NUREG/CR-3687
ORNL/TM-9107

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Loose-Part Monitoring Programs and Recent Operational Experience in Selected U.S. and Western European Commercial Nuclear Power Stations

R. C. Kryter

Prepared for the
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Under Interagency Agreement DOE 40-551-75

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161

Available from
GPO Sales Program
Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

NUREG/CR-3687
ORNL/TM-9107
Dist. Category R1

Instrumentation and Controls Division

LOOSE-PART MONITORING PROGRAMS AND RECENT OPERATIONAL EXPERIENCE IN SELECTED U.S. AND WESTERN EUROPEAN COMMERCIAL NUCLEAR POWER STATIONS

R. C. Kryter

Manuscript Completed: January 1984
Date Published: April 1984

Prepared for the
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Division of Facility Operations
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NRC FIN No. B0191

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
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U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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GLOSSARY OF TERMS AND ACRONYMS

ACRS	Advisory Committee on Reactor Safeguards
A-E	Architect-engineer
ANS	American Nuclear Society
ASME	American Society of Mechanical Engineers
B&W	The Babcock and Wilcox Company
BWR	Boiling-water reactor
C-E	Combustion Engineering
DIN	Deutsches Institut für Normung
EdF	Electricité de France
EPRI	Electric Power Research Institute
FM	Frequency modulated
FR	France
FRG	Federal Republic of Germany
FSAR	Final Safety Analysis Report
FW	Feedwater
"g"	Acceleration due to Earth's gravity (32.2 ft/s^2 or 9.81 m/s^2)
GE	General Electric Company
I&C	Instrumentation and Control
INPO	Institute for Nuclear Power Operations
KWU	Kraftwerk Union
LER	Licensee Event Report
LP	Loose part
LPM	Loose-part monitoring
LPMS	Loose-part monitoring system
MW(e)	Megawatts (electric)

GLOSSARY OF TERMS AND ACRONYMS (Continued)

NRC	U.S. Nuclear Regulatory Commission
NSSS	Nuclear steam supply system
OTSG	Once-through steam generator
PWR	Pressurized-water reactor
RCP	Reactor coolant pump
RCS	Reactor coolant system
RG	Regulatory Guide
rms	Root mean square
RV	Reactor vessel
SG	Steam generator
SGTR	Steam generator tube rupture
STA	Shift Technical Advisor
TMI-2	Three Mile Island, Unit 2
VMS	Vibration monitoring system
W	Westinghouse Electric Corporation

ABSTRACT

Technical personnel at thirteen nuclear power stations (ten in the U.S. and three in Western Europe) were interviewed during the summer of 1983 to ascertain their collective experience with acoustic-based loose-part monitoring systems (LPMSs). Subjects receiving special attention were the number and location of sensors (accelerometers) required to reliably detect and locate loose parts in both pressurized- and boiling-water reactors; detection sensitivity to loose objects in both primary and secondary coolant loops; false alarm experience; calibration procedures; day-to-day monitoring system operation; premature failure of in-containment components of the LPMS caused by hostile environments; and overall success to date in detecting the presence of potentially damaging loose parts and in assessing their operational and safety implications. The individual utilities' responses to questions addressing these and other issues are provided, along with the author's summary and interpretation of what the information gathered means in a collective sense, that is, a viewpoint of the present state of application of loose-part monitoring technology in this selected set of commercial nuclear plants.

It is concluded that the technology of loose-part detection and assessment is moving slowly toward increased acceptance by the utility industry but, at the same time, the full potential benefits of loose-part monitoring systems are not presently being realized and, furthermore, probably will not be unless actions are taken in four recommended areas.

1. INTRODUCTION

During the summer of 1983, two related surveys directed toward ascertaining technical capabilities and industry practices in the area commonly referred to as loose-part monitoring (LPM) were conducted for the U.S. Nuclear Regulatory Commission (NRC), thus updating a similar survey* performed by Oak Ridge National Laboratory for the NRC about six years earlier. One survey was directed toward the suppliers of loose-part monitoring systems (LPMSs) and was sponsored by the NRC Office of Nuclear Reactor Regulation's Core Performance Branch; the other survey was directed toward the users of LPMSs (i.e., the utilities who operate the reactors on which the monitoring systems are installed) and was sponsored by the NRC Office of Nuclear Regulatory Research's Instrumentation and Control Branch. This document, however, deals only with the user-oriented survey, since the results from the survey of monitoring system suppliers are being reported elsewhere.

The information sought from the utility users of these monitoring systems falls into three broad categories: current capabilities and operational practices, experiences with actual (or suspected) loose-part occurrences, and perceived need for improvements to equipment and/or monitoring programs. Further expansion of these categories yielded ten more specific topics (Table 1) which provided a foundation for the survey questions and the ensuing discussions.

The overall objective of the survey was to gather sufficient information from a variety of sources to permit the construction of a "broad-brush" picture of how matters presently stand in regard to utilities' implementation of loose-part monitoring programs. However, a survey that would include a majority of the commercial power stations worldwide in which LPMSs are in use was clearly an overly ambitious undertaking, so means were sought for reducing the scope of the survey without unduly biasing its findings. After some debate it was decided to limit the survey of foreign experience to Western European countries (thus ignoring potentially important contributions from British, Canadian, Swedish, Russian, and Japanese experience, in particular) and to limit the survey of U.S. experience to a small number of reactors having representative construction and operating history. With the further decision to concentrate attention in Western Europe on LPM technology developed through ongoing research programs rather than procured from commercial sources, our foreign survey choices were narrowed to France and The Federal Republic of Germany (FRG), from which we selected a total of three plants for interview. In the case of domestic plants, we made an initial selection on the basis of known experiences with loose parts (obtained, in large part, from Licensee Event Reports--LERs), with consideration also given to maintaining a balance among such additional considerations as plant age, size, and nuclear steam supply system (NSSS) manufacturer,

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*R. C. Kryter and C. W. Ricker, "Characteristics and Performance Experience of Loose-Part Monitoring Systems in U.S. Commercial Power Reactors," NUREG/CR-0524 (ORNL/TM-254), March 1979.

Table 1. Topics on which information was sought

- Achievable LPMS sensitivity; system calibration procedures
- Applicability of loose-part detection and assessment technology to BWRs
- Ability to detect secondary-side loose parts in PWRs
- Experience with false/unexplainable LPMS alarms
- Alarm logic details; procedure for choosing alarm setpoints and modifying them during plant operation
- Workability/usefulness of NRC Regulatory Guide 1.133:
  - Impact of the Guide on current operational procedures.
  - Technical correctness of the Guide; areas where additional guidance is needed.
  - Unreasonable requirements or restrictions?
- Experience with radiation and/or temperature damage of in-containment LPMS components (sensors, preamplifiers, cables, connectors)
- Experience with detecting loose parts and assessing their operational and safety implications
- Comparison of LPMS technology employed in the U.S. with that used in Western Europe
- Needed improvements; foreseeable trends

boiling-water and pressurized-water reactor (BWR and PWR) types, and positive versus negative experiences with loose-part indications.* The end result of this selection process was a decision to interview ten U.S. plants in addition to the three foreign ones, for a total of thirteen. Further information on these plants is provided in the following section.

*Since, in the U.S., so few BWRs are equipped with LPMSs, the choices were few and the requirement for actual plant experience with loose parts was dismissed for this reactor type.

2. DATA GATHERING

Information relating to the topics listed in Table 1 was obtained from on-site interviews with technical personnel who are closely associated with the day-to-day use of loose-part monitoring equipment.

In the case of the U.S. commercial plants, the interviewees typically comprised one or more persons stationed at the plant, plus a staff engineer from the utility's home office; a representative from the utility's licensing branch and/or the NRC resident inspector was also present on occasion. The interviews were structured around a list of discussion questions (Table 2), addressing the information needs of Table 1, that had been submitted to the interviewees in advance but for which no written responses had been requested. After going through the questions, which usually required about three hours, the accessible portion of the LPMS was examined, its general features were demonstrated, and all channels were monitored aurally. This "hands on" portion of the visit served to verify and elucidate some of the points brought out in the preceding discussions and, in a few cases, it revealed discrepancies between operational practices that had been claimed to be in effect versus what was actually being done.

In the case of the Western European commercial plants, the interviewees typically comprised a member of the R&D team responsible for the development, initial calibration, and periodic use of the LPMS; an engineer stationed at the plant; and a department-head-level representative of the operating utility. Owing to the unofficial nature of the arrangements, the interviews at the foreign plants were much less structured than those conducted in the domestic plants, and they employed no formal list of discussion questions.

A general profile of the thirteen plants and the LPMS users interviewed is provided in Table 3. The ten domestic plants are seen to cover a wide range of plant designs, LPMS technical characteristics, and proven performance capabilities, whereas the three Western European plants span a much narrower range (two of the three are brand new and embody the latest design concepts). Table 4 gives additional detail on the domestic plants (designated US 1 through 10), the single West German plant (FRG 1), and the two French units (FR 1 and 2) that were visited. The NSSSs are characterized by generating capacity, number of coolant loops (which is relevant to the number of sensors needed to achieve adequate coverage), and type (pressurized or boiling). The LPMSs are characterized by the total number of channels (sensors) available and the number that are continuously monitored by the hardware (active channels), as well as by code letters representing the respective LPMS manufacturers. The final column of Table 4 provides an abridged indication of the plant's experiences to date with loose-part monitoring. (Greater detail on LP experience will be found in Sect. 3 of this report under the utilities' responses to question 2d, Table 2.)

Table 2. Discussion questions for U.S. licensees

1. System description; operational procedures and principles

   a. How many sensors comprise your loose-part monitoring system (LPMS), and where are they located? Which sensors are continuously monitored and which are treated as installed spares?

   b. Describe the alarm logic used in your LPMS (e.g., is event occurrence rate as well as signal amplitude taken into consideration?).

   c. What procedures were (or will be) used to calibrate your LPMS initially (i.e., prior to full-power plant operation)?

   d. How did you (or will you) measure or infer system sensitivity to loose parts under normal plant operating conditions? What value was obtained?

   e. Describe the procedure by which the LPMS alarm threshold setting is (or will be) established. Have you found it necessary to use different threshold settings for different plant operating conditions? Does your system automatically adjust its threshold to account for varying background?

   f. Describe the day-to-day use of the LPMS by your plant operators and/or I&C personnel and Results Supervisor.

   g. Does your plant's total loose-part monitoring program (i.e., equipment plus related operating procedures, practices, and training) generally follow the approach recommended in Regulatory Guide 1.133? If "no," identify the major areas of difference and explain why you took (or plan to take) an alternative approach.

2. Experience to date

   a. What false alarm rate are you presently experiencing with your LPMS? Is this tolerable? What steps, if any, are being taken to effect an improvement? Do you find that a low false alarm rate is impossible to achieve simultaneously with the 0.5 ft-lb impact sensitivity called for by Regulatory Guide 1.133?

   b. Have you had difficulty in selecting accelerometer locations and mounting techniques that are compatible with industry codes and accepted practices and yet do not compromise LPMS performance potential?

Table 2. (Continued)

c. Have you experienced premature performance degradation or failure of in-containment components (i.e., accelerometers, charge converters/preamplifiers, and cables) due to high temperatures or radiation fields?

d. Describe any experience you have had in detecting the presence of loose, detached, or drifting metallic parts and in assessing their significance in terms of plant safety and operability. What role did your LPMS play in the detection and/or assessment? Were diagnostic specialists from the NSSS manufacturer or the LPMS supplier called in for assistance?

e. Do you believe that your LPMS has value as a means of protecting the NSSS?

f. What has been the single greatest problem with your LPMS?

3. Usefulness of Regulatory Guide 1.133

a. Does the Reg. Guide provide helpful guidance to your formulation of a loose-part monitoring program? Are there any ambiguities, technical shortcomings, or errors in the Guide? Overlooked subject areas?

b. Is the Guide overly restrictive in its recommended technical approach or overly demanding in its reporting requirements?

4. Future needs/directions

a. Do you plan to upgrade your present LPM program? If "yes," why and in which areas?

b. What additional features or improved performance capabilities would you like to see made available in "next generation" LPMSs? (For example, an ability to detect loose parts on the secondary side of PWR steam generators?)

c. What is your view of the future need for LPMSs? For example, will future technical developments and application practices be motivated more by plant operational needs or by regulatory demands?

Table 3. Profile of plants and LPMS users interviewed

Ten plants in U.S. [660 to 1180 MW(e) class]

- NSSS manufacturers
  - PWRs: 5 W, 2 B&W, 0 C-E
  - BWRs: 3 GE
- LPMS manufacturers[a]
  - 5 mfr. A
  - 3 mfr. B
  - 1 ½ mfr. C[b]
  - 1 mfr. D
- LPMS complexities
  - Incorporate 8 to 22 sensors; 5 to 13 continuously monitored channels
  - Some all-analog; some microprocessor-aided
- Characterized by diverse plant operating histories and LPM experiences

Three plants in Western Europe [900 to 1300 MW(e) class]

- All PWRs; none by U.S. manufacturers
- LPMSs represent "national consensus" designs
  - Incorporate 13 to 16 sensors, all continuously monitored
- LPM experience very limited in these particular plants, but have had predominately positive experience in plants of similar construction

[a]The designations A, B, C, and D are used in lieu of the actual corporate names, which are unimportant in the present context. These four manufacturers, however, are the principal suppliers of LPMSs to U.S. utilities, and their aggregate worldwide sales total at least 135 LPMSs at present.

[b]The "1/2" arises from a plant that has, in addition to a full-fledged LPMS from mfr. A, a temporary, limited-capability LPMS (only four channels) from mfr. C.

Table 4. Nuclear power stations visited
(domestic and foreign)

Station	NSSS	LPMS	LP experience?
US 1	1130 MW(e) 4-loop PWR	12 chs; 12 active mfr. A	Yes; real LP went undetected
US 2	1180 MW(e) 4-loop PWR	8 chs; 8 active mfr. A	Yes; indicated LP never found
US 3	806 MW(e) BWR	10 chs; 10 active mfr. A	No; LPMS usually turned off
US 4	880 MW(e) 3-loop PWR	10 chs; 5 active mfr. A + temporary 4 chs mfr. C	Yes, both positive detections and wild-goose chases
US 5	107[illegible] MW(e) BWR	12 chs; 12 active mfr. A	Maybe; one LP indication (went away)
US 6	1075 MW(e) 4-loop PWR	12 chs; 6 active mfr. C	No; a few indications were explained
US 7	666 MW(e) 3-loop PWR	Originally, 3 chs mfr. C; 13 chs, 13 active mfr. D on order	Yes; positive detection when LPMS was in operation
US 8	875 MW(e) 2-loop PWR	18 chs; 7 active mfr. B	Yes; positive detection on two occasions (indication ignored first time)
US 9	1050 MW(e) BWR	8 chs; 8 active mfr. B	Maybe; incompletely explained indication
US 10	860 MW(e) 2-loop PWR	22 chs; 11 active mfr. B	Yes; both positive detection and real LPs undetected
FRG 1	1225 MW(e) 4-loop PWR	16 chs; 14 active mfr. E	No; plant operational only 1 yr
FR 1	890 MW(e) 3-loop PWR	13 chs; 13 active mfr. F	Yes; nonimpacting tool in RV not detected, but nut in SG detected
FR 2	1290 MW(e) 4-loop PWR	15 chs; 15 active mfr. F	No; unit not yet in full-power operation

3. INFORMATION OBTAINED FROM U.S. PLANTS

As described previously, a uniform set of questions (Table 2) was submitted to the U.S. utilities interviewed well in advance of the actual site visits so as to provide structure to the ensuing discussions with utility technical staff. The questions are broken down into four areas, namely (1) LPMS description/operational procedures and principles, (2) experience to date, (3) usefulness of Regulatory Guide 1.133, and (4) future needs/directions. In paraphrased form, the responses provided by the interviewed utilities (identified only as Utility A through J) to the queries of Table 2 are given below, one question at a time.

The reader is reminded that since written responses were neither requested nor offered, the responses indicated are not verbatim transcriptions but rather represent the author's best effort to distill the substance from discussions that were sometimes lengthy. Also, it must be noted that the order in which the responses to the questions are listed has been jumbled purposely in order to preserve the anonymity of the interviewees; for example, Utility A of question 2(a) is not necessarily the same utility as Utility A of question 1(b). It is recognized that such jumbling prevents the reader from associating a cause (e.g., unsophisticated alarm logic) with a noted effect (e.g., a high rate of false alarms), but it must be remembered that this study was aimed at painting a "broad-brush" picture of the current status of loose-part monitoring and not at examining and criticizing any particular utility's loose-part monitoring program.

3.1 SYSTEM DESCRIPTION; OPERATIONAL PROCEDURES AND PRINCIPLES

(a) *How many sensors comprise your loose-part monitoring system (LPMS), and where are they located? Which sensors are continuously monitored and which are treated as installed spares?*

UTILITY A: 12 LPMS channels, all active (i.e., all 12 are continuously monitored; there are no installed spares). This is a four-loop PWR; one accelerometer is positioned near each of the four reactor coolant pumps (RCPs), two are mounted on the reactor vessel (RV) upper head tensioning studs, two more are clamped to the instrument tubes penetrating the RV lower plenum, and one is positioned at the primary inlet to each of the four steam generators (SGs).

UTILITY B: 8 channels, all active. This is a four-loop PWR; accelerometers are positioned the same as Utility A except that the RCPs are not monitored by the LPMS.

UTILITY C: 10 channels, all active. This is a BWR; four accelerometers are clamped to the in-core instrumentation tubes penetrating the RV lower plenum, two are positioned near the recirculating pump inlets, two are mounted on the feedwater header, and two more are placed on the steam header.

UTILITY D: 10 channels, five active and five passive (i.e., installed spares). This is a three-loop PWR; two accelerometers are positioned on the RV upper head tensioning studs, two are mounted on a single instrument guide tube (about 8 ft below the RV), and two (one active, one passive) are mounted on the hand-hole covers of each of the three SGs. In addition, because of potential problems with loose thermal sleeves, this utility has temporarily installed accelerometers on each of the reactor coolant system (RCS) cold legs downstream of the high-pressure injection system nozzles and on the pressurizer surge line; however, because of a shortage of containment penetration cables, these added sensors can be utilized only by disconnecting a similar number of the permanently installed accelerometer signal channels.

UTILITY E: 12 channels, all active. This is a BWR; four accelerometers are clamped to the control rod drive housings penetrating the RV lower plenum, two are strapped to the reactor recirculation suction lines, two are strapped to the feedwater (FW) inlet lines, two are strapped to the vessel pressure and level instrumentation lines, and two are positioned on the recirculation pump housings (between the motor and the coupling).

UTILITY F: 12 channels; all are supplied with amplifiers for auditory monitoring and/or recording, but only six channels are active (i.e., continuously monitored electronically). This is a four-loop PWR; two accelerometers are attached to the RV head lifting lugs, two are clamped to the flux monitoring thimble tubes penetrating the RV lower plenum, and two are positioned on each of the four SGs [the one mounted below the tube sheet is the active sensor and the one mounted above the tube sheet is treated as an installed spare (passive sensor)].

UTILTIY G: 3 channels, all active; accelerometers are clamped to instrumentation tubes penetrating the RV lower plenum. This is a three-loop PWR, and its LPMS was installed several years ago in response to a problem with loose SG tube plugs. The three-channel LPMS will soon be replaced with a 13-channel system (all channels active): two accelerometers will be positioned at the RV upper head, two at the RV lower plenum, and three on each SG (two on the hot leg side and one at the FW inlet).

UTILITY H: 18 channels, seven active and 11 passive. This is a two-loop PWR. Two accelerometers are positioned at the primary inlet to each once-through steam generator (OTSG), and accelerometers are also placed at the bottom (outlet) and at the FW inlet to each OTSG; in addition, one accelerometer is strapped to each of the two core flood lines near its RV entry point, two are strapped to in-core guide tubes where they penetrate the lower RV, two are bolted to the service structure near the RV upper flange (below the shroud fans), and four are strapped to the cold legs at the suction side of the four RCPs. The seven channels continuously monitored are the four at the OTSG inlets, the two on the core flood lines, and one of the pair on the in-core guide tubes.

UTILITY I: 12 channels, eight active and four passive. This is a BWR; the eight active channels comprise two accelerometers strapped to the main steam lines, two on the FW lines, two on the recirculation suction nozzles, one on the RV lower head drain, and one on a control rod drive housing penetrating the lower RV plenum.

UTILITY J: 22 channels, 11 active and 11 passive. This is a two-loop PWR with once-through steam generators. The accelerometers are positioned as follows: four on separate in-core instrument guide tubes below the RV, one on each OTSG vent line, one on each OTSG hand hold, one on each main feedwater line, two on control rod drive mechanisms, two on each RCP (one at the suction side and one at the discharge side), and one on each of the two core flood lines. All sensors placed on RCS piping are strap-mounted; others are stud-mounted to excess metal.

(b) Please describe the alarm logic used in your LPMS (e.g., is event occurrence rate as well as signal amplitude taken into consideration?).

UTILITY A: Alarm is generated if the signal amplitude in one or more channels exceeds the channel's preestablished threshold; the threshold detector has a nonlinear response characteristic and is offset from zero level (i.e., biased) so as to respond only to large bursts well above normal acoustic background. Rate of burst occurrence is not considered in generating an alarm. LPMS electronics originally were wide bandwidth (5 Hz to 10 kHz), but were recently modified for narrow-band response (1 to 10 kHz).

UTILITY B: Alarm logic utilizes signal amplitude, burst occurrence rate, and multiple-channel "coincidence" within a few-millisecond time interval (typically $0.5 \leq \Delta t \leq 15$ ms) that is based on reasonable acoustic propagation times within the RCS. The amplitude thresholds of the individual channels are not absolute but are background-following; that is, they are specified as a multiple (typically 3 to 5 times) of the short-term-averaged background level. The required burst occurrence rate for an alarm is specified as N events per M seconds. "Simultaneous" ($\Delta t \leq 0.5$ ms) bursts in three or more channels are considered invalid data (probably electrical noise).

UTILITY C: Same as Utility A; that is, nonlinear signal amplitude threshold discrimination, and no burst rate criterion or multiple-channel response requirement.

UTILITY D: The LPMS presently installed generates an alarm if the signal level on one or more channels exceeds a preestablished absolute value and bursts are received at a rate exceeding a preestablished value. The LPMS now on order will have similar alarm logic, except that amplitude alarm thresholds will be preset multiples of background rather than absolute acceleration levels.

UTILITY E: The LPMS has two preestablished amplitude discrimination levels, termed "threshold" and "alarm." Signals with amplitudes smaller than the threshold setting are disregarded, whereas signals exceeding the setting are considered "events" and their parameters are logged by the system. However, no alarm is generated unless two or more events having amplitudes greater than the alarm setting are received on the same channel within any one-minute interval.

UTILITY F: Preestablished signal amplitude threshold (absolute, not background-following) logic; any single channel can generate an alarm, and burst rate is not considered.

UTILITY G: Permanently installed LPMS employs same preestablished absolute signal amplitude threshold logic as Utility F, but temporarily installed LPMS considers rate of burst occurrence as well as amplitude.

UTILITY H: Preestablished absolute signal amplitude threshold logic, same as Utility F.

UTILITY I: Preestablished absolute signal amplitude threshold logic, same as Utility F.

UTILITY J: Preestablished absolute signal amplitude threshold logic, same as Utility F.

(c) What procedures were (or will be) used to calibrate your LPMS initially (i.e., prior to full-power plant operation)?

UTILITY A: This is an old LPMS; present plant staff knows nothing about its original calibration but surmise that it was performed by the LPMS supplier, using a pendulum impactor. In recent years the LPMS has received attention during each refueling outage. At that time the control room electronics are recalibrated, the charge converters (preamplifiers) are checked for correct bias voltage, and the RCS is tapped near the sensors with a screwdriver to see that an alarm is generated, but no calibrated impacts are performed.

UTILITY B: The alarm threshold settings were established in a manner prescribed by the LPMS supplier, namely, 0.75 ft-lb impacts (from a spring-loaded machinist's center punch) were delivered to the RCS components and piping at various positions ~3 ft from each of the accelerometers. A limited number of in-vessel impacts were also performed, but the results were said to be nonreproducible.

UTILITY C: Much the same as Utility B, that is, 0.75 ft-lb impacts from a spring-loaded machinist's center punch delivered to RCS components and piping ~3 ft from each of the accelerometers (as recommended by the LPMS supplier).

UTILITY D: The NSSS/LPMS manufacturer performed the original calibration (with assistance from utility personnel), using both a shaker table and a pendulum impactor. With the latter, a time-of-arrival matrix was generated for ~30 different impact positions, using pendulum weights of 2.2 and 12 lb.

UTILITY E: To calibrate the original LPMS, a 1-lb bolt was dropped from various heights onto the RV upper flange (cold plant conditions). The replacement LPMS was calibrated with a spring-loaded machinist's center punch which had been set to give results equivalent to a 0.25 ft-lb impact from a 1-lb object. These latter calibrations of sensors mounted on the SGs were performed under hot, full-flow (but not steaming) plant conditions.

UTILITY F: LPMS was calibrated using both pendulum and spring-loaded center punch impacts.

UTILITY G: Calibrated by the LPMS supplier, using repeated 0.5 ft-lb impacts from a center punch applied ~3 ft from each sensor.

UTILITY H: The NSSS/LPMS manufacturer performed the original calibration, using several different impacting masses, and reported the results to the utility as power spectra (for both impacts and natural acoustic background) and time-domain plots of accelerometer responses to the impacts.

UTILITY I: Same as Utility C.

UTILITY J: With assistance from the LPMS manufacturer, the utility generated sensitivity curves for each sensor, utilizing pendulum impacts of several energies and impactor masses at a number of locations on the RV and RCS piping exteriors.

(d) How did you (or will you) measure or infer system sensitivity to loose parts under normal plant operating conditions? What value was obtained?

UTILITY A: No changes to the original alarm setpoints were required during escalation to full rated power, so system alarm sensitivity is still presumably 0.5 ft-lb. Less energetic impacts probably can be detected aurally, but such capability has not been quantified.

UTILITY B: The utility staff honestly do not know. They are employing alarm threshold settings that were recommended by the LPMS supplier and declared to be in conformance with Regulatory Guide 1.133 (i.e., 0.5 ft-lb 3 ft from each sensor), but they were never supplied with the basis for these settings.

UTILITY C: Same as Utility A (presumably ~0.5 ft-lb).

UTILITY D: Quantitatively, system sensitivity is unknown, but it must be fairly good because rather small parts (RCP impeller nut, locking pins, etc.) have been detected readily.

UTILITY E: On recommendation from the LPMS supplier, alarm thresholds were set at an acceleration level of ~4 "g" (peak); however, no direct evidence was available to show that a 0.5 ft-lb impact would yield a control board alarm at this setting.

UTILITY F: Plant staff have no idea; gain settings may have been altered since the initial LPMS calibration.

UTILITY G: The alarm level of 0.5 ft-lb set initially was retained after plant startup, despite a large number of nuisance alarms (probably attributable to thermal expansion) that are received during each reactor heatup (it is said to take three days for the RCS to quiet down).

UTILITY H: No adjustments were required on attaining full power; therefore the alarm level is presumably ~0.5 ft-lb.

UTILITY I: Steam generator channels were calibrated under hot, full-flow conditions to alarm at 0.25 ft-lb. Reactor vessel channels were set to alarm at an acceleration level of ~1 "g", based on an observed peak background signal level of ~0.8 "g"; in other words, the RV channels are set at a maximum sensitivity commensurate with a tolerable rate of false alarms.

UTILITY J: Upon recommendation by the LPMS supplier, alarm settings of 3 times background (this is a background-following LPMS) were chosen initially (this is a new plant). Once plant background characteristics are established, these alarm settings may be revised if they do not conform to Regulatory Guide 1.133.

(e) Please describe the procedure by which the LPMS alarm threshold setting is (or will be) established. Have you found it necessary to use different threshold settings for different plant operating conditions? Does your system automatically adjust its threshold to account for varying background?

UTILITY A: Prior to reaching 100% power for the first time, the occurrence of a repetitive "clanging" on four LPMS channels mounted near the steam drier region of this BWR necessitated changing some of the alarm levels to 5 times background and others to 8 times background. Analysis provided by the LPMS supplier suggests that with these new settings some of the channels continue to meet the 0.5 ft-lb sensitivity target of Regulatory Guide 1.133, while others do not.

UTILITY B: Throughout different plant operating modes, alarm thresholds are continually readjusted (without documentation) to as high a sensitivity as can be tolerated without undue false alarms. Although they are of the same basic design, Unit 1 requires different alarm thresholds than Unit 2; this is the result of different brands of RCPs being used in the two units (one brand is noisier than the other).

UTILITY C: No alarm level adjustments have been required; plant acoustic background level seems to be relatively independent of operating conditions.

UTILITY D: Same as Utility C.

UTILITY E: Owing to what was described as an excessive false alarm rate, the power to the LPMS is turned off as soon as 100% power is achieved (the plant's FSAR requires the LPMS to be operational only during plant startup). No indication was given that the plant is attempting to rectify this situation by raising alarm thresholds or by investigating the origins of the noise bursts that cause the false indications.

UTILITY F: Alarm thresholds of 0.5 ft-lb are maintained regardless of plant conditions, even though this practice results in essentially continuous alarming of LPMS throughout the plant heatup phase.

UTILITY G: LPMS alarm levels established initially are retained, independent of operating conditions. Operators are accustomed to receiving LPMS alarms when control rods are moved and when certain equipment (pumps, valves) is actuated, so these indications are simply ignored as routine.

UTILITY H: As a result of accumulated operating experience, some of the system's original alarm settings have been revised upward (to lower the false alarm rate); however, the settings in use are logged automatically on a periodic basis by the microprocessor-aided LPMS and, being digital, can be accurately restored to former values if this should prove desirable.

UTILITY I: This utility originally employed alarm settings recommended by the LPMS manufacturer, namely, 2 times background, but has since discovered that the false alarm rate is tolerable with an alarm level only 1.5 times background and has adopted that setting. Surprisingly, no appreciable change in acoustic background level is noted when SGc start producing steam.

UTILITY J: Had been at full power for only one week at time of interview. No LPMS alarms had been received during power escalation (not surprising, as this is a BWR), and no changes to the 0.5 ft-lb alarm threshold initial settings appeared to be necessary.

(f) Please describe the day-to-day use of the LPMS by your plant operators and/or I&C personnel and Results Supervisor.

UTILITY A: Control room operators check the LPMS every four hours to see that the system is functioning normally and that an alarm is generated if the TEST button is depressed. The shift technical advisor (STA) listens, by means of a loudspeaker, to all LPMS channels at least once per day. No data recordings are made; plant personnel contend that there is no merit in recording because the bandwidth of the analog tape recorder supplied with their system is only 5 kHz, whereas the accelerometer bandwidth extends beyond 30 kHz. This plant receives many alarms from the LPMS each day, most of which are traceable to normal plant operations such as control rod movements or valve closures. Through experience and procedural control, they have learned to recognize and ignore such nuisance indications.

UTILITY B: Operators listen to all signal channels once each 8 h and verify the alarm function; the plant engineer attempts to listen carefully to each signal once each week. Tape recordings are made only if deemed necessary by the shift supervisor. Like Utility A, they receive many nuisance alarms, but this was said to be no real bother to the plant personnel, who feel that immediate detection of a real, damaging loose part is a virtual certainty.

UTILITY C: Each channel is listened to by operators four times a day, and the staff engineer listens on a fairly frequent (but not strictly scheduled) basis. Some data recordings are made during plant startups, but data are not recorded periodically. One man is stationed at the LPMS cabinet during all RCP startups, since this is thought to be a particularly opportune time to detect loose parts in the RCS.

UTILITY D: An operator listens to each LPMS channel for 10 to 20 s once each day. Every 30 days system operability is verified by substituting an electrical test signal in place of the accelerometers. Each 18 months the LPMS is completely recalibrated. Despite the fact that the LPMS is equipped with a four-channel tape recorder and a single-channel spectrum analyzer, neither is used on a routine basis.

UTILITY E: An operator listens to all channels once a day, and a functional test is performed monthly. At each refueling al' sensors are removed from the monitored RCS components and calibrated with a portable shaker table; no calibrated impacts are performed because the benefits are not judged to warrant the personnel radiation exposure that would be incurred. The spectrum analyzer supplied with the LPMS is not used on a routine basis.

UTILITY F: No routine listening during normal, at-power plant operation; no data recordings (plant is required to have LPMS in operation only during the startup phase following refueling outages).

UTILITY G: Each day an operator listens to each channel for a few seconds, files the event summary produced daily by the microprocessor-aided LPMS, and initiates the LPMS self-test. Each week the channels are listened to more carefully and the operator describes what is heard in the LPMS logbook.

UTILITY H: An operator listens to all channels at least once per shift, but no numerical information is recorded. Tape recordings of acoustic background are made quarterly.

UTILITY I: Once each 12-h shift an operator listens to all channels and verifies an absence of alarm indications. If any alarms will not reset, the shift enginee is notified. No tape recordings are made during normal plant operation.

UTILITY J: Once a day operators perform a channel check (which consists of verifying that charge converters are receiving correct bias voltage) and, optionally, listen to selected channels. (The STA's responsibilities include periodic careful listening to the LPMS channels during normal plant operation and assessing abnormal situations in which loose parts are suspected.) Once each month the LPMS receives a functional test, which includes simulation of an alarm condition and verification of tape recorder auto-start. Each 18 months (at refueling) the LPMS is completely recalibrated.

(g) Does your plant's total loose-part monitoring program (i.e., equipment plus related operating procedures, practices, and training) generally follow the approach recommended in Regulatory Guide 1.133? If "no," please identify the major areas of difference and explain why you took (or plan to take) an alternative approach.

UTILITY A: The monitoring program was formulated long before the RG was released but, in general, the utility's procedures parallel the prescribed program. Notable deficiencies are (1) the absence of tape recorder auto-start, (2) seismic and signal channel separation requirements are not met, and (3) certain system tests are performed too infrequently.

UTILITY B: This plant has not committed to follow the RG; however, plant procedures were formulated to meet Tech Spec requirements, which were selectively extracted from the Regulatory Guide on a negotiated basis. From a standpoint of hardware the LPMS conforms to the Guide, but this utility makes no attempt to follow the Guide's recommended reporting procedures (namely, RG Sects. 4, 5, and 6) or quarterly background level and character reassessment [RG Sect. 3.a.(2)(e)].

UTILITY C: No attempt has been made to conform to the RG. This utility considers the Guide unrealistic in that it presumes the existence of a mature technology that is, in fact, fragmentary. Major departures from the Regulatory Guide are: (1) no data tapes are recorded routinely for future reference, (2) accelerometers are not spaced apart so as to provide broad coverage of each natural collection area, (3) in-containment LPMS components and cables do not meet requirements for physical separation, and (4) the utility places much more emphasis on subjective, manual listening activities than on quantitative waveform analysis, data recording, and automated detection of loose-part impacts.

UTILITY D: No loose-part monitoring program is in place; the LPMS is turned on only immediately following refueling outages, and is said to be in a constant state of alarm at that time.

UTILITY E: This utility basically follows Regulatory Guide 1.133 (though not formally required to do so) except where they see no merit in the actions suggested by the RG (e.g., periodic recording of background).

UTILITY F: Plant procedures for use of the LPMS follow the general intent of the RG, though they were written entirely independently of it (in fact, they predate the RG by several years). Major hardware shortcoming: the LPMS does not have two sensors per natural collection region.

UTILITY G: Plant procedures follow the general intent of Regulatory Guide 1.133, though they have evolved over several years' experience completely independent of the RG. Major departures are: (1) the LPMS has never been calibrated with impacts of known kinetic energy, (2) the system does not meet Regulatory Guide requirements for channel separation and operability following an earthquake, (3) the system lacks a tape recorder autostart feature, and (4) no reference (background) data are recorded during routine plant operation.

UTILITY H: The present LPMS (soon to be replaced with a system of greater capability) has an insufficient number of accelerometers to meet the RG requirements, but the new system is intended to conform to the Guide in regard to both hardware and operating procedures.

UTILITY I: The LPM program follows Regulatory Guide 1.133 to the extent possible with a LPMS that was already on order when the RG was issued. Even though this utility is not required to conform to the Guide's recommendations, they feel that the RG offers good advice and they are attempting to follow it.

UTILITY J: LPMS hardware was procured on the supplier's statement that it complied with RG requirements; all procedures written by the plant were specifically keyed to the Guide, so if there is nonconformance it is strictly unintentional.

3.2 EXPERIENCE TO DATE

(a) What false alarm rate are you presently experiencing with your LPMS? Is this tolerable? What steps, if any, are being taken to effect an improvement? Do you find that a low false alarm rate is impossible to achieve simultaneously with the 0.5 ft-lb impact sensitivity called for by Regulatory Guide 1.133?

UTILITY A: Too little experience accumulated so far to say with certainty, but the plant has operated as long as two weeks without an alarm (alarm thresholds for this plant are set for 0.5 ft-lb).

UTILITY B: Essentially no experience yet at full reactor power (this plant is just coming on line), but at 92% power they got "a few" false alarms at the threshold settings initially recommended by the LPMS supplier. The alarm threshold settings have since been raised, with the result that no alarms have been received in the last 40 days. The new settings have been quantified as to sensitivity, and with only two or three exceptions, they continue to meet the Regulatory Guide target of 0.5 ft-lb.

UTILITY C: SG channels currently produce one or two alarms per shift, but this is because alarm thresholds have purposely been set very low (temporarily), owing to recent servicing of the SGs. On RV channels, one or two alarms per week is normal. (This utility considers one false alarm per day to be tolerable.) The sensitivity of their LPMS in terms of impact energy is not known, so conflict with the RG is indeterminable.

UTILITY D: False alarms are said to be sporadic--may go for weeks with none, then have several in one day for no apparent reason. The average rate may be one per week. No steps are being taken to effect an improvement because, lacking knowledge of the source(s) of the false alarms, they don't know where to begin.

UTILITY E: "Expected" alarms are a regular occurrence (i.e., during control rod movements, check valve operation, etc.), but totally unexplainable alarms are no longer a problem since the LPMS, originally wideband, was band limited to 1 to 10 kHz and some of the detection circuit's nonlinear response characteristic was removed. System response to impacts of known energy has never been determined, and therefore conflict with Regulatory Guide 1.133 is indeterminable.

UTILITY F: The false alarm rate is typically a few per week, not including expected alarms produced by control rod movement, etc. This rate is considered tolerable, and no steps are being taken to effect an improvement.

UTILITY G: The alarm rate is difficult to determine because the LPMS at this plant is required to be activated for only a limited time period following refueling outages. During such startup periods the LPMS was said to go into a continuous state of alarm, but on the day of the interview no channels alarmed when the system was turned on (although 4 of 12 channels were judged inoperable).

UTILITY H: The false alarm rate is apparently high (no numerical figure was available), but this was said to present no problem to the operators, who in fact view this confirmation of their actions and verification of continued accelerometer sensitivity as helpful and reassuring.

UTILITY I: Threshold settings employed when the LPMS was first installed were okay, in that a false alarm rate of less than one per month was obtained. More recently, the LPMS manufacturer recommended that more sensitive settings be used, with the result that false alarms rose to an unacceptable level (200 to 2000 events/day). Threshold levels on two particularly troublesome channels have since been restored to their initial values. The utility has no idea whether they now conform to the Regulatory Guide's 0.5-ft-lb target sensitivity, since they don't know how the LPMS supplier arrived at the recommended alarm threshold settings.

UTILITY J: When the LPMS was first placed in service, one or two false alarms occurred per shift. The system has since been returned and the false alarm rate has dropped to one every two or three days. Following a major loose-part occurrence, the LPMS was extensively reworked and recalibrated, and the false alarm rate is presently once per week or less. The LPMS impact energy sensitivity is, however, not established with any certainty, so potential conflict with the Regulatory Guide recommendation of 0.5 ft-lb is indeterminable.

(b) Have you had difficulty in selecting accelerometer locations and mounting techniques that are compatible with industry codes and accepted practices and yet do not compromise LPMS performance potential?

UTILITY A: No problems encountered; consultation was provided by both the NSSS manufacturer and LPMS supplier, but final mounting decisions were made by the utility. Some accelerometers are mounted with split clamps, others with studs threaded into excess metal.

UTILITY B: A consensus group composed of the utility and the NSSS and LPMS suppliers selected the accelerometer locations. They were guided in their choices by lessons learned from a costly loose-part occurrence at this plant about ten years ago.

UTILITY C: The only problem with selecting sensor locations is that a pair originally installed on a control rod drive motor housing proved noisy and poorly coupled acoustically to the RV, and so were relocated. This utility prefers threaded stud mounting, but where this is impractical (e.g., on instrument guide tubes) the accelerometers are attached to a metal block that is, in turn, strapped to the monitored RCS component.

UTILITY D: Sensor locations were specified jointly by the LPMS supplier and the plant architect-engineer (A-E); utility personnel feel that the choices were determined more by convention and convenience than by scientific analysis. A strap mounting technique is utilized throughout and has posed no problems.

UTILITY E: The A-E chose sensor locations; prime considerations were simplicity of mounting, sensor accessibility, and economy in routing signal cables (Regulatory Guide 1.133, which stresses "broad coverage of natural collection areas," had not been issued at the time this utility's LPMS was specified).

UTILITY F: Though they helped the LPMS supplier with actual installation of the sensors, this utility did not participate in the specification of sensor locations or mounting methods.

UTILITY G: Sensor locations were chosen by the LPMS supplier (who is also the reactor manufacturer) with no input from the utility. Drill-and-tap stud mounting is used in most locations.

UTILITY H: Sensor locations were chosen by the LPMS supplier (who is not a reactor manufacturer) with no utility input. At the time of its installation the LPMS utilized well-shielded coaxial containment penetration cables, but these have since been relinquished to higher priority uses. As a consequence, many signal channels of the LPMS are now plagued with 60-Hz contamination.

UTILITY I: Sensor locations were chosen by the LPMS supplier with no utility participation. The utility could not supply information on the mounting method used; drawings showing sensor locations did not detail the mounting, and the utility staff member interviewed ("primary coolant system plant engineer") admitted that he had never seen the accelerometers.

UTILITY J: This utility acts as its own A-E; it selected the sensor locations in consultation with the LPMS supplier.

(c) *Have you experienced premature performance degradation or failure of in-containment components (i.e., accelerometers, charge converters/preamplifiers, and cables) due to high temperatures or radiation fields?*

UTILITY A: Problems have been experienced with the mineral-insulated cables that connect the accelerometers to the charge-sensitive preamplifiers becoming brittle and breaking when disconnected. (As a related observation, excessive maintenance has been necessary to keep the four-channel FM tape recorder operational; apparently it is not designed for an industrial environment.)

UTILITY B: Preamplifiers, mineral-insulated cables, and subminiature coaxial connectors have all proved troublesome, but the problem has been mechanical damage rather than component degradation due to elevated temperature or radiation. This utility believes that with only a little additional engineering and expense these components could be made more robust and thereby more suited to and easier to handle in a contaminated environment.

UTILITY C: This utility's LPMS has been in operation for only one year, but in this time one charge converter has failed (or was defective when installed) and three accelerometers have required replacement because of cables and/or connectors that were broken as a result of routine in-containment maintenance operations. All accelerometers will soon be replaced with ones having an integral 4-ft mineral-insulated cable and a more robust, military-type connector.

UTILITY D: The subminiature, soft coaxial cable supplied with the LPMS for connecting charge converters to accelerometers deteriorated rapidly following full-power operation; it has since been replaced with high-temperature cable. One charge converter has failed in service; the cause of failure is unknown. This utility, as well as other utilities, has had problems caused by craft workers unwittingly abusing sensors. (As a related observation, the four-channel FM tape recorder purchased as a part of the LPMS has proved to be unmaintainable.)

UTILITY E: Several accelerometers have failed in service, presumably because temperatures in some locations exceed the sensor's rating; accordingly, these have been replaced with accelerometers having integral hardline cables and rated for 750°F.

Except for failures attributable to mechanical abuse or misinstallation, this utility has had no trouble with connectors, cables, or charge-sensitive preamplifiers. (As a related observation, spare parts are no longer available for the tape recorders supplied with the LPMS.)

UTILITY F: No problems with premature component failures have been experienced. The preamplifiers of this LPMS are located just outside the biological shield, where the radiation level never exceeds 20 mR/h.

UTILITY G: Charge-sensitive preamplifiers originally supplied with the LPMS proved to have poor radiation/temperature tolerance; six or eight of these have since been replaced with an improved design now offered by the LPMS manufacturer. They have also experienced problems with poor electrical connections where subminiature coaxial cables join the accelerometers, which may account for the large number of signal channels on which 60-Hz contamination was evident. The system supplier has been unable to offer any effective remedy.

UTILITY H: The failure of one accelerometer and damage to its mineral-insulated cable were traced to temperatures exceeding their ratings. Two charge converters have also failed during the 2 1/2 years this LPMS has been in service. Signal contamination with 60 Hz was reduced by moving the charge converters inside the drywell (on the advice of the LPMS manufacturer they had originally been placed outside).

UTILITY I: Only one charge converter or cable (the utility was not certain which) has failed after several years' service; however, some problems have resulted from unintentional mechanical damage inflicted by craft workers performing maintenance on RCS components near the LPMS sensors/preamplifiers. The upgraded LPMS now on order will employ accelerometers having 10-ft integral mineral-insulated cables joined to 25 to 50 ft of high-temperature, soft extender cable, thus allowing placement of the charge converters in accessible, protected locations.

UTILITY J: No component failures have been experienced, but the plant is just now coming into full-power operation.

(d) Please describe any experience you have had in detecting the presence of loose, detached, or drifting metallic parts and in assessing their significance in terms of plant safety and operability. What role did your LPMS play in the detection and/or assessment? Were diagnostic specialists from the NSSS manufacturer or the LPMS supplier called in for assistance?

Note: Details of certain utilities' responses to this question have been omitted to protect anonymity.

UTILITY A: Several years ago, loose (but undetached) surveillance specimen tube holders were detected, as was an impeller lock nut that had backed off of a reactor coolant pump shaft. In both cases, diagnostic assistance was obtained from the LPMS supplier, who is also the reactor manufacturer. The LPMS has also been useful to operations not directly concerned with loose parts, such as the detection and correction of clanking valves, loose control rod drives, and secondary coolant system noises. However, a recent problem involving the detachment of bolts and their retaining clips from the reactor's thermal shield was not detected by the LPMS, although it was fully operational at the time the bolts and retainers are thought to have become detached.

UTILITY B: This plant, a BWR, has experienced an unexplainable vibration-like sound that appears to be emanating from the steam drier region. The anomalous sound is characterized by bursts of noise that recur at intervals of ~32 ms; the maximum levels observed on the nearest LPMS accelerometers are 5 to 10 "g." These bursts appear to be related to steam flow rate and are present only at power levels >90%. All evidence suggests a captive loose part. A task force consisting of plant engineering and operations personnel, representatives from both the reactor and LPMS manufacturers, and an independent acoustic consultant thoroughly examined the available data and recommended plant shutdown and visual inspection of the upper vessel and drier. This was done, but no evidence of wear, looseness, or breakage was found. When the plant resumed operation the anomalous sound reappeared at high power level. The alarm thresholds of those LPMS channels monitoring the upper RV have been raised to accommodate these recurring noise bursts.

UTILITY C: This plant has experienced loose parts (thermal sleeves in the safety injection system nozzles that broke loose and were flushed by cold leg flow into the downcomer and thus to the bottom of the RV), but none were detected by the LPMS because at the time of the occurrence ". . . plant personnel did not understand the operating principles of the LPMS and were not interrogating the system routinely or listening to the channel outputs at regular intervals." Procedures for using the LPMS have since been issued, and if a suspicious noise were now to be heard diagnostic personnel from both the LPMS supplier and the reactor manufacturer would be called in.

UTILITY D: About a year ago there was evidence of impacting on a few LPMS channels and, partly as a result of Utility C's experience with lost thermal sleeves, plant personnel (supported by the opinion of the LPMS supplier, who was brought to the site) concluded that they likely had the same problem.

However, upon defueling no loose parts were found anywhere in the primary coolant system, and there was no recurrence of the impact sounds when the plant restarted. As a result of this negative experience, plant personnel now have little confidence in their LPMS; if today they experienced another indication from the LPMS, their confidence level would be "about 10%." Utility personnel attribute the poor performance of the LPMS in this instance to (1) too few sensors, (2) insufficient baseline data, and (3) inexperience on the part of both plant personnel and the LPMS manufacturer's representative in diagnosing loose-part situations. The utility intends to correct these deficiencies on their newest unit by installing more sensors and calibrating the LPMS with known impacts at various likely collection points.

UTILITY E: This plant has had two loose-part incidents, one several years ago involving a massive part that broke up and inflicted major damage to the SGs, and another about two years ago involving a small part that caused no apparent damage. The difference in the damage resulting from the two incidents is attributable not only to the loose-part size difference but also to prompt utility recognition and response (plant shutdown) at the second occurrence. (In contrast, the plant had remained in operation for many days following the LPMS indication in the earlier instance.) Assistance from the LPMS supplier (who is also the reactor manufacturer) was obtained in the first incident, but plant personnel performed their own diagnosis in the second instance.

UTILITY F: Though numerous false alarms have occurred, to date there have been no indications of loose parts that were judged to require investigation by plant personnel or the LPMS supplier. However, if a recurrent indication were received, this utility would have to rely heavily on outside assistance because no plant personnel have received training on how to diagnose loose-part situations.

UTILITY G: This plant has had both positive and negative experiences with loose-part monitoring: (1) a 13-g split pin was successfully detected by the LPMS in one of the SGs; (2) a large (20-lb) piece of a stop valve guide not detected during reactor operation was later discovered in the bottom of the RV during refueling; and (3) the unit has twice been shut down (or a shutdown has been extended) as a result of unusual noises detected by the LPMS but, upon visual inspection, nothing could be found amiss. In the opinion of the utility, there have been no safety implications to any of these loose parts. Diagnostic services of both the reactor manufacturer and a consulting firm have been used, but not the LPMS manufacturer, who was judged to have insufficient experience.

UTILITY H: This utility has had two loose-part incidents to date. The first, a loose and drifting SG tube plug, was readily detected during RCP startup. The second, a loose part on the secondary side that ultimately resulted in rupture of one of the SG tubes, was not detected because the SG accelerometers had been removed prior to the part's becoming detached within the coolant system. In each instance the LPMS supplier (who is also the reactor manufacturer) was called in to assist with data collection and on-site diagnosis; however, owing to lack of equipment at the plant, off-site data analysis was also required.

UTILITY I: No true loose parts have been experienced. However, anomalous sounds produced by the anti-vibration bars in the SGs, thermal expansion/contraction, and instrument guide tube vibrations have concerned the utility from time to time and caused them to seek assistance from off-site experts.

UTILITY J: Some time ago this plant experienced a recurrent indication of a loose part, but before plant personnel could decide what action should be taken the anomalous sound disappeared spontaneously and has not occurred again.

(e) Do you believe that your LPMS has value as a means of protecting the NSSS?

UTILITY A: Yes; chiefly as a remote listening device.

UTILITY B: No; as a result of too many nuisance alarms, operators don't always heed LPMS indications. This utility believes that early detection of loose parts is valuable as one means for protecting their investment, but feel that neither their original LPMS nor their brand new one (both were installed voluntarily, rather than as a result of any licensing requirement) lives up to their expectations for such an early warning system.

UTILITY C: Yes; any good operator listens to his machinery regularly to assure its continued "health," and the LPMS pr[illegible], an opportunity to monitor portions of the reactor internals and containment that are otherwise inaccessible in nuclear plants.

UTILITY D: Yes; but it must be remembered that the LPMS has only limited value in protecting the NSSS, owing both to inherent design limitations (e.g., there is no hope of detecting sonically inactive loose parts) and to incompletely developed technology.

UTILITY E: Yes; there is much incentive to maintain and, as technology and resources permit, upgrade the LPMS.

UTILITY F: No. This utility's only loose-part experience turned out to be a "wild goose chase," and for this reason they view their LPMS with distrust.

UTILITY G: Not sure what to believe. Confidence in LPMS technology has been severely shaken by an operational anomaly encountered when the plant first went to power, namely, the detection of rather strong, recurrent, impact-like noises at reactor power levels above 92% whose origin has so far escaped identification by a task force of experts. "The system is obviously sensitive, but what good is that if the source of the problem cannot be identified?"

UTILITY H: Absolutely not; the LPMS is energized only during those periods when there is an FSAR requirement for it to be operational.

UTILITY I: Yes. This utility is convinced of the merits of loose-part monitoring, but wishes that the technology were better developed.

UTILITY J: Yes. This utility has had a LPMS in operation for about 10 years and considers it very valuable to the operation of the plant, not only for detecting loose parts but also for reassurance with regard to continued correct operation of many in-containment systems.

(f) What has been the single greatest problem with your LPMS?

UTILITY A: Don't know how to interpret the data provided by the LPMS, that is, how to diagnose and determine the operational and safety significances of a loose part once you've detected its presence. Innocuous noises occurring during plant heatup and cooldown are disconcerting to an untrained operator. The training courses offered by LPMS vendors dwell too much on the theory of acoustic propagation and spectral analysis and on how the LPMS was developed rather than on how to use the system most effectively to detect and diagnose loose parts.

UTILITY B: Lack of an experience base for BWRs, coupled with the apparent technical inability of present-day LPMS to distinguish between impacts occurring within the vessel internals and impacts occurring at the RV wall.

UTILITY C: Repeated requests for rejustification of the technical adequacy of the utility's 10-year-old LPMS before the ACRS and the NRC. Although their system admittedly fails to conform to Regulatory Guide 1.133, this utility holds that the added benefits to safety and/or plant availability that are claimed for the later-generation LPMSs are, in fact, vanishingly small and do not justify the considerable cost of retrofitting.

UTILITY D: Acquisition of the technical expertise that is necessary to correctly diagnose loose-part situations. Equipment reliability is also a problem; the full complement of 17 channels comprising this utility's LPMS is seldom operational by the end of a fuel cycle.

UTILITY E: The equipment and technology comprising today's LPMSs cannot be relied upon to perform the intended function of providing unambiguous indication of potentially damaging loose parts in the RCS, and so are inconsistent with the almost-safety-grade performance that seems to be presumed by Regulatory Guide 1.133.

UTILITY F: The biggest problem has been a lack of continuity in personnel and less than conscientious operation of the loose-part monitoring equipment. The only real complaint with the LPMS hardware itself centers on the magnetic tape recorder: it has insufficient high-frequency response to record noise bursts with fidelity, can't possibly capture isolated events, has a limited operational life, and requires an undue amount of maintenance.

UTILITY G: Continual problem with signal contamination by 60-Hz noise due to inadvertent cable or preamplifier groundings that result in ground loops. When the LPMS was first calibrated, the staff had difficulty devising a method for generating reproducible impacts of known energy, but this problem has since been overcome.

UTILITY H: Problem same as Utility E, that is, equipment does not provide a sufficiently reliable indication to be useful from the standpoint of making plant decisions.

UTILITY I: The LPMS was said to be in a constant state of alarm and therefore useless as an early warning device. (The accuracy of this pronouncement may well be questioned, however, since no engineer conversant with loose-part monitoring or intimately familiar with the plant's LPMS could be identified at this plant.)

UTILITY J: Problems same as Utility A, that is, difficulty in diagnosing a loose-part situation and determining the likely safety and operational consequences of continued plant operation.

3.3 USEFULNESS OF REGULATORY GUIDE 1.133

(a) Does the Guide provide helpful guidance to your formulation of a loose-part monitoring program? Are there any ambiguities, technical shortcomings, or errors in the Guide? Overlooked subject areas?

UTILITY A: The RG provided the model for this plant's LPMS operating/maintenance procedures. However, a shortcoming of the Guide is its lack of guidance with regard to what follow-up actions should be taken once the likely presence of a loose part has been established.

UTILITY B: This plant's LPMS procedures were written without reference to the RG. Like Utility A, Utility B sees a shortcoming in that no guidance is provided for determining the safety significance of a probable loose part.

UTILITY C: This plant's original LPMS procedures predated the RG; since the Guide's issuance, an attempt has been made to bring their procedures into line with it. The utility takes no issue with the RG's recommendations, but in several cases (e.g., the monthly execution of a functional test) doesn't know how to implement them in an acceptable yet practical manner.

UTILITY D: This plant has made no commitment to Regulatory Guide 1.133 and is not even familiar with its contents.

UTILITY E: This utility had a LPMS in operation many years before the RG was issued. Over the years the LPMS operational procedures have been revised more than once (typically, each time new personnel were assigned responsibility for the system's operation), but in no case was the Guide ever consulted as a source of good practice.

UTILITY F: Like Utility E, this plant has had a LPMS installed for a number of years and developed their own procedures completely independent of the RG. As a matter of fact, however, the plant's procedures incorporate the major features of the Guide, though the details are somewhat different.

UTILITY G: Yes, the RG is useful, but it's too slanted toward PWRs (Utility G is a BWR). It fails to recognize some special considerations pertaining to BWRs, such as their higher acoustic background noise level and their less easily defined "natural collection regions."

UTILITY H: Regulatory Guide 1.133 is unrealistic; it assumes a state of the art that is, in fact, nonexistent.

UTILITY I: The RG gives sound guidance in most areas, and this utility follows it rather closely.

UTILITY J: Like Utility D, this plant has made no commitment to the RG and is unfamiliar with its contents. This cavalier attitude may soon change, however, since the loose-part monitoring system and program of this utility system's newest unit will have to conform to the Guide.

(b) Is the RG overly restrictive in its recommended technical approach or overly demanding in its reporting requirements?

UTILITY A: Can't comment; unfamiliar with Regulatory Guide 1.133.

UTILITY B: Same as Utility A.

UTILITY C: Not really familiar enough with the RG to comment (this plant's LPMS program was formulated without recourse to the Guide), but if channel checks, for example, are recommended each day, that's too frequent.

UTILITY D: The RG is not overly restrictive or demanding. (This utility's LPMS program was formulated without recourse to the Guide, but is remarkably similar.)

UTILITY E: The RG places too much emphasis on Tech Spec requirements and provides too little guidance on how to use the LPMS to maximum advantage during routine plant operation. Requirements for LPMS recalibration at each refueling should be reexamined in light of historical experience with component degradation and system calibration drift, since the radiation dose received by personnel performing the recalibration (using present methods) is not insignificant. Also, the RG requirements for physical separation of signal channels and for seismic qualification are much too severe for a mere operational aid that is in no way a part of the plant protection system.

UTILITY F: The suggested frequency of LPMS recalibration (namely, once each fuel cycle) is too often. Also, requiring that operability of the LPMS be a limiting condition for plant startup and power operation (Regulatory Guide 1.133, Sect. C.5.b) is completely unwarranted.

UTILITY G: This plant has no problems with the technical aspects of the RG, but reporting requirements are too demanding for a nonsafety-grade monitoring system.

UTILITY H: This plant has no problems with the technical restrictiveness of the RG, but the required reporting of inoperative channels (Sect. C.5.b) could become a real nuisance at this plant if accelerometers and preamplifiers continue to fail at their present rate.

UTILITY I: The RG demands too much reporting in the area of prompt notification of any and all loose-part indications (Sect. C.6). This utility's experience shows that many seemingly real loose-part situations either cease spontaneously or prove, upon further investigation, to be explainable false alarms.

UTILITY J: Response essentially the same as Utility I, that is, special reports are superfluous, since prompt notification with written followup will certainly take place in any situation that appears to have potential safety significance.

3.4 FUTURE NEEDS/DIRECTIONS

(a) Do you plan to upgrade your present LPM program? If "yes", why and in which areas?

UTILITY A: No major alterations or additions to the LPMS are anticipated, but this utility plans to fine-tune present equipment by (1) relocating a few of the accelerometers to provide more complete coverage of the RCS; (2) tightening up the time delay "window" for multiple channel coincidences to decrease the likelihood of false alarms; and (3) adding an auto-stop feature to the LPMS tape recorder to relieve the operator of this chore.

UTILITY B: Yes; a second four-channel tape recorder will be purchased and the auto-start feature will be added to both tape recorders. The result will be an ability to capture events of greater than a few seconds duration on as many as eight LPMS signal channels.

UTILITY C: Yes; both technical personnel and management recognize the place of loose-part monitoring in the overall plan to ensure safe and economic operation of the plant. (This utility presently has on order a LPMS of considerably greater capability than the six-year-old system it replaces.)

UTILITY D: Yes; like Utility A, this utility will make no major hardware additions (such as additional accelerometers) in the near future but plans to upgrade loose-part programs by (1) implementing the auto-start feature on the tape recorder; (2) continuing to implement design modifications (software improvements to microprocessor-based system logic) recommended by the LPMS supplier; (3) replacing all fragile connectors originally supplied with in-containment LPMS components; and (4) improving the completeness and clarity of system operating procedures.

UTILITY E: No hardware additions or alterations are anticipated, with the exception that the antiquated tape recorders will eventually be replaced when parts become unobtainable.

UTILITY F: This utility would upgrade its LPMS only if NRC demanded it. The supplier of the present LPMS has already approached the utility with suggestions for upgrade, but the utility's response was negative (too expensive; cannot be justified on a basis of either safety or operability).

UTILITY G: This plant has no plans to upgrade system hardware, and would alter the loose-part monitoring program now in place only if substantial improvements in the plant's operating record and economics could be expected therefrom.

UTILITY H: Absolutely no plans for upgrade; this plant was said to face too many mandatory changes at present to allow personnel any significant amount of time to devote to improvements in the LPMS.

UTILITY I: Yes, indirectly. This utility is voluntarily installing, on a trial basis, a computerized surveillance system that is expected to trend signals from the LPMS (as well as those from other systems), thereby relieving plant personnel of this chore and responding more vigorously to the spirit of Regulatory Guide 1.133.

UTILITY J: No major hardware additions are planned, but two system improvements will be effected: (1) as they fail, the charge-sensitive preamplifiers originally obtained with the LPMS will be replaced with radiation-hardened models, and (2) the circuitry of the arrival-time-difference module will be modified as necessary to make the alarm threshold level of this module consistent with the remainder of the LPMS.

(b) What additional features or improved performance capabilities would you like to see made available in "next generation" LPMSs? (For example, an ability to detect loose parts on the secondary side of PWR steam generators?)

UTILITY A: This utility would not be seeking nor expecting to find LPMSs having significantly greater capabilities than those presently on the market, but rather would like to see modest refinements to present system capabilities. For example, by means of a pre-trigger delay feature, provide digital capture of an entire single-burst impact waveform, so that isolated loose-part events do not go unrecorded. (Note: owing to mechanical inertia of the tape transport, magnetic tape recorders normally miss data arriving within the first second or two following the recorder's start command.)

UTILITY B: New features desired include (1) automated trending of LPMS data; (2) an ability to distinguish between impacts with the RV walls versus impacts with internal structures (i.e., an ability to "see into" the RV internals); and (3) increased attention to the special needs and problems of BWRs.

UTILITY C: "Smarter" microprocessor-assisted LPMSs would be helpful. Also, would like to see (1) simplified switching between active and passive channels (this particular utility's present system requires manual substitution of BNC-terminated cables at the rear of the LPMS cabinet to perform such interchange); (2) application of LPMS principles to achieve improved reliability and operability of secondary-side equipment; and (3) improved ability to detect loose parts promptly at first operation immediately following an extended shutdown during which loose parts may have been introduced inadvertently into the RCS.

UTILITY D: Three areas where improved LPMS performance would be desirable are (1) reliable indication of loose-part mass, so that the identity of the part and the safety significance of its being detached might be determined; (2) means for recording a single-impact event in its entirety; and (3) increased system sensitivity to the lower frequencies, so that information of a different nature, perhaps from larger structures, might be obtained (e.g., a loosened thermal shield).

UTILITY E: This utility does not see any need for additional features; they would just like to see performed whatever fundamental studies or engineering developments are required to realize reliable performance of the functions already claimed for present-day LPMSs.

UTILITY F: First and foremost, they would like to see a LPMS that lives up to user expectations by providing information that is truly useful in the realm of plant operations. Three additional areas where improvements might be made are (1) development of an affordable waveform recording device that has good service life and bandwidth commensurate with that of the accelerometers (i.e., 0 to 25 kHz); (2) development of a remotely operable, calibrated, in-containment impacting device that might be employed to reduce radiation exposure to personnel (alternatively, establishment of a database that would demonstrate that LPMS recalibrations at each refueling are unnecessary); and (3) careful assessment of the suitability of certain accelerometer mounting techniques now widely used; for example, stainless steel straps used to hold sensors in contact with carbon steel coolant pipes.

UTILITY G: They see a need for microprocessor-assisted, "smart" systems to replace an operator's trained ear, because experienced personnel are a volatile commodity. Furthermore, since even the most attentive operators have limited recall and may tire after listening to audio channels day after day, there is need for automated trending of LPMS signal characteristics, performed in such a manner that it is woven into the day-to-day operations and so becomes a means for achieving a better understanding of the plant's operating characteristics.

UTILITY H: They had no suggestions for additional LPMS capabilities; their personnel are poorly trained in the use of the capabilities already provided by their present system.

UTILITY I: Like Utility E, they would just like to see a LPMS that truly lives up to the performance claims already being made by the suppliers of present-day systems.

UTILITY J: Like Utility A, they would like to have uninterrupted recording of data (including the entire waveform from single-impact events) and rapid, convenient recall and display of the information collected. Some indication of loose-part mass or energy associated with impact (hence, damage potential) would also be desirable. Monitoring of the RCS secondary side was judged to be of secondary importance.

(c) *What is your view of the future need for LPMSs? For example, will future technical developments and application practices be motivated more by plant operational needs or by regulatory demands?*

UTILITY A: NRC is the driving force. Utilities don't perform research and development; other than regulatory pressures, dollar return on the plant investment is the only justification for the purchase of any equipment, and benefits exceeding costs are difficult to demonstrate for LPMSs.

UTILITY B: LPMSs are probably more justifiable on a basis of operational economics than on safety to the public; nevertheless, regulatory motivation is very real to the utilities. Both neutron noise analysis and loose-part monitoring are interesting endeavors and will probably show economic payoff in the long term, but benefits are somewhat intangible and are therefore difficult to justify to utility management with hard facts at present.

UTILITY C: They see no present or future need for LPMSs.

UTILITY D: They believe that the better-managed nuclear plants will perceive the valid operational need for LPMSs; the poorer-managed ones, by contrast, will simply react to regulatory pressures and never see the virtues of systems whose main function is actually to protect the utility's capital investment. This utility is concerned, however, over the present sluggish market for LPM systems in view of the need for better technology and the fact that sales are the only source of funds for product development.

UTILITY E: They believe that if utility personnel, both engineers and managers, knew more about loose-part monitors and how to use these systems to their maximum advantage--and if the base technology were better developed so that loose-part assessments were less ambiguous--loose-part monitoring might become a truly useful operational tool for the utilities. As it stands now, however, the LPMS is "just another black box" requiring the attention of engineers and operators and distracting them from their more important duties.

UTILITY F: The future of LPMSs rests upon whether suitable diagnostic functions and indications can be provided; the mere detection of a loose part is insufficient.

UTILITY G: There will be a continuing need for LPMSs. However, maximum benefit to the utilities will be obtained only when the system is accepted by the operator as an extension of his senses and the more traditional control room instrumentation. To achieve such acceptance, the LPMS must be placed in the main control room where the operator has immediate access to it (not hidden away, as many are, in some little-frequented room). The utility industry could benefit immensely from a wider dissemination of the experience that has been gained by both U.S. and foreign plants (e.g., sharing of tape recordings of actual loose parts). Perhaps INPO could perform a clearinghouse role.

UTILITY H: LPMSs will continue to be needed. This utility originally installed its LPMS because of regulatory pressures, but is now convinced of its value for protecting capital investment.

UTILITY I: Although it is too early to tell, experience may prove that LPMSs are not needed for BWRs because their construction may be more tolerant of loose parts. (This plant is a BWR.) Some utilities will surely be driven by regulatory pressures, while others will recognize their own need.

UTILITY J: From this utility's viewpoint, operational need is the true motivating force behind loose-part monitoring; the issuance of Regulatory Guide 1.133 merely shocked the utilities into acknowledging the existence of a problem that was, in fact, real and whose solution would be to their economic benefit.

The facts and opinions on the various issues discussed in the preceding detailed commentaries obtained from U.S. plants are summarized in Sect. 5.

4. INFORMATION OBTAINED FROM FOREIGN PLANTS

As noted in Sect. 2, a formal list of questions was not employed in surveying the loose-part monitoring experience of the three Western European plants visited. The findings from this portion of the LPM survey are therefore documented in a narrative style, beginning with the 1225-MW(e) PWR visited in the Federal Republic of Germany and followed by the two French PWRs [890 and 1290 MW(e)].

4.1 POWER STATION FRG 1 (WEST GERMANY)

FRG 1 is a four-loop, 1225-MW(e) PWR built by Kraftwerk Union (KWU). This particular plant was selected for a visit because it and its combination loose-part and vibration monitoring system (VMS) are typical of the latest generation of West German nuclear power stations.

The LPMS installed on FRG 1 was constructed by Siemens (of which KWU is a subsidiary) and comprises 14 channels, all of which are active (i.e., permanently connected to dedicated amplifiers and discriminators, thereby providing continuous monitoring for structure-borne sounds such as would be produced by impacts) and located in the following positions:

- Six accelerometers on the RV (three on the upper head and three on the lower head, the latter mounted via split clamps on the in-core guide tubes).
- Two accelerometers on each of the four steam generators (one on each inlet water box and one on each shell at the height of the feedwater inlet nozzle).

In addition to these 14 sensors, there are two installed spares (i.e., passive channels) on the RV upper head that could be called into play if a loose part is suspected. The total installed cost of the combined vibration and loose-part monitoring system at FRG 1 (including sensors, amplifiers, spectrum analyzer, control room cabinets, cabling and installation, and documentation and drawings) is said to be ~2,000,000 DM ($800 K), split approximately equally between the VMS and the LPMS.

In the FRG 1 LPMS, ~20 m of mineral-insulated cable connects the accelerometers to the charge-sensitive preamplifiers, which are located inside containment but in rooms that are accessible during reactor operation. This is somewhat different from U.S. systems, which ordinarily employ only ~2 m of hardline cable joined to special temperature-tolerant soft coaxial cable for the remaining cable run to the preamplifiers.

All of the electronics comprising a measurement channel of the FRG 1 LPMS (exclusive of the accelerometer) can be calibrated in one step by means of a sine wave of known amplitude that is injected at the preamplifier input in place of the normal connection to the accelerometer. This switching is accomplished remotely from the auxiliary control room instrumentation rack by reed relays, and so can be done as often as desired. The plant's procedures call for such calibration verification once each month, but once each quarter is said to be customary in most other West German plants.

The accelerometer signals are band limited 1 to 10 kHz before being sent to the discriminator modules, although the wideband signals are also available for aural monitoring or tape recording. Although the West German LPMS DIN standard recommends setting the alarm thresholds at five times the root mean square (rms) background, doing so results in an unacceptable number of false alarms at FRG 1; therefore their procedure is to monitor ~15 min of steady-state, 100% power background noise using an ultraviolet stripchart recorder having a 15-kHz bandwidth, and then to set the discriminator at 2.5 times the largest background peak observed during the 15 min.

Exceeding the threshold signal level on any of the 14 channels causes an alarm in the control room and starts the ultraviolet stripchart recorder for a few seconds, so that the waveforms of any subsequent noise bursts are captured. An audio-quality tape recorder is also provided with the FRG 1 LPMS, but it is used only for aural comparisons because its recording fidelity was said to be insufficient to permit meaningful spectral analysis.

The following was learned with regard to impact calibration and daily use of the LPMS by the operators:

- Impact calibrations were performed as a part of the plant commissioning (i.e., prior to initial hot operation). The work was done cooperatively by KWU and the utility, with on-site overview by a regulatory agency representative.

- All 14 accelerometer signals are aurally monitored by control room personnel once each 8-h shift, using a special listening station (installed in one corner of the main control room) at which all channels of the LPMS are simultaneously available for listening, either singly or summed in any desired combination. However, no quantitative data are recorded.

4.2 POWER STATIONS FR 1 AND FR 2 (FRANCE)

These two plants were chosen for interview on the basis of their typicality; they are the lead units for the Framatome/EdF 900- and 1300-MW(e)-class plants.

While the total number of accelerometers employed in the Electricité de France (EdF) LPMS design (9 to 13 for three-loop plants; 15 or 16 for four-loop plants) is roughly the same as for West German LPMSs, the sensor placement favors the steam generators rather than the reactor vessel. This emphasis reflects French experience with damage caused by loose parts. However, the French design has evolved over time. It initially employed two accelerometers mounted on the central in-core instrumentation guide tube at the point where it penetrates the lower RV head, plus five on upper head studs and one on each SG (in the earliest reactor series); an intermediate design employed three accelerometers on three separate guide tubes 120° apart, plus two on each SG but none on the RV upper head; and the current French LPMS design employs three accelerometers on each SG plus the other provisions of the intermediate design. The trend seems clear: more sensors (to provide redundancy and permit triangulation of noise source) in natural collection regions (lower vessel head and steam generator inlet box) where problems have actually occurred, and sensor elimination in non-problem areas (upper plenum and pumps). In all fairness, however, it must be pointed out that elimination of the accelerometers from the RV upper head was said to be a temporary economy measure, and it was hoped that these sensors would be reinstated for future plants and backfitted to those presently lacking them. Another design evolution is the transition from expensive high-temperature accelerometers mounted directly on the SG shell to considerably cheaper low-temperature accelerometers mounted on waveguides, which are simply the support studs for the mirror insulation surrounding the SG.

Signal transmission from the sensors to the conditioning equipment (amplifiers, discriminators, loudspeaker for auditory monitoring, etc.) was found to be conventional in FR 1 and FR 2 except that, in contrast to the West German LPMSs, there is no provision for injecting calibration signals directly into the charge converters in substitution for the normal accelerometer signals. The auxiliary control room instrumentation in each plant is separated into two distinct functional units:

1. A continuous monitoring device called DEVIANT, which alarms when any channel's signal exceeds either a selected multiple of rms background or an absolute rms limit, and which logs the time of occurrence and other relevant parameters.

2. A manually operated listening and data logging station consisting of the usual loudspeaker/selector switch, 4-channel cassette recorder, and ultraviolet graphic recorder; plus a digital transient capture oscilloscope and two true rms meters, one operating in time-averaged rms mode and the other in peak-hold mode (these two indications permit a manual calculation of signal crest factor).

The DEVIANT system, which is installed in some form in all French plants, originally had only three active channels (the steam generator accelerometers); for the new 1300-MW(e) plants like FR 2, however, it has been expanded to monitor 16 channels.

The sensitivity of the standard EdF LPMS has been determined at a few plants by impacting the interior surfaces of both the reactor pressure vessel and the steam generator inlet water box in a controlled manner, recording the peak waveform values, and comparing these to the peak background noise values observed under various operating conditions at the large number of French plants that have been studied. Defining the "detectability" of an impact immersed in noise as that level required to produce a peak signal value three times larger than is likely to be observed in the normal background, the French results show that an impact delivering ~0.1 J to the bottom of the RV or ~0.03 J to the bottom of the SG will be detectable. (By comparison, the NRC Regulatory Guide 1.133 suggests a target sensitivity of 0.68 J for an impact occurring 0.9 m from the sensor.) These three impact energies (0.1, 0.03, and 0.68 J) translate into loose-part masses of 50, 15, and 340 g, respectively, assuming the speed at impact to be 2 m/s. The reported EdF LPMS sensitivity compares favorably with that reported by the West Germans.

The approximate cost of a typical EdF 16-channel LPMS such as installed at FR 1 and FR 2 is $80,000, including the DEVIANT continuous monitoring device.

In talking with the manager of technical services at each of the French plants and observing the on-site collection of data, it became apparent that there are two major differences between the surveillance modes in which the vibration and loose-part monitoring systems are utilized at French and West German plants:

- In France the surveillance systems are used continually, and quantitative LPMS data are recorded frequently; in West Germany the surveillance systems are mostly held in a reserve or standby condition, and the LPMS serves chiefly as a qualitative remote listening device.
- In France surveillance is performed primarily by plant personnel, technically assisted by EdF noise specialists; in West Germany experts from outside the utility perform all surveillance other than daily listening to the LPMS channels.

Since its first attainment of full power, FR 1, for example, has executed a surveillance program with the following procedural frequencies:

- Daily the operation of the LPMS is verified. All sensors are monitored with the loudspeaker, and the signals from five selected accelerometers--the bottom of the steam generator on each loop and the reactor vessel lower and upper heads--receive special attention: they are examined on an oscilloscope and their peak and rms readings are recorded. The continuously operating stripchart recorder is also annotated. This is said to require ~15 min/day of one plant technician's time.
- Weekly the signals from all sensors are recorded on the wideband ultraviolet chart recorder. This work, exclusive of analysis of the data obtained, is said to require ~1 h of technician time, including the calibration of the recorder.
- Monthly the condition of the reactor internals is assessed by using on-site equipment to perform spectral analyses on four selected sensors (two accelerometers and two ex-core neutron sensors positioned 90° apart). The results are then compared

with reference spectra acquired at the beginning of the current fuel cycle. The alarm threshold settings of DEVIANT are checked and the magnetic tape recorder autostart feature is verified, all of which requires ~4 h. Copies of the spectra so obtained are sent to EdF offices in Paris for scrutiny, trending, and cataloging.

- Quarterly full neutron flux and acceleration spectra (covering an analysis range of 0 to 50 Hz on both accelerometers and neutron flux, plus 0 to 20 kHz on accelerometers only) are acquired on all surveillance system sensors in order to verify their continued "health" and that of the plant. Simultaneously, the raw signal waveforms of all sensors are recorded on the ultraviolet chart recorder. The acquisition of all these data was said to require ~20 h of a technician's time. Detailed analysis of the spectra so obtained is performed by EdF noise specialists in Paris.

- Semiannually (particularly at the beginning and end of each fuel cycle) all surveillance system sensor signals are recorded on a four-channel cassette magnetic tape recorder. The cassette is then sent to EdF offices for a full-fledged cross-spectral analysis, because only single-channel analyses can be performed at the plants. Neutron flux signals are recorded simultaneously with reactor vessel accelerometer signals on this recording to permit evaluation of reactor internals. The data acquisition typically requires 40 h of a technician's time. No estimate of the analysis time expended by the EdF noise specialists was available.

FR 1's comprehensive program of data acquisition and interpretation is said to be typical and is the very heart of the French surveillance program; it seems, to a great extent, to account for their success* in detecting primary system performance problems at an early stage.

Being the first of a new series of nuclear power plants, FR 2 is equipped with rather elaborate monitoring facilities. For example, this plant actually has four distinct LPMSs:

- A three-channel DEVIANT monitor temporarily installed in a room adjoining the main control room. The system is operated by the EdF Construction Division and is intended to provide protection until the plant is commissioned, after which it will be removed.

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*For examples, see C. Puyal, A. Fernandes, and C. Vincent, "Primary System Surveillance and Diagnostics of PWR Power Plants in France," *Proc. Fifth Power Plant Dynamics, Control, and Testing Symp., March 21- 23, 1983, Knoxville, Tennessee*, Vol. 2, Paper 42.01. Also, C. Puyal, A. Brillon, and A. Fernandes, "French Experience in Loose Parts Detection," *Proc. IAEA Specialists' Mtg. on Early Diagnosis of Failures in Primary System Components of Nuclear Power Plants, June 21-25, 1982, Prague, Czechoslovakia*, IAEA TC-SR/1, pp. 202-19.

- A 16-channel DEVIANT monitor (presently incomplete), which will eventually replace its three-channel predecessor.

- A classic, completely manual 16-channel LPMS, which will be used by the plant operators once the plant is placed in commercial operation to perform the daily, weekly, monthly, and other data acquisitions and analyses described earlier in connection with FR 1.

- A four-channel, acoustic-emission-type system temporarily installed (using magnetic attachments) on the steam generators by Framatome because the steam generators of FR 2 have modified internal structures that are heavily instrumented and there is some concern that these temporary internal sensors might become detached (as they have in the past) and thereby become damaging loose parts.

As in West Germany, an abundance of high-quality, modern equipment was found to be in use on the French surveillance programs. At FR 2, for example, the team of two engineers and six technicians who were performing acoustic monitoring during the plant's startup testing program had at their disposal two 14-channel analog tape recorders, a single-channel Fourier spectrum analyzer, two dual-channel Fourier analyzers (one of which was controlled by a desktop computer and interfaced to a floppy disk and a four-color digital plotter), ~20 channels of charge-sensitive preamplifiers, and ~10 channels of miniature signal-monitoring oscilloscopes.

4.3 SUMMARY OF FOREIGN PLANT EXPERIENCE AND OUTLOOK

Apparently both the French and the West German reactor communities regard NSSS vibration and loose-parts monitoring as being important to the overall operability and safety of their plants, as evidenced by the considerable investment that has been made in specially installed hardware and in the personnel necessary to perform periodic measurements and data assessment. Both communities have experienced a modest amount of success in using these systems to detect design defects and operational problems sufficiently early to minimize mechanical damage and resultant reactor downtime. As a result, both countries are expanding their monitoring system designs in the latest series of large [1300-MW(e)] nuclear units. There is considerable difference, however, in the manner in which the monitoring systems of the two countries interface with routine plant operation: in France, measurements of increasing thoroughness are performed (for the most part by plant personnel) on a daily, weekly, monthly, quarterly, and semiannual schedule and are analyzed independently by plant personnel and off-site noise specialists; in West Germany, comprehensive measurements are typically performed (by KWU, overseen by a representative of the regulatory agency) only at initial plant commissioning, with some data updates (performed at the utilities' discretion by private organizations) following major plant outages such as refueling. Stated somewhat differently, the French use their surveillance systems almost continuously, whereas the West Germans place theirs in a standby condition once initial plant commissioning is complete.

The loose-part monitoring systems employed in all of the newer French and West German reactors (their implementation is mandatory) usually have more sensors, all of which are "active," and more special features (such as remote calibration) than is typical for U.S. plants, thereby making the cost of these systems somewhat higher than the norm for LPMSs in U.S. plants. However, with the exception of the additional sensors, there is nothing novel about either the Western European LPMS equipment or the data processing operations performed during routine monitoring for loose parts and during the diagnostic phase which occurs if a loose part is suspected.

The degree of automation employed in both the West German and the French surveillance system designs is quite low, thereby demanding the periodic attention of plant personnel (and perhaps noise experts). However, it appears that the degree to which both loose-part and vibrational monitoring in French and West German reactors has been successful is attributable in large measure to just such periodic attention by humans, which brings into play their ability to discern the minor changes in signal character that may be harbingers of trouble, and their accompanying curiosity in trying to associate a cause with an effect.

It is generally agreed among West German and French LPMS experts that the major challenge now facing LPM technology is the development of a reliable, clear-cut indication of the presence of a damaging loose part during plant startup following maintenance operations that necessitated entry into the RCS primary, since the likelihood of correctly diagnosing a loose part is poorest under these conditions (owing to the high level of acoustic background) while, simultaneously, a loose part is most apt to be present in the RCS and the need to detect it without delay is greatest.

5. SUMMARY AND CONCLUSIONS

This section summarizes, insofar as possible, the findings of this survey of loose-part monitoring system users, particularly as they relate to the ten general topics on which information was sought (Table 1). It may be argued that this endeavor is neither necessary nor wise, since (1) the detailed responses of the U.S. utilities (Sect. 3) and the observations from the Western European plant visits (Sect. 4) speak for themselves; and (2) among the U.S. utilities surveyed there appears to be almost no unanimity of opinion in the question areas, so any attempt to generalize the responses and draw succinct conclusions therefrom will necessarily distort the findings and make issues seem more clear-cut and opinions less controversial than they really are. However, it is felt that despite such pitfalls, there remains an obligation to the reader to sift through the mass of somewhat diffuse information and digest it into a set of concise statements whose significance can be more readily grasped.

Another concern must also be raised: A small and very likely biased sample of plants were interviewed. Ten U.S. and three Western European generating stations cannot be presumed to speak for the entire nuclear industry. Moreover, since plant experience with one or more LP incidents was a high-ranking criterion for inclusion in this survey (BWRs excepted), older plants (implying smaller NSSS capacities, less sophisticated LPMSs which were put into operation prior to the issuance of Regulatory Guide 1.133, etc.) are necessarily overrepresented.

With the above caveats in mind, the major survey findings are presented below in the order of their appearance in the topical listing (Table 1).

5.1 ACHIEVABLE LPMS SENSITIVITY; SYSTEM CALIBRATION PROCEDURES

- *The ability to detect LPs in the primary coolant system during full-power operation appears to be substantially better than called for by NRC Regulatory Guide 1.133 (which recommends a sensitivity of 0.5 ft-lb = 0.68 J).*

  - The French and West Germans have calibrated impact data which show detectability limits of 0.03 J in the SGs and 0.1 J in the lower RV at 3 to 5 times normal background (which corresponds to 15 to 50 g mass for v = 2 m/s).

  - Plants in both the U.S. and Europe have, in fact, detected parts of mass 30 to 100 g by means of their LPMSs.

- *The calibration methods in common use have not been entirely satisfactory, either for "cold" plant conditions (initial LPMS calibration) or "hot" conditions (recalibration at refueling).*

- The methods for introducing calibrated impacts are generally slow and clumsy, lack reproducibility, and may not produce sonic waves that are representative of the variety of potential loose parts.

- Plant personnel receive an excessive radiation dose while performing system recalibration once the plant has operated at power.

- Completely remote means for introducing calibrated impacts of various energies should perhaps be considered.

5.2 APPLICABILITY OF LP TECHNOLOGY TO BWRs

- *Experience with loose parts and the LPM technical database are both very meager for U.S. BWRs. At present, there are only one or two large U.S. BWRs that have had LPMSs in operation for an appreciable length of time, and these plants have only rudimentary LPM programs.*

- *Experience and a technical database for Western European BWRs are likewise limited. The French have no BWRs and the West Germans have had only two or three minor LP occurrences in their BWRs.*

- *The only other likely sources of BWR information would be Japan and Sweden, who were not surveyed in this study.*

5.3 ABILITY TO DETECT SECONDARY-SIDE LOOSE PARTS IN PWRs

- *Impact response data with which to support conventional choices for the number and specific locations of acoustic sensors necessary to assure adequate monitoring capability are largely unavailable, even for primary-side LPs.*

- *The sensitivity of present-day LPMSs to secondary-side LPs appears to be unknown. Some speculate that different sensor locations and/or mounting techniques could improve sensitivity if that is needed. Despite a number of secondary-side incidents (e.g., SGTRs), this topic does not seem to be of intense interest to utilities.*

5.4 EXPERIENCE WITH FALSE/UNEXPLAINABLE LPMS ALARMS

- *The LPMSs presently offered are technically superior to and better human engineered than the systems available at the time of the previous survey (1977). False alarms are no longer a major problem, provided the systems are correctly installed and the alarm setpoints are properly chosen.*

5.5 ALARM LOGIC DETAILS; PROCEDURE FOR CHOOSING ALARM SETPOINTS AND MODIFYING THEM DURING PLANT OPERATION

- *Unfortunately, alarm setpoints are not always chosen properly. Setpoints are often established by utilities on a basis of* *tolerable false alarm rate, without regard for LP sensitivity. Likewise, setpoints recommended by LPMS suppliers are sometimes adopted unquestioningly by the utilities, without a proper understanding of their technical basis. Some utilities alter alarm setpoints during plant operation without proper documentation.*

5.6 WORKABILITY/USEFULNESS OF NRC REGULATORY GUIDE 1.133

- *U.S. utilities have exhibited some reluctance to accept NRC Regulatory Guide 1.133 in its entirety.*

  - Some have formulated their LPM programs independently of the RG; some have never read the Guide.

  - Some believe that the Guide is unrealistic because it presumes a mature technology that is, in their view, still in its infancy.

  - Seismic, channel separation, and sensor redundancy aspects of the RG are, quite generally, thought to be unwarranted and are rarely met completely (at least for LPMSs placed into operation prior to the Guide's implementation date, January 1, 1978).

  - Most plants make no periodic data recordings and neglect the background trending called for by the Guide.

  - LP reporting requirements are largely ignored.

  - Few (if any) of the older, backfitted plants have committed to follow all aspects of the Guide.

5.7 EXPERIENCE WITH RADIATION AND/OR TEMPERATURE DAMAGE OF IN-CONTAINMENT LPMS COMPONENTS (SENSORS, PREAMPLIFIERS, CABLES, CONNECTORS)

- *When properly selected, in-containment LPMS components have shown minimal calibration drift and adequate service life despite high temperatures and radiation. In view of this experience, LPMS recalibration during each reactor refueling period may be unwarranted.*

5.8 EXPERIENCE WITH DETECTING LOOSE PARTS AND ASSESSING THEIR OPERATIONAL AND SAFETY IMPLICATIONS

- *LPMS experience in both Western Europe and the U.S. has been, for the most part, positive in the last few years. Improved performance in the U.S. since the previous ORNL survey (1977) is a result of better hardware plus additional experience and understanding of how to interpret loose-part indications. Reflections of this positive outlook:*

- Western European utilities are expanding their on-line monitoring systems (both loose parts and vibrations) in their latest series of large [1300-MW(e)] nuclear units.

- In the U.S., some utilities are now installing or upgrading their LPMSs because of recognized need; regulatory pressure is no longer the sole motivating force behind LPM programs.

- *However, as in 1977, most U.S. utilities still have little in-house expertise with LPM and therefore rely heavily on the NSSS supplier, the LPMS manufacturer, or outside consultants for assistance if a LP is suspected. Surprisingly, the sharing of LP experience among U.S. utilities appears to be minimal.*

- *The U.S. utilities with the most successful loose-part monitoring programs are those with staff that are well trained in LP technology, dedicated to the realization of their system's full potential, and supported by their management.*

5.9 COMPARISON OF LPMS TECHNOLOGY EMPLOYED IN THE U.S. WITH THAT OF WESTERN EUROPE

- *The technology employed is essentially the same. However, the European systems surveyed were found, generally, to*

  - Employ more continuously monitored sensors

  - Be more carefully integrated into the overall NSSS design and instrumentation philosophy

  - Require more periodic attention by both plant personnel and noise specialists

  - Be regarded more seriously as important adjuncts to overall plant operability and safety

  than their U.S. counterparts. Their philosophy of LPMS use is somewhat different as well:

  - in the U.S., it is a watchdog

  - in the FRG, it is a watchdog plus a plant commissioning tool

  - in France, it is a watchdog, a plant commissioning tool, and a complement to more conventional instrumentation in making daily plant operational decisions.

5.10 NEEDED IMPROVEMENTS; FORESEEABLE TRENDS

- *The French and West Germans consider the major challenge remaining in LPM technology to be reliable indication during plant startup following RCS maintenance (when there is the greatest need for detection of LPs but poorest detectability), and they have initiated research in this area.*

- *Many U.S. utilities see a need for microprocessor-assisted, "smart" systems to replace an operator's trained ear, because experienced personnel tend to be a volatile commodity and are always in short supply.*

- *Although it is reasonable to anticipate additional user convenience and packaging improvements in future LPM hardware, there is presently no driving force behind this technology and therefore little reason to expect vastly improved performance capabilities in future LPMSs.*

- *Since U.S. utilities are increasingly recognizing the value of LPMSs as a protection of their investment, deliberate yet cautious upgrading of both personnel training and the LPM equipment utilized seems likely in the future.*

6. RECOMMENDATIONS

The overall prognosis suggested by the condensed survey findings listed under Items 8 and 10 of Sect. 5 is that, despite its rather rough beginnings, the technology of loose-part monitoring in commercial light-water reactors now appears to be proceeding on a somewhat smoother course--one of slow but steady progress--that will ultimately repay the utilities for their investments in hardware and training by decreasing the likelihood of unnecessary and/or lengthy plant shutdowns resulting from reactor coolant system damage inflicted by the undetected presence of loose or drifting metallic parts.

Nonetheless, the survey findings also revealed deficiencies in four principal areas which, if they were to be corrected, would likely yield smoother, more rapid progress toward the desired goals of early and reliable detection of significant loose-part situations. Recommendations for correcting these deficiencies are listed below without regard for priority.

6.1 IMPROVE COMMUNICATIONS AMONG UTILITY USERS OF LPMSs

One way to improve communications would be to hold periodic workshops (perhaps organized by the Institute for Nuclear Power Operations--INPO) at which LPM experience could be shared freely among those who are intimately familiar with the equipment and are in a position to benefit from the lessons learned by their counterparts at other utilities.

Another way to improve communications would be to assemble a group of experienced LPM practitioners and charge them with producing an "industry standard practice" document to provide guidance and promote uniformity in this new and little-published field. Interest in the creation of such a guideline document (which should not be duplicative of NRC Regulatory Guide 1.133) has already been expressed by a subcommittee of the American Society of Mechanical Engineers (ASME).

As the LPM field comes on firmer footing, public forums--perhaps in the form of special sessions, panel discussions, or workshops held in conjunction with topical conferences or general meetings sponsored by ASME or ANS--might also prove beneficial as means for promoting the best available technology and practices.

An added benefit accruing from improved communications among utility users is the likelihood of greater interest in and adherence to the practices recommended by Regulatory Guide 1.133 as a result of an increased appreciation for both the operational and safety benefits of well-founded loose-part monitoring programs.

6.2 ESTABLISH COMPREHENSIVE TRAINING IN LPMS TECHNOLOGY FOR PLANT PERSONNEL

A complaint heard many times during the plant interviews was, "I've never heard what a real loose part sounds like, so I have no idea what

I'm listening for during daily aural monitoring." Given the number of loose-part occurrences now on record in both U.S. and foreign reactors, such lack of training is inexcusable.

In the same vein, personnel in more than one of the plants interviewed revealed that though the LPMS manufacturer offered a training course in how to maintain and use the monitoring system, "I haven't gotten around to taking it yet," even though his LPMS had been operational for several months. Another reason offered for lack of adequate training was "My company won't send me; it costs too much, and besides they can't spare me here at the plant."

To correct such shortsightedness, it is important that personnel at all levels of a utility's organization recognize that present-day LPMSs are not always completely automatic in their indication--subjective interpretation is often required--and hence thorough personnel training is an essential ingredient to the realization of their monitoring system's performance potential.

6.3 IMPROVE LPMS BASE TECHNOLOGY

This survey failed to reveal the existence of a body of "hard" scientific data, gathered under controlled experimental conditions, providing answers for some very fundamental, practical questions associated with LPM technology. For example, how many sensors are really necessary to ensure adequate acoustic coverage of a PWR (or BWR), and exactly where should they be placed for optimum LP detection sensitivity and signal interpretability? Can impacts occurring deep within a vessel (e.g., within the tube bundle of a steam generator or within the steam separator region of a BWR's upper internal structures) be sensed reliably by accelerometers mounted on the thick vessel's exterior surface? What frequency region(s) is optimum for LP monitoring, taking into account that the mass, shape, and energy of a credible LP may range over a considerable span of values? How can acoustic clicks, pops, and creaks arising from thermal expansion and contraction within the NSSS during plant startup/shutdown be confidently distinguished from the very similar sounds (for which there should be genuine concern) produced by metallic impacts of true loose parts? Until definitive answers are obtained for fundamental questions such as these, the development of LPMSs having superior performance capabilities will necessarily be impeded.

6.4 REESTABLISH A DRIVING FORCE FOR LPM TECHNOLOGY DEVELOPMENT

There is a need to reestablish a driving force--provided in years past by NRC Regulatory Guide 1.133--which would keep LPM technology development from becoming stagnant. Means should be sought for improving communications among utility users, method developers, and manufacturers of LPMSs and for encouraging the suppliers of these systems to further develop the application technology and refine their products. Such encouragement might be provided indirectly by INPO in the form of recommendations to utilities to upgrade their LPM programs. A more direct, and likely more effective, approach would be for the utility purchasers themselves--acting either individually or through an industry-representative agency such as EPRI--to demand more effective LPMSs from their suppliers, at the same time expressing a willingness to shoulder a portion of the development costs.

In addition, means should be sought to encourage vigorous, joint efforts among utilities and LPMS suppliers to correct the technical deficiencies of LPMSs already in service.

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If the above four issues are addressed, over the next few years the full benefits--to both plant safety and economics--of loose-part monitoring systems could be realized in U.S. nuclear plants.

NUREG/CR-3687
ORNL/TM-9107
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109. Office of Assistant Manager for Energy Research and Development, ORO, Oak Ridge, TN 37831.
110-111. Technical Information Center, Oak Ridge, TN 37831.
112-386. Given distribution under NRC category R1 (NTIS-10).

NRC FORM 335 (11 81)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER (Assigned by DDC)
NUREG/CR-3687
ORNL/TM-9107

4. TITLE AND SUBTITLE (Add Volume No., if appropriate)
Loose-Part Monitoring Programs and Recent Operational Experience in Selected U.S. and Western European Commercial Nuclear Power Stations

2. (Leave blank)

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
R. C. Kryter

5. DATE REPORT COMPLETED

MONTH	YEAR
January	1984

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37831

DATE REPORT ISSUED

MONTH	YEAR
February	1984

6. (Leave blank)

8. (Leave blank)

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Facility Operations
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

10. PROJECT/TASK/WORK UNIT NO.

11. FIN NO.
B0191

13. TYPE OF REPORT
NUREG/CR

PERIOD COVERED (Inclusive dates)

15. SUPPLEMENTARY NOTES

14. (Leave blank)

16. ABSTRACT (200 words or less) Technical personnel at thirteen nuclear power stations (ten in the U.S.A. and three in Western Europe) were interviewed to ascertain their collective experience with acoustic-based loose-part monitoring systems (LPMSs). Subjects receiving special attention were the number and location of accelerometers required to reliably detect and locate loose parts in both pressurized- and boiling-water reactor types; detection sensitivity to loose objects in both primary and secondary coolant loops; false alarm experience; calibration procedures; day-to-day monitoring system operation; premature failure of in-containment components of the LPMS; and overall success to date in detecting the presence of potentially damaging loose parts and in assessing their operational and safety implications. The individual utilities' responses to questions addressing these issues are provided, along with the author's summary and interpretation of what the information gathered means in a collective sense.

It is concluded that the technology of loose-part detection and assessment is moving slowly toward increased acceptance by the utility industry but, at the same time, the full potential benefits of loose-part monitoring systems are not presently being realized and, furthermore, probably will not be unless actions are taken in four recommended areas.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS (This report)
Unclassified

20. SECURITY CLASS (This page)
Unclassified

21. NO. OF PAGES

22. PRICE
$

NRC FORM 335 (11 81)

120555078877 1 1AN1R1
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POLICY & PUB MGT BR-PDR NUREG
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