was asked to complete a brief questionnaire (developed in [Demsetz 1996a]) designed to capture the levels of the various factors shown in Figure 1. The results of these standard visual inspections were aggregated and analyzed; the results were provided to the team carrying out the second type of inspection: the visual follow-up. In order to allow each team to inspect the tank under the same conditions, the inspectors were instructed not to scrape, mark, or otherwise disturb the tank. Thus, in areas where waxy build-up or corrosion were present, the inspectors were reporting "suspect areas" — areas they would have scraped if possible — rather than actual cracks. Because the tank's condition remains constant throughout the experiment, the vessel and environment factors (except for time in tank) remain the same for each inspector.

The purpose of the second inspection, the visual follow-up, was to determine the "true" state of the vessel. The follow-up inspector was asked to verify the standard visual inspections and to take as much time and as much care as possible to identify any additional cracks.[1] The aggregated results of the standard inspections, augmented with the findings of the visual follow-up, would be considered the "true" data as far as existence and location of cracks.

The third type of inspection, non-destructive evaluation, was to be carried out to assess the true length of cracks as part of a related project. The lengths observed through non-destructive evaluation techniques were to be compared with the lengths recorded during visual inspections of the same cracks. Non-destructive evaluation was carried out on only two cracks during the first experiment. Non-destructive evaluation was not included in the second experiment.

---

1 During the first experiment, the follow-up inspector did not clean the suspect areas because it was anticipated that the tank would be used in a subsequent experiment. During the second experiment, the follow-up inspector cleaned all suspect areas.

1.2.2 Markers

There was concern in advance of the experiment that the effort would be wasted if the tanks that were inspected turned out to contain few cracks. Therefore, to make sure that at least some usable information would be obtained, it was decided that an additional tank would be outfitted with markers. A marker would be roughly as difficult to see as a crack, but would not necessarily look like a crack. The markers would be placed in locations where cracking could reasonably be anticipated, and in some additional locations as well.

2. Experiment One

2.1 The Ship

Experiment One was carried out on Ship One, a 165,000 DWT oil tanker. At the time of the experiment, Ship One was laid up at dockside in Portland, Oregon. The cargo tanks had been cleaned after the last voyage.

The general arrangement of the tanks and a typical midsection are shown in Figure 2. For the experiment, Cargo Tanks 3P, 3S, and 5P were used. Based on an earlier walk-through of the tanks, the owner anticipated that there would be between 10 and 20 fractures in each of Tanks 3P and 3S. The owner also provided historical information on locations of cracks in Ship 1 and sister ships. This information was used to guide the placement of markers in Tank 5P.

2.2 The Inspectors

Once Ship 1 was identified as the platform for the experiment, and Portland, Oregon, as the location, the United State Coast Guard (USCG) recruited inspectors to participate in the study. The goal was to allow as many inspectors as possible to participate while limiting the length of the experiment to two or three days. Six inspectors — four from the USCG, one from the American Bureau of Shipping (ABS), one from a commercial firm — completed the entire experiment; a seventh (from ABS) inspected only Tanks 3P and 3S. The inspectors varied greatly in their experience; two of the USCG inspectors did not carry out inspections as part of their jobs at the time of the experiment. More information on the inspectors is included in Section 2.5.1.

2.3 The Schedule

Experiment 1 was carried out September 25-28, 1995. On the afternoon of September 25, an owner's representative, UC researchers (Cabrera and Demsetz), and a U.S. Coast Guard representative walked through Tanks 3P, 3S, and 5P to assess overall condition and to label frames and selected longitudinals (see Section 2.4). Markers were placed on September 26. Visual inspections were carried out on September 27; results from all participants were aggregated that evening to develop a baseline for the follow-up inspection, which took place on the morning of September 28.

2.4 Tank Preparation

The first step in preparing the tanks for the experiment was to become familiar with the tank structure and the areas that were historically prone to fracture. In addition, the preliminary locations for markers that had been developed before visiting the ship had to be verified as reasonable given the observed structure and condition of Tank 5P. Tank preparation involved a walk-through of the tanks, labeling of the structure, and selection and placement of markers. Tank preparation was carried out by U.C. researchers and a member of the USCG, with assistance from a representative of the ship's owner. Prior to the experiment, the tanks had been ventilated. The tanks were gas free at the time of the experiment. Blowers were used as necessary through the experiment so that participants were able to carry out inspections without wearing half-mask respirators.

Figure 2. General Arrangement and Typical Midsection, Ship One.

2.4.1 Walk Through

A representative of the ship's owner gave a thorough walk through of Tanks 3P, 3S, and 5P. Locations that had a previous history of fatigue or fracture problems on this or sister ships were pointed out. All three tanks were found to be in relatively dry condition and free of debris.

2.4.2 Labeling

During the walk through, web frame and selected longitudinals were labeled to correspond to the owner's numbering system. This was done for two reasons: first, so that inspectors not familiar with the ship would more easily be able to orient themselves; and second, to reduce errors in recording the location of cracks and markers.

2.4.3 Marker Selection and Placement

In Tank 5P, markers were used to simulate cracks. The intent was that the markers be roughly as easy or hard to detect as cracks, not that they necessarily look like cracks. An additional objective was that a marker, once detected, could be easily identifiable by an inspector as indeed being a marker. Lead pencils, grease pencils of various colors, and brown and black architectural drafting tape in 1/8 and 1/16-inch widths were tried on various locations within Tank 5P. A lead pencil line most closely resembled a crack. However, in locations with waxy buildup, it was difficult to mark with the pencil without significantly disturbing the surface. Furthermore, in some locations it was difficult to determine whether the pencil mark was indeed a pencil mark or was just a shadow. Of the other marker options, the black architect's tape most closely satisfied the detectablility criterion; in many different locations, it was roughly as easy to detect as a crack. Once seen, the black tape was clearly identifiable as a marker; inspectors would not confuse it with any other feature in the tank. Although the black tape did not stick well in a few locations where there was dusty or dried residue, in most locations it adhered well to the tank structure and any residue present. Therefore, black architect's tape was selected as the marker material. Figure 3 shows typical markers.

Preliminary marker locations had been derived from information provided by the ship owner prior to the experiment. At the time of the experiment, these locations had to be verified as realistic fatigue areas and as being suitable for marker placement (that is, free of dusty or dried residue). The first criterion was not completely satisfied. Of the three tanks available, Tank 5 was considered least likely to contain actual cracks. It was therefore selected for use in the marker portion of the experiment. However, because cracking would not be anticipated in Tank 5, there were no truly "realistic" areas in which to place the markers. Markers were placed in locations similar to those historically prone to fracture in tanks located in the forward portion of the ship. In addition, a few markers were placed in locations where fractures would not be expected in the forward tanks. There are referred to as "rogue" markers. All told, 106 markers were placed; of these, 98 remained in place throughout the experiment. These included 81 markers in locations historically prone to fracture in the forward tanks and 17 rogue markers.

Figure 3. Typical Markers, Ship One.

2.5 The Experiment

U.C. Berkeley researchers (Cabrera and Demsetz) and a U.S. Coast Guard representative served as coordinators for first experiment. The weather during the experiment was pleasantly cool, with occasional light rain.

2.5.1 Participants

Six inspectors took part in the complete experiment; a seventh inspected only Tanks 3P and 3S, and is not included here. The inspectors had different levels of experience in tank inspection and were from different organizations. In a previous research project, a questionnaire was developed to record conditions for many of the Inspector and Environment factors shown in Figure 1 [Demsetz et al. 1996]. The questionnaire and responses from each inspector are included in Appendix A. Table 2 summarizes the participating inspectors' experience, as reported on the questionnaire.

	Inspector and affiliation					
	1 USCG	2 USCG	3 USCG	4 USCG	5 CLASS	6 COMM
Hours of inspection in 7 days prior to experiment	<50	50-64	<50	<50	50-64	50-64
Years of inspection experience	5-8	2-4	0-2	5-8	>9	5-8
Prior inspections of Ship 1	0	0	0	0	>3	>3
Prior inspections of sister ship(s)	>5	1-2	0	0	>5	>5
Prior inspection training (years)	1-2	1-2	<0.5	0.5-1	>2	0.5-1
Viewed ship's past inspection reports prior to experiment?	No	Yes	No	No	No	No

USCG = U. S. Coast Guard; CLASS = Classification Society; COMM = Commercial Inspector.

Table 2. Inspectors' Experience, Experiment One.

Various levels of general inspection experience are represented among the inspectors. Although only two of the inspectors had previously inspected Ship 1, two other inspectors had carried out inspections of at least one of the vessel's sister ships. Only one of the six inspectors had reviewed prior inspection reports for the Ship 1.

2.5.2 Tank Inspection

For the initial visual inspections, the inspectors were divided into groups of two. Each group started in a different tank. To minimize interaction between inspectors, inspectors in the same tank started their inspections on opposite ends of the tank. One of the coordinators was present in each tank at all times to observe the participants and as a safety measure. Additional safety precautions included direct radio communication between all the coordinators and the ship's crew. The communication channel was frequently checked to ensure proper radio operation and to maintain contact between all parties.

Inspectors were initially allotted two hours in each tank. However, the large number of markers used in Tank 5P greatly increased the time required in this tank. The coordinator in Tank 5P estimated that it took approximately one minute for an inspector to record a marker or crack. An inspector who found only half of the 98 markers in Tank 5P would still required nearly an hour just to record this information. To allow each participant to finish the inspections for all three tanks, inspectors who started in Tanks 3P and 3S were allowed to enter Tank 5P immediately after completing the initial tank. This meant that at times there were as many as four inspectors in Tank 5P, but the tank was large enough that interaction between inspectors was still minimal.

Inspectors were asked not to scrape, wipe, or otherwise disturb the tank. In most locations in the tanks, waxy build-up and corrosion made it impossible to determine, without disturbing the tank, whether a crack existed. In Tanks 3P and 3S, inspectors were instructed to record both fractures and "suspect areas"; areas that they would have scraped in an actual inspection. In Tank 5P, inspectors were asked to look for actual cracks and markers. However, with few cracks and many markers, the inspectors ultimately focused on markers only.

Climbing along the shell or inboard bulkheads was not permitted, and access was limited to below the third longitudinal as measured from the bottom. The inspectors were asked to use whatever means of recording the information they were comfortable with; most used a pencil and notepad to record their results.

Upon the completion of each tank inspection and prior to continuing to another tank, each inspector was debriefed by a coordinator who recorded location, fracture type and length, and any other pertinent information for each fracture found. When an inspector was done with all three tanks, the questionnaire in Appendix A was completed. Questionnaire responses were used to determine the impact of various factors on detection rate.

2.5.3 Follow-up Inspection

In the evening following the initial inspections, the coordinators combined the results from the individual inspectors to form a master list. To reduce the chances of misinterpreting the inspection reports, the location and description of each fracture and suspect area were included in the same words as reported by the inspectors during the experiment.

On the next day, a follow-up inspection was carried out to verify the reported fractures. One of the participants, a commercial inspector who had prior experience with the test ship, conducted the follow-up visual inspection to verify the fractures as reported in the baseline data set for Tanks 3P and 3S. Because it was anticipated that this ship might be used for the second experiment as well, the follow-up inspector was also instructed not the mark or scrape the tank except for the few instances when NDT techniques were applied. No time limit was set for the follow-up inspection.

Following the experiment, the coordinators went through Tank 5P and verified that the markers were still attached at the locations where they were placed prior to the experiment. Of the 106 samples that were put in place two days earlier, eight could not be found. Thus the baseline for Tank 5P consists of 98 markers.

2.6 Results

Results from the inspections of Ship 1 are included in Appendix B. A qualitative assessment of the experiment is provided here, followed by a quantitative analysis of detection rate and the factors that affect it.

2.6.1 Qualitative Analysis

The instructions for the experiment requested inspectors to record the length and location of suspected fractures or areas of buckling. Most of the reported defects in tanks 3P and 3S were areas of corrosion or washed out welds; however, due to the nature of the instructions, these areas are not included in the analysis. In all, 14 fractures or suspect areas were found in Tank 3P, while 22 fractures or suspect areas were found in 3S. Waxy build-up was present throughout the tanks. Inspectors were prohibited from scraping away the residue during the experiment, and were therefore limited, in many cases, to reporting suspect areas — areas that they would have scraped if permitted to. This was a problem in both the initial visual inspections and in the follow-up inspections as well, and was especially common along the bottom shell. The reporting of suspect areas rather than actual cracks makes it difficult to analyze the results. A more skilled inspector might be better both at finding questionable areas and at discerning that they do not, in fact, indicate a fracture. An inspector who identifies fewer areas as suspect may in fact have a greater detection rate than one who identifies more suspect areas if the additional areas do not turn out to be fractures.

During the follow-up inspection, the inspector was asked to scrape several suspect locations and measure fracture length using a non-destructive technique (magnetic particle) so that visual estimates of crack length could be compared with nondestructive testing results. The inspector was not under a time constraint during the follow-up procedure, but the wax deposits made the verification process quite tedious. In the end, conclusions based on the comparisons between visual and nondestructive techniques could not be made.

In Tank 5P, some inspectors appeared to conduct their examination of the tank's structure with a different strategy than in Tanks 3P and 3S. Rather than focus on locations where fracture would have been expected in another tank, they searched throughout the entire (accessible) structure for markers. The physical appearance of the black architectural tape against the dark wax deposits made detection of the markers difficult in some locations. In some cases, the inspectors seemed to search for the slight reflections of a flashlight beam as it came across a piece a black tape.

2.6.2 Quantitative Analysis

Table 3 shows the overall results for each inspector in each tank. The term "hit rate" is used (rather than "probability of detection") to emphasize the inaccuracy inherent in the reporting of suspect areas. For these tanks, the calculated rate is based on the total number of verified fractures and suspect areas. That is, only identifiable fractures and areas considered to be suspect by the follow-up inspector are included. As noted above, the follow-up inspector was not permitted to scrape most of the suspect areas. Therefore, the denominator used to calculate the hit rate for Tanks 3P and 3S does not necessarily represent the true condition of the tank. In Tank 3S, each of the 22 reported fractures/suspect areas was found by only a single inspector. Due to the small number of data points, the disparity in suspect locations reported by the different inspectors, and the difficulty in defining a suspect area, no further analysis of Tanks 3P and 3S was carried out.

Tank:	5P	3P	3S
Defect type:	marker	suspect area or fracture	suspect area or fracture
Number of defects:	98	14	22
Inspector (affiliation)	Detection Rate	Hit Rate	
1 (USCG)	.53	.21	.05
2 (USCG)	.65	.43	.33
3 (USCG)	.40	.07	.00
4 (USCG)	.32	.07	.05
5 (CLASS)	.27	.21	.50
6 (COMM	.49	.21	.09
Average	.44	.20	.17

USCG = U. S. Coast Guard; CLASS = Classification Society;
COMM = Commercial Inspector.

Table 3. Results by Inspector, Experiment One

The remainder of the analysis of data from Experiment One focuses on the detection of markers in Tank 5P, and on determining the factors that affect detection rate.

One factor that may affect inspection rate is the amount of time available for an inspection (procedural environment factor in Figure 1). Inspectors 2 and 6 measured each marker that they found. It is estimated that this added roughly 10 seconds to the time required to record each marker that these inspectors detected, as compared with the time required by other inspectors. Thus, in evaluating the effect of time in tank, an "adjusted time in tank" is used for inspectors 2 and 6. The adjusted time is the observed time less 10 seconds for each marker found.

Inspector 3, who had no previous tank inspection experience, was observed to carry out a very careful examination of all structural details. This resulted in a 0.40 overall detection rate, even though Inspector 3 did not have time to inspect the entire tank. In the portion of the tank inspected, Inspector 3's detection rate was 0.58. This modified detection rate is used in subsequent analysis.

It is important to keep in mind that, due to the possible differences in inspection strategy and ease of detection, the detection rate for markers may not be indicative of the detection rate for fractures. For Tank 5P, the detection rate shown in Table 3 is the percentage of the 98 markers that were found by a particular inspector. This rate ranges from 0.27 for Inspector 5 to 0.65 for Inspector 2.

2.6.2.1 Vessel Factors

Of the vessel factors shown in Figure 1, only the defect factors vary in this experiment. Defect size, location, and number can be compared with detection rate. Table 4 and Figure 4 shows the detection rate as a function of marker length. The number of markers at each length is also shown. Where there are 17 or more markers at a particular length, the mean detection rate ranges from 0.44 to 0.53.

Length mm	number of markers	Detection Rate						
		Inspector and affiliation						MEAN
		1 USCG	2 USCG	3 USCG	4 USCG	5 CLASS	6 COMM	
12.5	1	1.00	0.00	0.00	0.00	0.00	0.00	0.17
25	5	0.40	0.40	0.60	0.40	0.60	0.20	0.43
50	31	0.52	0.65	0.45	0.35	0.23	0.42	0.44
60	1	0.00	0.00	0.00	1.00	0.00	1.00	0.33
75	37	0.54	0.70	0.38	0.30	0.30	0.49	0.45
100	17	0.65	0.82	0.47	0.35	0.29	0.59	0.53
150	4	0.25	0.00	0.00	0.00	0.00	0.75	0.17
200	2	0.50	1.00	0.00	0.00	0.00	1.00	0.42

USCG = U. S. Coast Guard; CLASS = Classification Society; COMM = Commercial Inspector.

Table 4. Detection Rate and Marker Length, Experiment One.

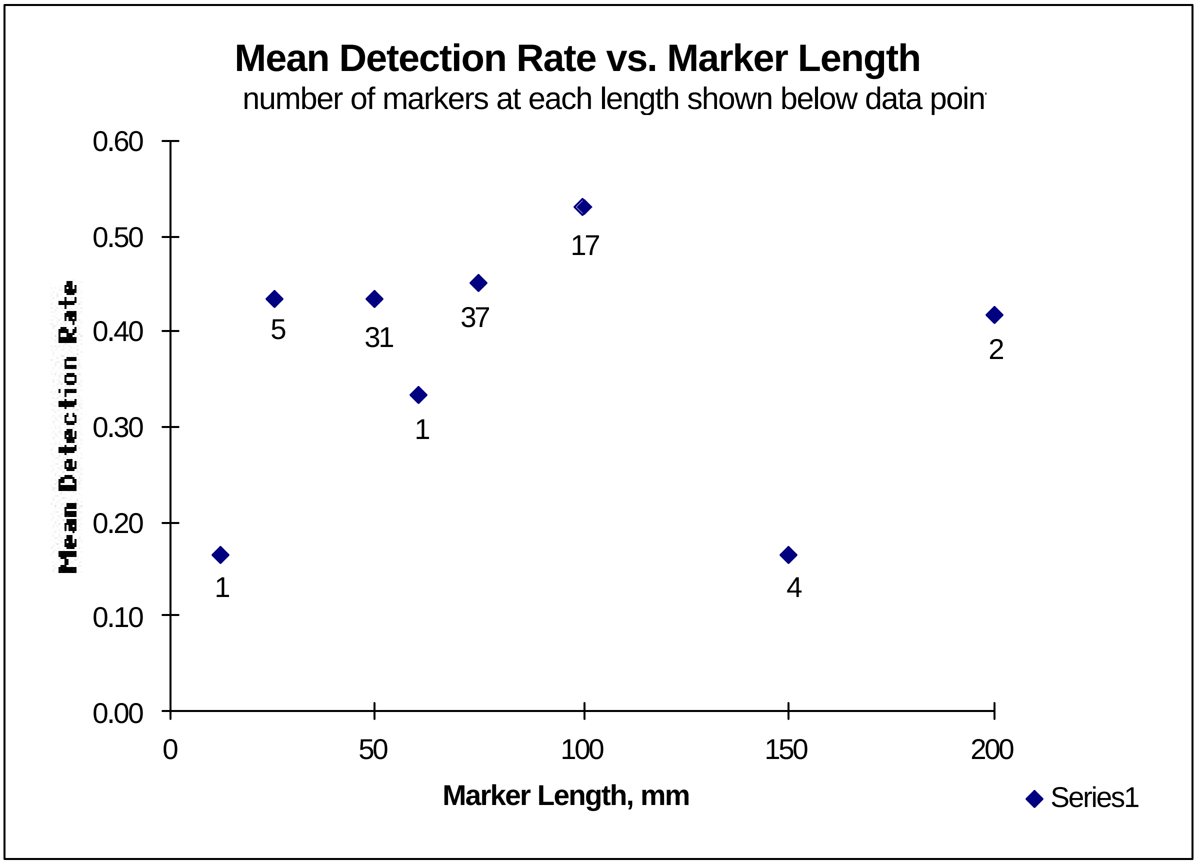

Figure 4. Detection Rate vs. Marker Length, Experiment One

Marker placement was such that the markers could be considered to represent defects in six generic locations, as shown in Table 5. Detection rates for "Butt Weld Seams" and "Stringer Plating" markers were noticeably lower than for other generic types. However, this may be due in part to the smaller number of markers in these categories.

Defect Type	Description	# markers	Detection Rate
1	Longitudinal to Web Connection	44	0.43
2	Web to Bottom Connection	19	0.45
3	Bilge Brackets	9	0.56
4	Butt Weld Seams	5	0.23
5	Stringer Plating	3	0.28
6	Stringer Longitudinal Conn.	18	0.50

Table 5. Detection Rate and Marker Type, Experiment One.

2.6.2.2 Inspector Factors

The inspector factors shown in Figure 1 include factors related to experience (overall experience, experience with the particular vessel, training) and factors related to the inspector's current situation (fatigue and motivation). Questionnaire responses allow an investigation of the effect of the experience factors, and, to a lesser extent, the effect of fatigue. The only information regarding the motivation of the inspectors is through the researchers' casual observations.

Table 6 presents the available measures of experience along with the detection rate for each inspector. None of the factors shown in Table 4 correlates well with modified detection rate, although review of past inspection reports may have contributed to inspector 2's high detection rate.

	Inspector and affiliation					
	1 USCG	2 USCG	3 USCG	4 USCG	5 CLASS	6 COMM
Inspection hours in previous week	<50	50-64	<50	<50	50-64	50-64
Years of inspection experience	5-8	2-4	0-2	5-8	>9	5-8
Prior inspections of Ship 1	0	0	0	0	>3	>3
Sister ship(s) inspections	>5	1-2	0	0	>5	>5
Inspection training (years)	1-2	1-2	<0.5	0.5-1	>2	0.5-1
Past inspection reports reviewed?	No	Yes	No	No	No	No
Detection rate, 5P	0.53	0.65	0.40	0.32	0.27	0.44
Modified detection rate, 5P	0.53	0.65	0.58	0.32	0.27	0.44

USCG = U. S. Coast Guard; CLASS = Classification Society; COMM = Commercial Inspector.

Table 6. Inspector Experience and Detection Rate, Experiment One

The effects of fatigue were investigated by looking at changes in detection rate as an inspector moved through Tank 5P; no evidence of a change in detection rate was found.

Only casual observations of inspectors' motivation can be made. Inspector 4, from the U.S. Coast Guard, had been closely involved in the development of this research project, and appeared to be highly motivated to do a thorough job of inspection. Inspector 3, from the U.S. Coast Guard, also appeared to be highly motivated to do a thorough job of inspection. Neither of the U.S. Coast Guard participants carried out inspection work as a part of their daily routine at the time that the experiment was conducted.

2.6.2.3 Environment Factors

Of the environment factors shown in Figure 1, only inspection strategy and time available varied among inspectors in this experiment. There is no objective information available on inspection strategy. However, Inspector 3, who had no prior tank inspection experience, was observed to work very carefully and methodically through Tank 5P, while the other inspectors initially carried out a broader scan of a particular area, then focused on critical areas. This "scan/focus" strategy appeared to change for at least some inspectors as they made their way through the tank and found markers in non-critical areas. Inspector 6 reported switching to an "Easter egg hunt" strategy; looking at all areas, rather than carrying out a broad scan and then focusing on critical areas.

Table 7 shows the time each inspector took in Tank 5P along with detect rate. Figure 5 shows this same information graphically. The two inspectors who spent the least time in Tank 5P also had the lowest detection rates. However, there is no clear relationship between time in tank and detection rate for the other inspectors.

	Inspector and affiliation					
	1 USCG	2 USCG	3 USCG	4 USCG	5 CLASS	6 COMM
Adjusted time in tank, minutes	150	129	150	120	85	157
Modified detection rate, 5P	0.53	0.65	0.58	0.32	0.27	0.44

USCG = U. S. Coast Guard; CLASS = Classification Society; COMM = Commercial Inspector.

Table 7. Time in Tank, Experiment One.

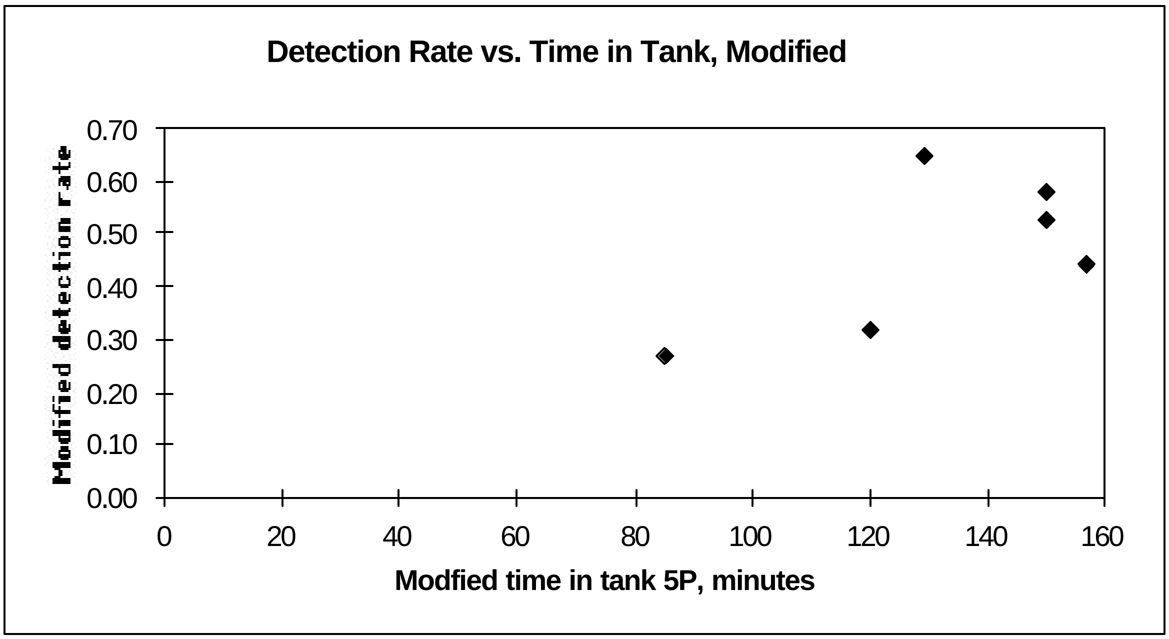

Figure 5. Detection Rate vs. Time in Tank 5P, Experiment One.

2.6.2.4 Factor Combinations

A variety of combinations of factors were investigated to attempt to explain detection rate. The detection rate is most accurately predicted by considering the adjusted time in tank along with whether or not past inspection reports were reviewed prior to the experiment. The only inspector to review past reports was Inspector 2; including this information allows Inspector 2's strong detection rate to be explained. However, the differences in inspection strategy between the marker inspection in Tank 5P and a normal inspection were such that these results should not be generalized to other situations.

2.7 Summary of Results of Experiment One

Several lessons were learned from Experiment One. First, it is always possible that an in situ experiment will indeed yield far fewer defects than anticipated. It therefore makes sense to continue the use of markers. However, the observed changes in inspection strategy in Tank 5P, which contained 98 markers, indicate that a more "realistic" number and placement of markers is required.

The experimental procedure used in Experiment One required inspectors to leave the tank undisturbed. Thus, inspectors could report only "suspect" areas, making it difficult to judge performance.

Finally, it is important to keep in mind that the detection rates observed in this experiment may be significantly different from actual practice due to changes in inspection strategy (among other issues), and should not be used other than to guide the direction of subsequent work.

3. Experiment Two

For Experiment Two, the protocol used in the first experiment was modified in two ways to address the problems observed. To provide at least some information on actual detection rates (as opposed to only the detection rates for suspect areas), the last inspector in a particular tank was allowed to disturb the tank's condition and scrape suspect areas to determine if they were indeed defects. Prior to the experiment, the owner of the ship felt certain that there would be many cracks in the tanks to be inspected. Markers were still used, both to help determine whether detection rates for properly placed markers were similar to detection rates for defects and in case there were fewer cracks than expected (which, in fact, there were). To permit inspectors to maintain their normal inspection strategy, far fewer markers were used and these markers were placed throughout the various tanks to be inspected (rather than concentrated in a single tank).

3.1 The Ship

Experiment Two was carried out on Ship Two, a 32,650 ton deadweight oil tanker. At the time of the experiment, Ship Two was docked in Port Arthur, Texas. While other work was being done in anticipation of the replacement of the ship's forebody, the owner allowed access to the existing forebody for the inspection experiment. The existing forebody was to be scrapped, and the owner anticipated that it would contain many cracks. Figure 6 shows the general arrangement and typical midship section of Ship Two. In the side tanks, bottom longitudinal #20 (the center of the tank) had been built up; in the center tanks, bottom longitudinal #28 had been built up on each side of the center line.

3.2 The Inspectors

Seven inspectors participated in Experiment Two. Four were hired through a separate contract with a commercial inspector. Two inspectors were with the local USCG group. One inspector was provided by ABS. All participants regularly carried out inspections as part of their work at the time of the experiment. More information on the inspectors is included in Section 3.5.1.

3.3 The Schedule

Experiment 2 was carried out July 22-26, 1996. Prior to the dates of the experiment, U.C. Berkeley researchers (Cabrera and Demsetz) had only limited information on the ship. U.C. Berkeley researchers arrived in Houston on the afternoon of July 22, and reviewed inspection history of Ship Two at ABS Houston, and then drove to Port Arthur. On July 23, U.C. researchers walked through Ship Two's tanks, labeled tanks, and placed markers. Visual inspections were carried out on July 24 and the morning of July 25. Results of visual inspections were aggregated in the evening after the inspection so that a complete list was available for follow-up inspections. Follow-up inspections took place on the afternoon of July 25 and the morning of July 26. The weather was hot throughout the experiment, but especially on July 23 and 24.

Figure 6. General Arrangement and Typical Midsection, Ship Two.

3.4 Tank Preparation

Eleven cargo tanks were used in this experiment, as shown in Figure 7. Tank 5S could not be used due to petroleum product at the base of the ladder. Tank preparation involved a walk-through of the tanks by U.C. Berkeley researchers, labeling of the structure in some tanks, and selection and placement of markers. Web frames and selected longitudinals were labeled (with white spray paint) in the first several tanks to provide a consistent reference frame for reporting of inspection results.

1P	1C	1S
2P	2C	2S
4P		4S
5P	5C	
	6C	

Figure 7. Tanks Used in Experiment Two.

The same criteria were used for marker selection as in the first experiment. The intent was that the markers be roughly as easy or hard to detect as cracks, not that they necessarily look like cracks. An additional objective was that a marker, once detected, could be easily identified by an inspector as indeed being a marker. The tanks used in this experiment were coated; brown electrical tape approximately 1/8 inch wide proved to be the marker material that best met the selection criteria. Markers were placed on an ad hoc basis in realistic locations (that is, locations where cracking might have been anticipated) in seven of the 11 tanks. Only two to four markers were placed in each tank to avoid the change in inspection strategy that was observed in Experiment 1. Marker lengths ranged from 25 mm to 150 mm. A total of 24 markers were placed; two of them were not present during the follow-up inspection. The remaining 22 markers are used in analyzing the results of Experiment Two. Table 8 shows the number of markers in each tank; Table 9 shows the number of markers of each length.

Tank	1P	1C	1S	2P	2C	2S	4P	4S	5P	5C	6C
Number of Markers	3	4	2	4	4	3	0	2	0	0	0

Table 8. Number of Markers by Tank, Experiment Two.

Length, mm	50	75	100	125	150
Number of markers	7	4	2	5	2

Table 9. Number of Markers by Length, Experiment Two.

3.5 The Experiment

U.C. Berkeley researchers served as coordinators for the experiment. The shipyard provided a place to change and to eat lunch, but left the researchers and inspectors alone to carry out the experiment independently. As noted above, the weather during the experiment was hot and humid.

3.5.1 Participants

The seven inspectors who took part in this project were all actively involved in inspection work at the time the experiment was conducted. Their backgrounds and experience, as reported on the post-inspection questionnaire, are summarized in Table 10; questionnaire responses are included in Appendix A. The inspectors in this experiment had considerably more experience with ships of the same class as the one being inspected than was the case for the inspectors in the first experiment. Three of the inspectors reported having carried out more than 65 hours of inspection work in the previous week; two of these reported carrying out more than 80 hours during this period.

	Inspector and affiliation						
	A	B	C	D	E	F	G
	CLASS	USCG	COMM	COMM	USCG	COMM	COMM
Inspection hours in previous week	65-80	<50	<50	<50	<50	>80	>80
Years of inspection experience	5-8	<2	5-8	5-8	5-8	>9	5-8
Prior inspections of Ship 2	1	0	0	0	0		>3
Sister ship(s) inspections	>5	1 or 2	>5	3 or 4	1 or 2	>5	>5
Inspection training (years)	1/2 - 1	< 1/2	>2	1/2 -1	>2	>2	>2
Past inspection reports reviewed?	no	yes	no	no	no	no	no

USCG = U. S. Coast Guard; CLASS = Classification Society; COMM = Commercial Inspector.

Table 10. Inspector's Experience, Experiment Two

3.5.2 Tank Inspection

For each tank, six of the seven inspectors carried out a visual inspection without disturbing the tank's condition. Thus, these inspectors were able to report visible defects, markers, and suspect areas (areas that they would have scraped under normal circumstances). The seventh inspector (the last one in the tank) carried out a visual inspection including scraping; the seventh inspector was thus able to determine whether a suspect area did indeed contain a defect. The seventh inspector, therefore, reported defects (visible and scraped) and markers.

A tank inspection schedule was developed to rotate inspectors through groups of tanks so that each inspector would be the "scraper" (that is, the seventh inspector) for one or two tanks, with appropriate rest periods. Two inspectors were allowed in the wing tanks simultaneously; in the center tanks, two, three, or four inspectors worked simultaneously.

Inspectors were shown a sample marker upon entering the first tank, and were instructed to carry out the inspection as they normally would, but to record visible defects, suspect areas, and markers. The seventh inspector was instructed to carry out a standard inspection (including the cleaning of any suspect areas) and to record defects and markers.

During rest breaks, each inspector was debriefed by one of the researchers, who recorded location, type (visible defect, suspect area, marker), and length (if visible defect or marker) for each area reported.

Several of the commercial inspectors climbed throughout the tank and thus recorded defects and suspect areas that were not accessible to the other inspectors.

3.5.3 Follow-up Inspection

In the evening following the initial inspections, the coordinators combined the results from the individual inspectors to form a master list. To reduce the chances of misinterpreting the inspection reports, the location and description of each fracture and suspect area were included in the same words as reported by the inspectors during the experiment.

Follow-up inspections were carried out by two of the commercial inspectors, those with the most tank inspection experience, after the initial inspections were completed. One U.C. researcher accompanied each inspector and read out the list of visible defects, suspect areas, and markers from the baseline data set (the combination of all items recorded by all inspectors). For visible defects and markers, the follow-up inspector confirmed that the recorded defect or marker was indeed present. For suspect areas, the follow-up inspector gave his opinion as to whether or not the area was indeed suspect, and then scraped the area to determine if a fracture was present.

3.6 Results

Results for all inspectors are available for ten of the eleven tanks inspected. No results are available for Inspectors B and C in Tank 2C. Inspector B was the designated scraper for Tank 2C. However, rather than record defects and markers on a paper, Inspector B marked the areas in the tank. Time did not permit a review of the tank to compile a written record of the defects and markers found. Inspector C did not inspect Tank 2C. Therefore, detection rates for defects, suspect areas, and markers found in Tank 2C are calculated using five as the total number of inspectors (rather than seven for the other tanks).

Eight fractures were found in accessible areas (two in Tank 2C; one in Tank 5S; five in Tank 6C). Detection rates for these fractures ranged from 0.14 (found by one of seven inspectors) to 0.86 (found by all seven inspectors). Four additional fractures were found by at least one commercial inspector in areas that were inaccessible without climbing. However, it is not known how many of the commercial inspectors climbed in each tank, so detection rates cannot be reported for these cracks.

Of the 24 markers initially placed, the positions of 22 could be verified at the end of the experiment. For these 22 markers, detection rates ranged from 0.00 (four of the markers were not found by any of the seven inspectors) to 0.86 (two of the markers were found by six of seven inspectors).

Buckling was reported at 21 locations. The instructions did not specifically ask inspectors to report buckling, and most of the buckling was reported by only one inspector. Therefore, buckling is not considered in the analysis of results.

During the follow-up inspections, 95 of the reported locations were considered to be suspect by the follow-up inspector after they were pointed out. However, 68% of these locations were reported by only one inspector (that is, the other inspectors did not think that the area was suspect during the initial inspection).

Complete results from the inspections of Ship Two are included in Appendix C. A qualitative assessment of the experiment is provided next, followed by a quantitative analysis of detection rate and the factors that affect it.

As has been stated often in the literature, the size of tankers (and other structures) is such that an inspector does not thoroughly inspect the entire structure. Instead, the inspector scans the structure as a whole and then more carefully inspects critical areas — areas in which problems are anticipated. It would therefore be reasonable to expect that detection rates would be higher for defects in critical areas. Two members of the Project Technical Committee for this project reviewed the list of fractures, markers, and suspect areas to identify those that could be considered critical. This information is used in the quantitative analysis section below.

3.6.1 Qualitative Analysis

All the inspectors seemed highly motivated to do a thorough job of inspection during the experiment. However, there were obvious differences in the physical condition and agility of the inspectors. Inspector A reported that he had a history of back problems, but these did not seem to affect his mobility in the tank. Inspector B had a much harder time negotiating the tanks than the other inspectors. Inspector E had sustained a cut on one leg the evening before the second day of inspection. The cut reopened part way through the second day of inspections; Inspector E completed the experiment nonetheless.
The presence of markers did not appear to cause the inspectors to modify their inspection strategy.

3.6.2 Quantitative Analysis

3.6.2.1 Vessel Factors

Of the vessel factors shown in Figure 1, only the defect factors vary in this experiment. There are, in effect, three kinds of "defects" reported: visible fractures, markers, and suspect areas. For visible fractures and markers, the effect on detection rate of size and type (critical or non-critical) can be examined. For suspect areas, only the effect of type can be examined.

Of the eight visible fractures, six were considered to be critical by at least one reviewer. Only these six fractures are included in the quantitative analysis. Detection rates for these fractures ranged from 0.20 (one of five inspectors) to 0.86 (six of seven inspectors). Figure 8 shows detection rate vs. length for the six fractures considered critical. In general, there is an increase in detection rate with length. This is clear when the mean detection rate for the four inch fractures is considered. The overall detection rate for these fractures (that is, the average of the detection rate for each individual fractures) was 0.60. The average detection rate for the two non-critical fractures was 0.29.

The locations of all 22 markers were considered to be critical by at least one reviewer. As noted above, marker detection rates ranged from 0.00 to 0.86. Figure 9 shows detection rate vs. length for the markers. In general, there is an increase in detection rate with length. This is more clearly shown in Figure 10, where the mean detection rate for each marker length is plotted. However, a linear regression on the marker data shows only a slight correlation (R^2 = 0.094), due to the broad range of observed detection rates within each marker length. Figure 11 shows mean marker and critical fracture detection rates; for this experiment, markers appear to yield detection rates that are comparable to or slightly lower than those of critical fractures. Table 11 shows fracture and marker detection rates by length for each inspector.

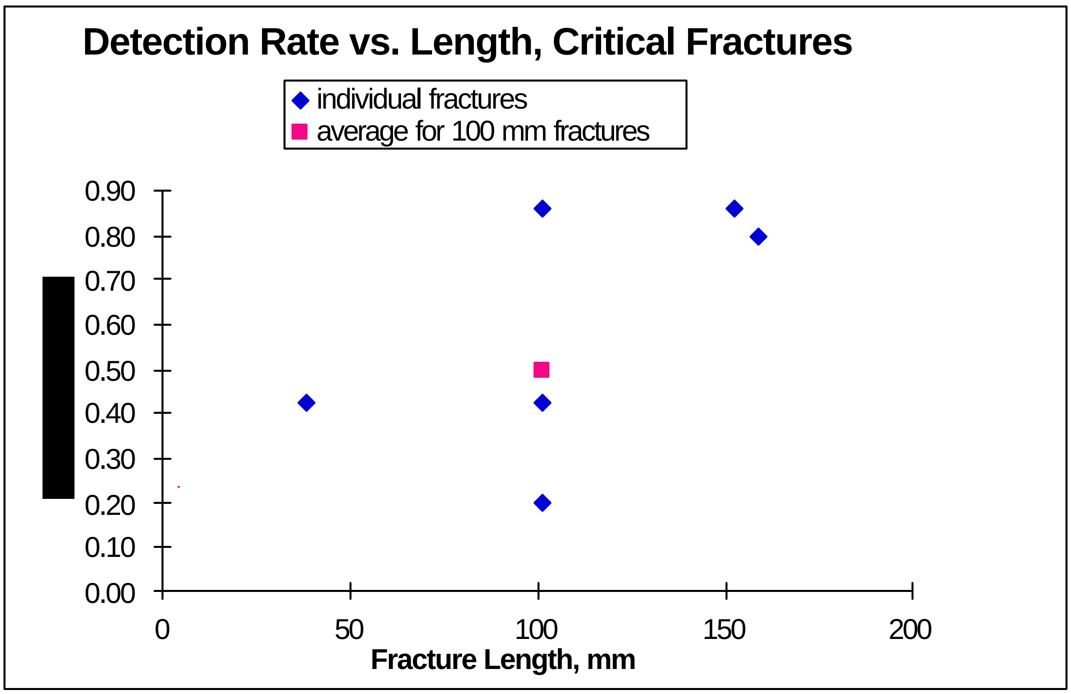

Figure 8. Detection Rate vs. Fracture Length, Experiment Two.

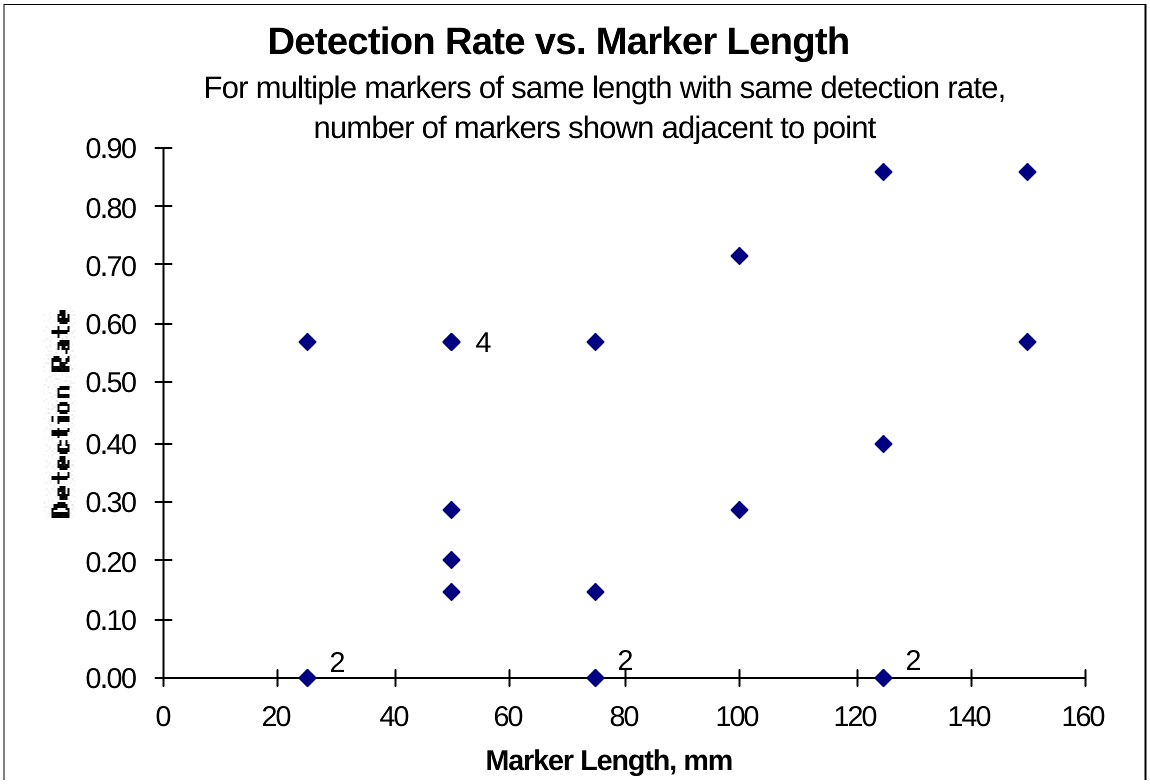

Figure 9. Detection Rate vs. Marker Length, Experiment Two

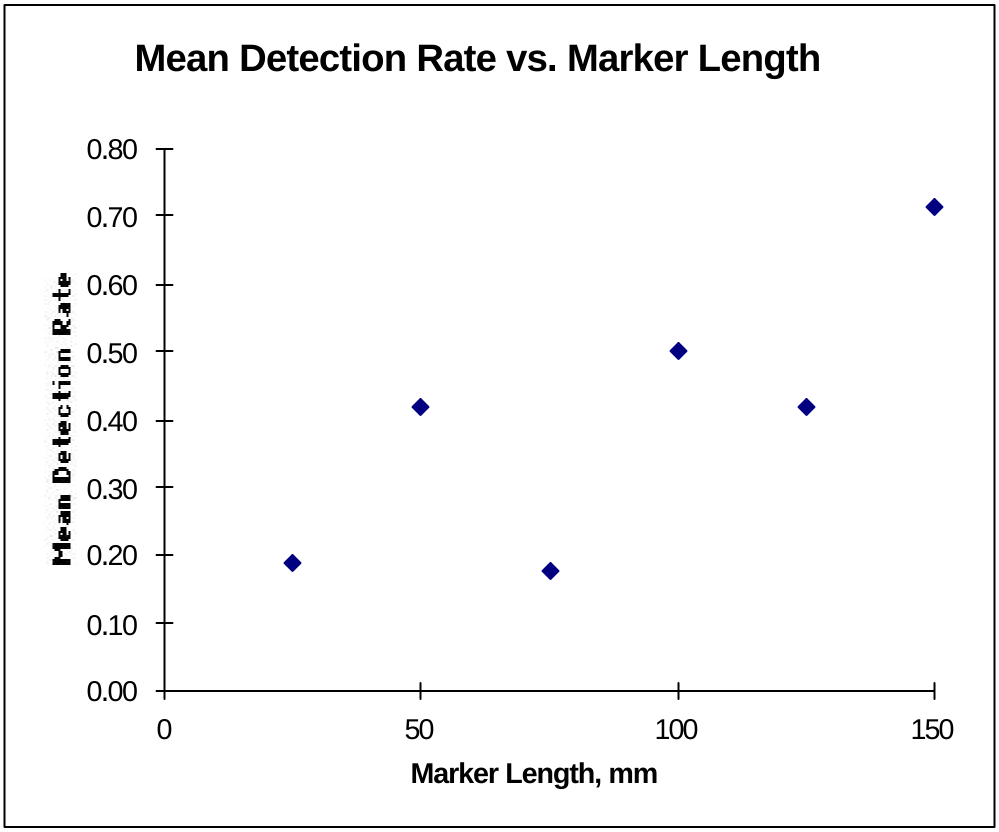

Figure 10: Mean Detection Rates vs. Marker Length, Experiment Two

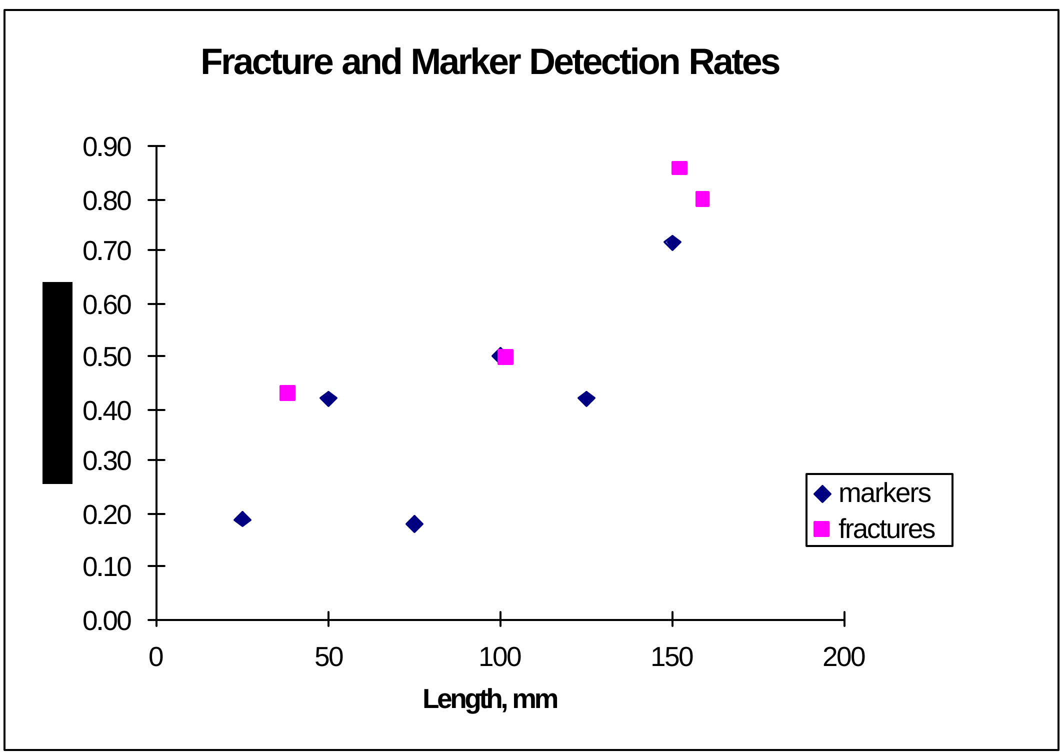

Figure 11. Detection Rates for Fractures and Markers, Experiment Two.

		Inspector and affiliation						
		A CLASS	B USCG	C COMM	D COMM	E USCG	F COMM	G COMM
Fractures		Fracture Detection Rate						
Length, mm	number	x = did not inspect; see note below						
40	1	0	0	0	1	0	1	1
100	3	.33	0.5	0.5	0.67	0.33	0.67	0.67
150	1	1	1	1	1	0	1	1
160	1	1	x	x	1	0	1	1
Mean detection rate:		0.5	0.5	0.5	0.83	0.17	0.83	0.83
Markers								
Length, mm	number	Marker Detection Rate						
25	3	0	0	0.33	0.33	0	0.33	0.33
50	7	0	0.14	0.71	0.71	0.14	0.57	0.57
75	4	0	0.25	0.25	0.25	0.25	0	0.25
100	2	0	0.50	0.50	1	0	0.50	1
125	4	0.25	0.25	0.25	0.25	0.5	0.25	0.25
150	2	0.50	0.50	1	1	0	1	1
Mean detection rate:		0.09	0.23	0.50	0.55	0.18	0.41	0.50

USCG = U. S. Coast Guard; CLASS = Classification Society; COMM = Commercial Inspector.

note: Tank 2C contained two factures (100 mm, 150 mm). Inspectors B and C did not inspect Tank 2C. Detection rates at 100 mm for these inspectors are based on two fractures only.

Table 11. Fracture and Marker Detection Rates, Experiment Two.

Of the 95 suspect locations, 18 were not considered to be critical by reviewers. The mean detection rate for these 18 areas was 0.20. For the remaining 77 areas, which were considered critical by at least one reviewer, the mean detection rate was 0.24. The mean detection rate for the 23 suspect areas that were considered critical by both reviewers was 0.30. For this experiment, the detection rate appears to be greater for fractures and suspect areas that are considered critical than for those that are not viewed as critical.

3.6.2.2 Inspector Factors

The inspector factors shown in Figure 1 include factors related to experience (overall experience, experience with the particular vessel, training) and factors related to the inspector's current situation (fatigue and motivation). The purpose of an inpsection Questionnaire responses allow an investigation of the effect of the experience factors. The only information regarding the motivation of the inspectors is through the researchers' observations, summarized in Section 3.6.1.

Table 12 presents the available measures of experience along with the detection rate for each inspector. There are no clear relationships between the experience measures and detection rate. However, the inspectors with noticeable physical difficulty (B) or injury (A, E) had lower detection rates than the other inspectors. The most evident relationship is between the inspector's organization and detection rate: the commercial inspectors (C, D, F, G) had high detection rates; the USCG inspectors (B, E) had low detection rates. These inspectors also had less experience with sister ships than did the other inspectors. Inspector A had a very low marker detection rate.

	Inspector and affiliation						
	A CLASS	B USCG	C COMM	D COMM	E USCG	F COMM	G COMM
Inspection hours in previous week	65-80	<50	<50	<50	<50	>80	>80

Years of inspection experience	5-8	<2	5-8	5-8	5-8	>9	5-8
Prior inspections of Ship 2	1	0	0	0	0		>3
Sister ship(s) inspections	>5	1 or 2	>5	3 or 4	1 or 2	>5	>5
Inspection training (years)	1/2 to 1	< 1/2	>2	1/2 to 1	>2	>2	>2
Past inspection reports reviewed?	no	yes	no	no	no	no	no
Average time in tank, minutes	39	49	43	37	41	33	37
Critical Fracture Detection Rate	0.50	0.50	0.50	0.83	0.17	0.83	0.83
Marker Detection Rate	0.09	0.23	0.50	0.55	0.18	0.41	0.50
Suspect Area Detection Rate	0.21	0.43	0.10	0.32	0.22	0.12	0.27

USCG = U. S. Coast Guard; CLASS = Classification Society; COMM = Commercial Inspector.

Table 12. Inspector Experience and Detection Rates, Experiment Two.

3.6.2.3 Environment Factors

Of the environment factors shown in Figure 1, only inspection strategy, time available, and inspection type & objective varied among inspectors in this experiment. No difference in strategy was observed among the seven inspectors. There is a slight inverse relationship between time in tank and detection rate; those inspectors who spent, on average, less time in the tank had higher detection rates.

The inspectors who participated in this experiment came from three different types of organizations: a regulatory agency (USCG), a classification society, and commercial inspection firm. These organizations typically carry out different types of inspections with different objectives. For example, the primary role of regulatory agency and classification society inspectors is to verify problem areas identified by the owner/operator's inspection. Thus, it is reasonable to expect that detection rates might differ for inspectors from different organziations. Table 12 shows that the marker detection rates of commercial inspectors are noticably better than those of the other inspectors. The fracture detection rates for commercial inspectors are also better than those of other inspectors, though the difference is not as significant as for markers. The suspect area detection rates for commercial inspectors are not noticably different from those of other inspectors.

Because the last inspector in the tank was allowed to scrape the tank, the set up for this experiment would have allowed pure comparison of the scraper's performance had more fractures been found upon scraping. However, with most of the fractures visible without scraping, these is insufficient information to compare the performance of the "scraper" with that of the follow-up inspector.

3.7 Summary of Results of Experiment Two

Experiment Two demonstrated yet again that it is possible that an in situ experiment will indeed yield far fewer defects than anticipated, making markers a necessity if meaningful quantities of data are to be collected. The use of markers in Experiment Two was much more successful than was the case in Experiment One. The limited number of markers used in each tank did not divert the inspectors from their usual inspection strategy. Markers in critical locations were detected at roughly the same rates as critical cracks of the same length.

The fact that few fractures were found meant that, once again, the bulk of the data gathered was for suspect areas. Still, enough marker and fracture data were acquired to draw some tentative conclusions. As expected, average detection rates increase with crack/marker length. Lower detection rates were observed for inspectors with physical difficulties, with less sister ship experience, and who work for the USCG or ABS. It should be noted that the usual role of USCG or ABS inspectors is to verify the existence of problem areas and severity of fractures, but not necessarily to detect all fractures.

Commercial inspectors are typically the "front line" in inspection, hired by owners and operators to identify problem areas and critical fracture characteristics and number. For many purposes, commercial inpsectors' performance is the most relevant measure of probability of detection. The fracture and marker detection rates of commercial inspectors are shown in Figure 12. For the limited data generated by this experiment, the two fractures and two markers with length of approximately 150 mm were detected by all four commercial inspectors. For shorter fractures and markers, detection rates were lower. Average detection rates for markers ranged from 0.19 (for four markers of 75 mm in length) to 0.75 (for two markers of 100 mm in length). The lowest observed fracture detection rate was 0.61 (for three fractures of 100 mm in length).

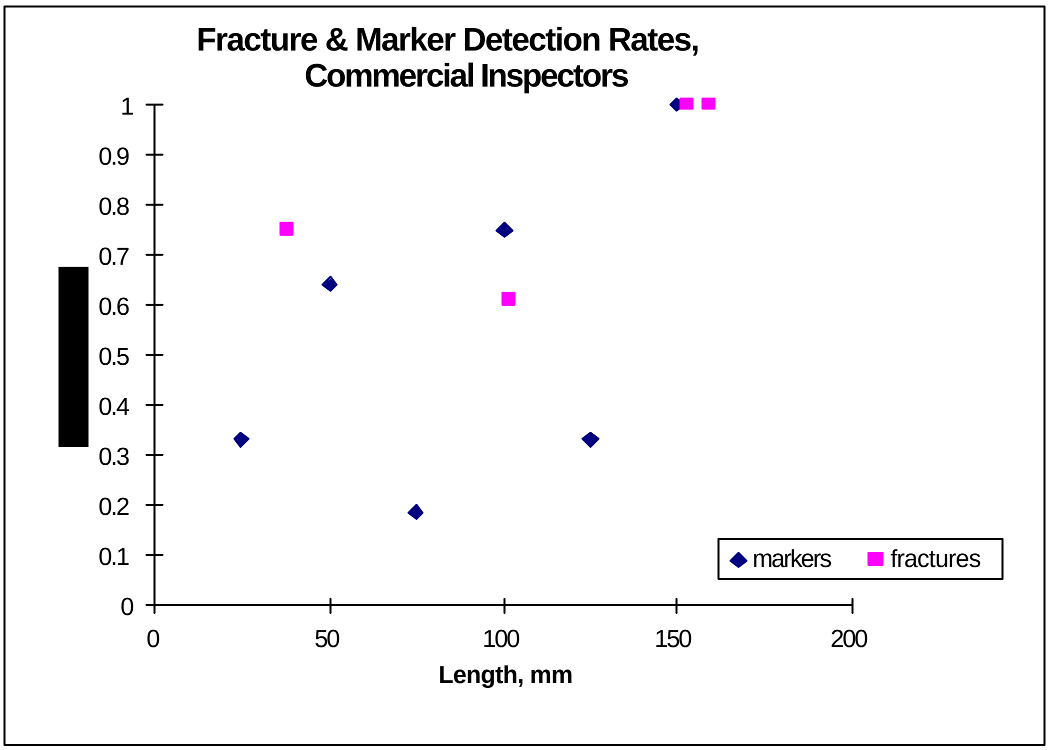

Figure 12. Fracture & Marker Detection Rates, Commercial Inspectors, Exp't. Two.

4. Summary and Conclusions

4.1 Summary

Two in situ inspection experiments were carried out as a part of this study. In each experiment, a number of experienced inspectors carried out visual inspections of an existing ship (each ship was out of service — for some other reason — at the time of the experiment). These in situ inspections provide a simulation of inspections done underway. The results of these inspections were aggregated into master lists of visible fractures, markers, and suspect areas. A follow-up inspection was carried out, guided by this list, to determine the true condition of the tank. Subsequent analysis of results was directed at determining whether marker detection rates are comparable to fracture detection rates, deducing which factors have a demonstrable impact on probability of detection, and observing levels and variability of probability of detection.

Due to the small number of fractures found in the first experiment and to the non-standard inspection strategy resulting from the large number of markers, the results of the first experiment provide little useful information (beyond ideas for improving the experimental protocol). The second experiment, however, yielded results that, while not statistically significant, do shed some light on the usefulness of in situ testing as a means of determining probability of detection, on the factors affecting probability of detection, and on probability of detection itself.

4.2 Conclusions Regarding Experimental Method

The initial concern that not enough fractures would be found to make an in situ experiment worthwhile was well founded. The owners of each of the ships used in this experiment were confident that many fractures would be found. In both cases, they were proven wrong. However, the mix of a few cracks and a few markers that was used in Experiment Two allowed extra information to be obtained without dramatically changing the inspection strategy used. The detection rate for markers was comparable to the detection rate for critical fractures. Therefore, in situ experiments should not be ruled out as a means of obtaining POD information. However, appropriate markers should be used for in situ experiments on structures whose condition is not already known.

In a tank with more fractures, assigning the last inspector as the "scraper" (as was done in Experiment 2) would allow additional information to be gleaned from the results.

Even with donated ship time, these in situ experiments are costly. The costs must be weight against the benefits of the information obtained.

4.3 Conclusions Regarding Factor Evaluation

Although statistically significant conclusions could not be drawn from the data generated by the in situ experiments, certain factors appear to be somewhat related to detection rate. Due to the unusual inspection strategy used in Experiment One, this discussion is based on the results of Experiment Two. As expected, detection rate appears to increase with increased defect or marker length. However, the scatter of detection rates at any given length is such that this relationship is not strong in a statistical sense.

Lower detection rates were observed for inspectors with physical difficulties, with less sister ship experience, and who work for the USCG or ABS (these inspectors normally verify only problem areas and severity of fractures). Higher detection rates wre observed for commercial inspectors, who are normally hired to indentify problem areas and the characteristics and number of fractures.

Higher detection rates were observed for defects and suspect areas that were considered by reviewers to be critical. This supports the notion than an experienced inspector pays attention to trouble spots. Higher detection rates were observed for commercial inpsectors than for other inspectors.

To make definitive statements about the effect of factors on detection rate, additional experiments would have to be conducted so that information is available for a greater number of fractures and markers.

4.4 Conclusions Regarding POD for Underway Inspection

It would be a mistake to draw far-reaching conclusions about POD for underway inspection from the limited information presented here. However, for the six fractures found in experiment two, detection rates for commercial inspectors averaged 0.75 (one at 0.50, three at 0.83). For the two fractures and two markers that were 150 mm or longer, detection rates for commercial inspectors were 1.00; every commercial inspector found each fracture or marker.

4.5 Recommendations for Further Work

Based on the results of Experiment Two, in situ experiments do have the potential to increase our knowledge of POD in tanker inspection. However, these experiments are expensive to carry out. It would be worthwhile to carry out additional experiments only if the results would lead to changes in design or maintenance practices. Prior to carrying out any additional experiments, current design and maintenance practices should be reviewed to see whether they would be changed if additional information on POD were to be developed.

5. References

Ayyub, B.M. and White, G.J. (1992). *A Plan for the Evaluation of Alternative Vessel-Tank Visual Inspection Practices*, Report to the Marine Engineering Branch, U.S. Coast Guard Research and Development Center, August.

Berens, A.P. (1989). NDE Reliability Data Analysis, in *Metals Handbook Ninth Edition Volume 17 - Nondestructive Evaluation and Quality Control*, ASM International.

Demsetz, L.A., Cario, R., and Schulte-Strathaus, R. (1996a). *Inspection of Marine Structures*, Final Report to the Maritime Administration under Project DTMA91-93-G-00040, 1996, published as SSC-389.

Demsetz, L.A., Robert Cario, Rong T. Huang, Rolf Schulte-Strathaus (1996b). Factors Affecting Marine Structural Inspection Performance, to be presented at the SSC/SNAME Symposium on Human and Organizational Error in Marine Structures, November 18-20, Arlington, VA.

Dinkeloo, C.J. and Moran, M.S. (1978). *Structural Area Inspection Frequency Evaluation (SAIFE)*, U.S. Department of Transportation, Federal Aviation Administration, Report No. FAA-RD-78-29.

Rudlin, J.R. and Wolstenholme, L.C. (1992). Development of Statistical Probability of Detection Models using Actual Trial Inspection Data, *The British Journal of Non-Destructive Testing*, Vol. 34, No. 12.

Rummel, W.D., Hardy, G.L., and Cooper, T.D. (1989). Applications of NDE Reliability to Systems, in *Metals Handbook Ninth Edition Volume 17 - Nondestructive Evaluation and Quality Control*, ASM International.