UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

NOV 27 1979

MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

Robert B. Minogue, Director
Office of Standards Development

FROM: Saul Levine, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 75
INVENTORY, DETECTION, AND CATALOG OF OKLAHOMA EARTHQUAKES AND EARTHQUAKE MAP OF OKLAHOMA, MAP GM-19

REFERENCES:
1. Letter W. R. Stratton to Dixie Lee Ray dated May 16, 1973. Subject: Report on Seismic Research.
2. Title 10, Chapter 1, Part 100, CFR Appendix A - Seismic and Geologic Siting Criteria for Nuclear Power Plants.
3. Memo: N. B. Steuer to R. J. Mattson dated July 15, 1975. Subject: U.S. Tectonic Province Map.

INTRODUCTION

This memo transmits "Inventory, Detection and Catalog of Oklahoma Earthquakes and MAP GM-19 (Earthquake Map)." The research effort to produce this report was conducted by the Oklahoma Geological Survey. This research is a cooperative geologic, seismic and geophysical effort of the State Geological Surveys of Oklahoma, Kansas, Nebraska, Iowa and Minnesota to study the earth science parameters of the Nemaha Uplift and the Midcontinent Gravity Anomaly. The Nemaha Uplift and Midcontinent Gravity Anomaly are buried geologic structures with which some scientists have associated history of earthquake activity. Hence, a knowledge of the Nemaha Uplift and Midcontinent Gravity Anomaly is of vital importance in the siting and licensing of nuclear power plants.

SUMMARY

Geologic and seismologic investigations of the Nemaha Uplift began on October 1, 1976. The geological studies have focused, thus far, on the construction of a series of structure-contour maps on key stratigraphic horizons--the top of the Viola Formation, the base of the Pennsylvanian, and the top of the Oswego Formation. It appears that the uplift and associated faults began in Early Pennsylvanian time and that tectonic activity ceased in Middle Pennsylvanian time, at least in central Oklahoma.

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Seismological Studies

Following an initial site-analysis study, which incorporated earthquake-detection levels, an eight seismometer installation was proposed in such a way as to include detailed coverage of the entire Nemaha Uplift as well as most of the remaining area of Oklahoma (Fig. 1). This network of seismograph stations would allow the following capabilities: (a) marginal detection of all m_{3Hz} 1.7 earthquakes; (b) reliable detection of all m_{3Hz} 2.0 earthquakes; (c) marginal location of all m_{3Hz} 1.8 earthquakes; and (d) reliable detection of all m_{3Hz} 2.1 earthquakes.

It was anticipated that the maximum detection capability of the network would overlap into Kansas and provide with the Kansas and Nebraska networks, continuous coverage of the Nemaha Uplift area.

Since 1900, at least 182 earthquakes have occurred in Oklahoma. Of these, 90 earthquakes were reported felt by people, and the locations of the remaining earthquakes were determined from data recorded at distant and/or local seismograph stations. Prior to 1954, more than half of the known Oklahoma earthquakes occurred in the vicinity of El Reno. In fact, the most intense earthquake disturbance known in Oklahoma took place near El Reno on April 9, 1952. This earthquake was felt in Des Moines, Iowa, as well as in Austin, Texas, and covered a felt area of approximately 362,000 square kilometers (140,000 square miles). An earthquake near Cushing in December 1900 is the earliest documented earthquake in Oklahoma. This event was followed by two additional earthquakes in the same area in April 1901.

The accompanying earthquake map of Oklahoma and catalog display the location of earthquake epicenters and their corresponding intensity values arranged into four time-period intervals. The beginning of each new time period represents a major change in seismic instrumentation, which resulted in improved earthquake detection and location accuracy. The map is intended for use as a guide to earthquake intensity and epicentral locations. The epicentral locations are based on data that may vary greatly in accuracy, particularly regarding earthquakes that occurred prior to 1960.

Tectonic Setting

Oklahoma is situated near the southern end of a geologic region referred to as the Stable Central Province (King, 1951; Hadley and Devine, 1974). This province, which covers more than 2.5 million square kilometers (1 million square miles), extends westward from the Appalachians to the eastern edge of the Rocky Mountains and from the Gulf Coastal Plain to south-central Canada.

The geologic and tectonic record in Oklahoma is mainly characterized by marine sedimentation which was termined by episodes of uplift, gentle folding, and erosion, which, in turn, was followed by renewed sedimentation occurring on the unconformable surfaces (Ham and Wilson, 1967). The three principal mountain belts in Oklahoma are the Ouachita, Arbuckle, and Wichita Mountains (Fig. 2). These were the sites of folding, faulting, and uplift during the Pennsylvanian and Early Permian Periods. In addition to exposing a great variety of structures, these fold belts brought to the surface igneous rocks in the Arbuckle and Wichita Mountain areas and exposed thick sequences of folded and faulted Paleozoic sedimentary rocks in the Ouachita Mountains. Principal sites of sedimentation were in elongated basins that subsided more rapidly than adjacent areas and received sediments 3,000 to 12,000 meters (10,000 to 40,000 feet) thick. The major sedimentary basins were confined to the southern half of the State and include the Anadarko, Arkoma, Ardmore, Marietta, and Hollis Basins and also the Ouachita Basin at the site of the present Ouachita Mountains. The Nemaha Uplift, a prominent feature in central Oklahoma, is a long north-south structure that extends northward from central Oklahoma through Kansas and into Nebraska. The Oklahoma portion of the ridge is 16 to 32 kilometers (10 to 20 miles) wide and nearly 240 kilometers (150 miles) long. The Nemaha Uplift, which developed mainly during the Pennsylvanian, consists of small crustal blocks that were raised sharply along the axis of the uplift. Uplifted crustal blocks that make up the Nemaha Uplift are typically 5 to 8 kilometers (3 to 5 miles) wide and 8 to 32 kilometers (5 to 20 miles) long and are bounded by faults on the east and/or west sides of the Nemaha structures.

The Stable Central Province has displayed little tectonic activity since Late Pennsylvanian time. The historical record of seismicity in the region has been limited, with a notable exception being the area of New Madrid, Missouri, and adjacent regions in Kentucky, Tennessee, and Illinois.

The New Madrid earthquakes of 1811 and 1812 are probably the earliest historical earthquake tremors felt in Oklahoma (then Arkansas territory) by early residents in southeastern Oklahoma settlements. The earliest documented earthquake in Oklahoma occurred near Cushing in December 1900. This event was followed by two additional earthquakes in the same area in April 1901 (Wells, 1975). The largest known Oklahoma earthquake occurred near El Reno on April 9, 1952. This magnitude 5.5 (Gutenberg and Richter, M_b) earthquake was felt in Austin, Texas, as well as Des Moines, Iowa, and covered a felt area of approximately 362,000 square kilometers (140,000 square miles) (Docekal, 1970; Kalb, 1964; von Hake, 1976). The April 9, 1952 earthquake was followed by numerous aftershock events that lasted until August 14, 1952. While the El Reno area was the site of Oklahoma's most famous earthquake, several earthquakes have occurred in this area since 1908. In Oklahoma at least 182 earthquakes have occurred (Earthquake Map).

Earthquake Inventory

Knowledge of an earthquake, at least in historic times, depended entirely on the perception and sensitivity of people. An earthquake produces seismic waves with vibrations that can be felt and/or heard by humans, and a large earthquake may also cause damage to buildings or other man-made objects as well as altering river courses and felling trees. The waves can also be recorded by seismographs, instruments designed and operated to record earthquake waves.

Prior to about 1950, the few seismographs that operated in states adjacent to Oklahoma were not sensitive enough to detect most earthquakes occurring in the state. Only written records of humans having felt earthquakes were available. These records were usually in local newspapers only. Some of the larger earthquakes felt had been listed in the "Seismological Notes" column of the bimonthly bulletin of the Seismological Society of America. A more complete listing appeared, beginning about 1929, in the annual publication United States Earthquakes.

The University of Oklahoma Earth Sciences Observatory, the Oklahoma Geological Survey, and the U.S. Nuclear Regulatory Commission started a cooperating program in 1976 to study seismicity of the Nemaha Uplift and other areas of Oklahoma. The Observatory staff began a program to computerize the accumulated earthquake catalog, which included a compilation of earthquake information from published and unpublished reports, with the data held on magnetic tape for complete or selected printing whenever needed.

The accumulated earthquake data were grouped according to earthquake intensity as well as four time-period intervals (Earthquake Map). The time categories were chosen to reflect those changes, such as seismograph improvements, that enhanced the detection and location of Oklahoma earthquakes.

Seismograph Network

The data required for location of local earthquakes consist of the arrival times of P and S phases at several (at least three) separate locations. These arrival times are obtained from seismograms that record an irregular line within amplitude that varies with time. It represents vertical ground motion over a frequency range of 1 hertz to about 20 hertz. The seismograms are also used to determined amplitude of ground motion, which is used to calculate earthquake magnitude.

In Oklahoma, ground motion at ten widely separate locations is recorded (Fig. 1, Table 1). One of these sites is the Oklahoma Geophysical Observatory (abbreviation TUL) near Leonard, formerly the University of Oklahoma Earth Sciences Observatory. It was operated by Jersey Production Research Co. (now Exxon) from December 1961 to 1965 and by the University of Oklahoma from 1965 to 1978. In July 1978, the Observatory was transferred to the Oklahoma Geological Survey and renamed the Oklahoma Geophysical Observatory. However, before 1972, the seismographs, designed to record phases from distant earthquakes, were not optimum for recording the higher frequencies, characteristic of local earthquakes. Beginning in 1972, the recording of local earthquakes was greatly improved by the development and operation of additional seismographs.

Earthquake Catalog

An inventory of all known, locatable Oklahoma earthquakes is kept in a permanent file and stored on magnetic tape for use with a Hewlett Packard HP-9825 desk-top computer system for easy storage and retrieval. Major catalog categories include the event number, date, origin time, county, intensity, magnitude, location, focal depth, and source information. The information can be printed in a page-size format, and Appendix B contains a modified version of a 1900-1978 Oklahoma earthquake catalog.

The event number is the first entry in the catalog. The earthquakes are chronologically numbered, with number 1 being the first earthquake known to have occurred in Oklahoma. Each earthquake is numbered on the earthquake map, and this number corresponds to the equivalent event number in the catalog.

BACKGROUND

Support for Licensing Decisions

In 1973 (Ref. 1) the ACRS recommended that investigations be initiated to determine the reasons for, and source of, earthquakes in areas of the eastern U.S. where large shocks have occurred.

Also, this recommendation was, in part, brought about by Appendix A, 10 CFR Part 100 (Ref. 2), which establishes requirements for seismic and geologic site investigations for nuclear power plants and associated nuclear facilities necessary for evaluation of the site and for providing information needed for engineering purposes. Paragraph (6), Section IV of Appendix A requires that, where possible, epicenters of historically reported earthquakes be correlated with tectonic structures, any part of which are within 200 miles of the site; and that epicenters or locations of highest intensity, which cannot reasonably be correlated with tectonic structures, should be identified with tectonic provinces, any part of which are within 200 miles of the site.

This part of the Regulation was developed to take into account the fact that tectonic settings of the eastern U.S. are significantly different from those of the western U.S. The Regulation does not provide guidance in the form of a map to establish seismotectonic provinces in the East. This has resulted in lengthy licensing delays because of the time needed to resolve controversies among applicants, the public and NRC regarding tectonic province boundary locations.

In 1974 the Office of Standards Development undertook an effort to develop an eastern U.S. Seismotectonic Province Map; however, when the map was completed, there was a consensus opinion that it was not adequate to clarify Appendix A to 10 CFR which requires the tectonic province approach. There remained specific information needs to be satisfied in order to develop a map which will be a useful regulatory tool. That is, more geologic data and seismologic input are needed to more accurately delineate eastern U.S. seismotectonic provinces. Consequently, the cooperative geologic and seismic programs were undertaken with state geological surveys and universities to gather regional data to: (1) help delineate tectonic provinces; (2) identify earthquake source mechanisms; (3) improve knowledge of regional geologic conditions; (4) provide data to confirm past licensing decisions; (5) expand the existing geologic and seismic data base; and (6) to provide a consistent data base.

Approximately 23 state geological surveys and universities are cooperating under NRC funding to provide data needed to develop a data base for an eastern U.S. seismotectonic province map. The studies are being conducted in three phases: Phase I - existing data compilation (complete), Phase II -- new data acquisition, and Phase III -- problem areas of the eastern U.S. and a seismotectonic provinces map. Many of these cooperative programs were funded initially by the Office of Standards Development (Ref. 3). Later, the program responsibility was transferred to the Office of Nuclear Regulatory Research because of their long-term nature.

CRITERIA FOR STUDY AREA SELECTION AND OBJECTIVES OF STUDY

The midcontinent area of the United States has a number of population centers that have undergone rapid growth during the period since the second World War. This increased growth, in conjunction with the increase in fossil fuel costs, has stimulated electrical generation companies to consider nuclear power plants as a viable means to provide additional energy. There are, at the present time, two operating and four proposed nuclear power plants in Nebraska, Kansas, and Oklahoma. At least three more are being considered for this same area. All of the existing and proposed plants are located within or adjacent to an area which has been designated as seismic risk zone 2, an area having had earthquakes with resulting moderate damage and corresponding to seismicity up to MM VII.

NRC rigorous guidelines must be adhered to before a permit to construct a nuclear power plant is granted to an applicant. Local, as well as regional seismicity and structural relationships play an integral role in the final design criteria for nuclear power plants. This requires that a value for the maximum expectable seismic event be assigend at a proposed site. The existing historical record of seismicity is inadequate in a number of areas of the Mid-continent region because of the lack of instrumentation and/or the sensitivity of the instruments deployed to monitor earthquake events. This inadequacy has made it necessary to rely on the delineation of major tectonic provinces that are based on broad regional geologic structures and associated seismicity. The delineation of tectonic provinces, which accurately reflect the potential magnitude of seismic events, is an important cost and risk factor in assigning appropriate design criteria for nuclear power plants.

Many earthquakes have occurred along the Nemaha Uplift, and they have, in the past, been ascribed to crustal adjustment associated with that structure. More recently, geologists have theorized that they are related to Precambrian basement configuration, structure and lithology, and are genetically related to the Arbuckle, Nemaha, and Keweenawan Mafic Belt structures stretching from Southern Oklahoma to the Northern Peninsula of Michigan. Little is known about the relationships of these structures, and this project will be a part of a larger study effort to investigate their possible interaction.

The objectives of the project are to delineate the Nemaha Uplift and its associated structures, to investigate the relationships between the Nemaha Uplift and the Keweenawan Mafic Belt, and to assign realistic values for maximum seismic magnitude in the region. In order to carry out the above objectives, the Geological Surveys of Oklahoma, Kansas, and Nebraska have established seismic networks in Oklahoma, central and eastern Kansas, and eastern Nebraska. Seismic data the networks collect are forwarded to the Oklahoma Geological Survey.

Seismograms already in existence but unpublished are being gathered and compiled. Gravity and aeromagnetic studies are being performed, and detailed field studies undertaken where necessary. Final results will be presented in the form of a series of maps and tables at scale of 1:1,000,000 accompanied by explanatory text. These will outline the relative seismicity in the study area and attempt to correlate it with tectonic features known from surficial and subsurface geological and geophysical evidence.

This investigation will be closely related to an NRC-sponsored study conducted by the Geological Surveys of Michigan and Minnesota and the University of Minnesota and Michigan Technological University.

PLANNING

Initially, a 5-year program was planned. Project work is separated into the three phases listed below. This report presents results of work completed in Phase I.

Phase I

- Purchase and installation of equipment to establish the seismic network.
- Recruitment and training of volunteer operators.
- Compilation and synthesization of existing geologic and geophysical data.
- Analysis of the seismograms.
- Prepare an interim report for fiscal year ending October 1977.

Phase II - Installation of a microearthquake network.

- Operation and monitoring of the seismic network.

- Analysis of the seismograms.

- Aeromagnetic studies.

- Prepare an interim report for fiscal year ending October 1979.

Phase III - Gravity profiles.

- Operation and monitoring of the seismic network.

- Analysis of the seismograms.

- Field studies of known or inferred fault areas.

- Final compilation and report after fiscal year ending October 1981.

RECOMMENDATIONS

It is recommended that the information in "Inventory, Detection and Catalog of Oklahoma Earthquakes and Earthquake Map GM-19" be considered by the Office of Standards Development and the Office of Nuclear Reactor Regulation as input to the development of a tectonic province or seismic zoning map of the eastern U.S. and to provide a basis and guide for ongoing studies in the area.

Additionally, RES recommended that studies be continued in this area so that we may better understand the geology and seismicity of the eastern U.S., and that researchers make annual oral presentations to all NRC geologists and seismologists so that work progress can be discussed and work redirected or modified, if necessary.

Technical questions concerning the subject publication results may be directed to Neil B. Steuer at 427-4370.

Saul Levine

Saul Levine, Director
Office of Nuclear Regulatory Research

Enclosures:
1. Figure 1
2. Figure 2
3. Table 1
4. Map GM-19

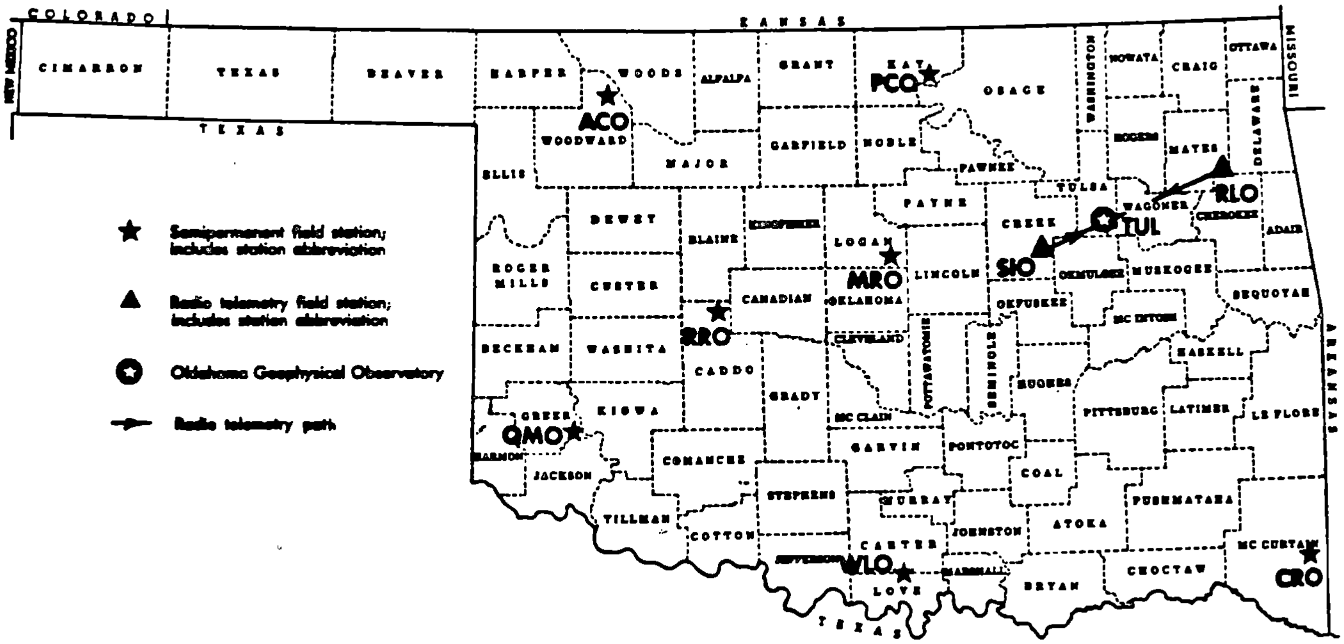

Figure 1. Active seismograph stations in Oklahoma.

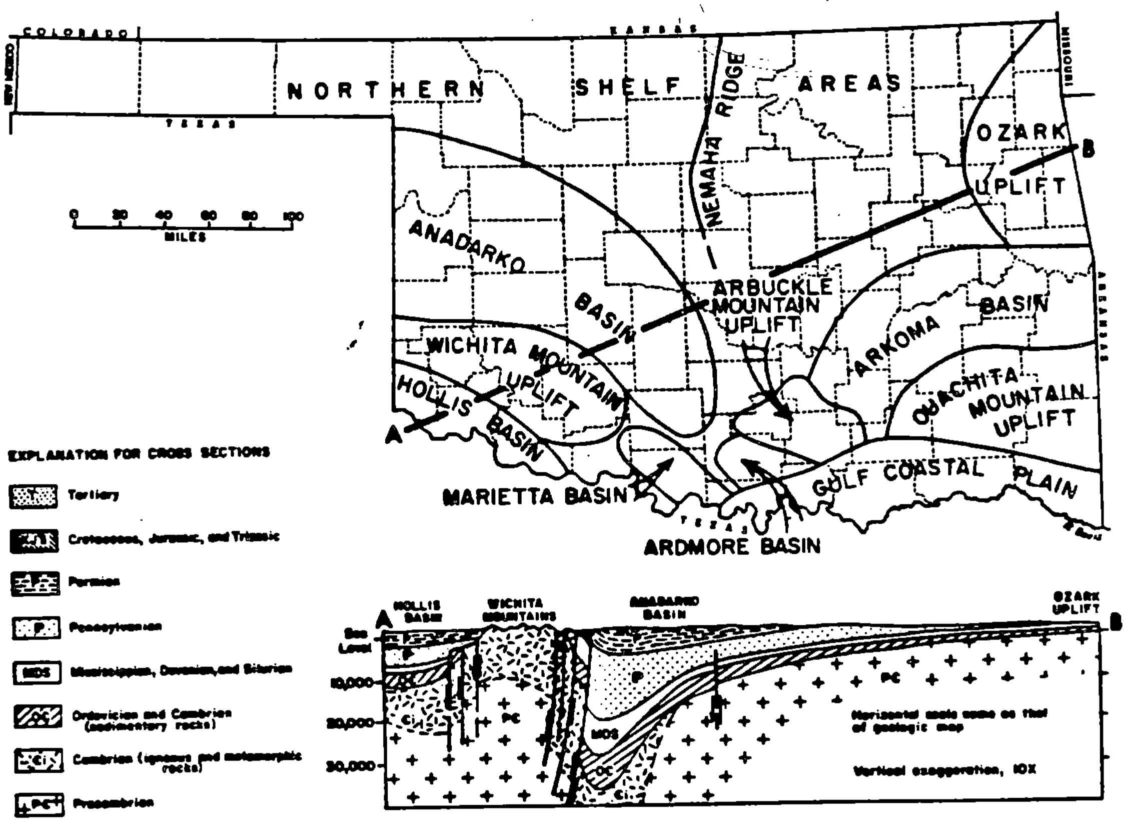

Figure 2. Major geologic and tectonic provinces of Oklahoma.

Table 1. Oklahoma Station Locations and Operators

Abbr.	Geographic name and county	Latitude (° N.)	Longitude (° W.)	Elevation (meters)	Volunteer operator and operating date(s) (year/month/day)
TUL	Okla. Geophys. Observatory, Tulsa Co.	35.900000	95.792500	256	Observatory Staff P/J/K/S 61/12/08
WLO	SE of Wilson, Love Co.	34.064778	97.369722	284	James L. Steel 77/04/25
CRO	Carnasaw Mountain Lookout Tower, McCurtain Co.	34.149917	94.555611	302	Wanda Webb 77/05/17
ACO	Alabaster Cavern State Park, Woodward Co.	36.698556	99.146083	521	L. H. Shepherd 77/06/22
PCO	Ponca City, Kay Co.	36.691222	96.978222	325	H. Walther 77/07/05
RLO	Rose Lookout Tower, Mayes Co.	36.167000	95.025194	363	77/07/22
QMO	Quartz Mountain State Park, Greer Co.	34.892917	99.307056	479	J. Briley 77/07/29
MRO	Meridian, Logan Co.,	35.835556	97.226528	294	Roy F. Starks 78/03/16
SIO	Slick, Creek Co.	35.746333	96.307056	323	78/07/12
RRO	Red Rock Canyon State Park, Caddo Co.	35.456917	98.358444	482	Bud Turner 78/08/09
MZO	Mazie Landing, (CLOSED) Mayes Co.	36.131639	95.300139	182	Randy Blackwell 76/09/16-78/06/16
OLO	Oologah, (CLOSED) Rogers Co.	36.457250	95.710778	196	T/T/C Estes 76/11/28-77/08/07

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Enclosures:
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2. Figure 2
3. Table 1

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Saul Levine

Saul Levine, Director
Office of Nuclear Regulatory Research

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*see previous yellow for concurrence

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