U.S. NUCLEAR REGULATORY COMMISSION
NOTICE OF GRANT/ASSISTANCE AWARD

1. GRANT/AGREEMENT NO.	2. MODIFICATION NO.	3. PERIOD OF PERFORMANCE	4. AUTHORITY
NRC-04-10-155		FROM: 9/30/2010 TO: 9/30/2012	Pursuant to Section 31b and 141b of the Atomic Energy Act of 1954, as amended

5. TYPE OF AWARD	6. ORGANIZATION TYPE	7. RECIPIENT NAME, ADDRESS, and EMAIL ADDRESS
[X] GRANT [ ] COOPERATIVE AGREEMENT	DUNS #111310249 University Affiliated Foundation	SOUTH CAROLINA RESEARCH FOUNDATION 901 SUMTER ST STE 511 COLUMBIA SC 292080001

8. PROJECT TITLE: Ultrasonic Guided Wave Sensor for Gas Accumulation Detection in Nuclear Emergency Core Cooling Systems

9. PROJECT WILL BE CONDUCTED	10. TECHNICAL REPORTS ARE REQUIRED	11. PRINCIPAL INVESTIGATOR(S) NAME, ADDRESS and EMAIL ADDRESS
PER GOVERNMENT'S/RECIPIENT'S PROPOSAL(S) DATED AND APPENDIX A-PROJECT GRANT PROVISIONS	[ ] PROGRESS AND FINAL [ ] FINAL ONLY [X] OTHER (Conference Proceedings)	Dr. Yong-June Shin 301 S Main Street Columbia, SC 29208 shinjune@engr.sc.edu

12. NRC PROGRAM OFFICE (NAME and ADDRESS)	13. ACCOUNTING and APPROPRIATION DATA	14. METHOD OF PAYMENT
Zeechung Wang RES/DE/MEEB 301-251-7643; E-Mail: zeechung.wang@nrc.gov	APPN. NO: 31X0200.060 B&R NO: 060-15-111-195 JOB CODE: G6002 BOC NO: 4110 OFFICE ID NO: RES-C10-861	[ ] ADVANCE BY TREASURY CHECK [ ] REIMBURSEMENT BY TREASURY CHECK [ ] LETTER OF CREDIT [X] OTHER (SPECIFY) Electronic ASAP.gov (See Remarks in Item #20 "Payment Information")

15. NRC OBLIGATION FUNDS		16. TOTAL FUNDING AGREEMENT		
THIS ACTION	$40,000	NRC	$300,000	This action provides funds for Fiscal Year in the amount of
PREVIOUS OBLIGATION		RECIPIENT		
TOTAL	$40,000	TOTAL	$300,000	

17. NRC ISSUING OFFICE (NAME, ADDRESS and EMAIL ADDRESS)

U.S. Nuclear Regulatory Commission
Div. of Contracts
Attn: Usha Ganti
Mail Stop: TWB-01-B10M
Washington, DC 20555 Email: usha.ganti@nrc.gov

18.	19. NRC CONTRACTING OFFICER
Signature not required	Sheila Bumpass 9/27/2010 (Signature) (Date) NAME (TYPED) Sheila Bumpass TITLE Contracting Officer TELEPHONE NO. 301-492-3484 Email: sheila.bumpass@nrc.gov

20. PAYMENT INFORMATION

Payment will be made through the Automated Standard Application for Payment (ASAP.gov) unless the recipient has failed to comply with the program objectives, award conditions, Federal reporting requirements or other conditions specified in 2 CFR 215 (OMB Circular A110).

21. Attached is a copy of the "NRC General Provisions for Grants and Cooperative Agreements Awarded to Non-Government Recipients.
Acceptance of these terms and conditions is acknowledged when Federal funds are used on this project.

22. ORDER OF PRECEDENCE
In the event of a conflict between the recipient's proposal and this award, the terms of the Award shall prevail.

23. By this award, the Recipient certifies that payment of any audit-related debt will not reduce the level of performance of any Federal Program.

TEMPLATE - ADM001 SUNSI REVIEW COMPLETE ADM002

ATTACHMENT A - SCHEDULE

A.1 PURPOSE OF THIS GRANT AWARD

The purpose of this Grant is to provide support to conduct research for a fundamental breakthrough for system wide detection, localization and evaluation of gas accumulation in nuclear emergency core cooling pipeline systems as described in Attachment B entitled "Program Description."

A.2 PERIOD OF PERFORMANCE

1. The effective date of this award is September 30, 2010 with an estimated completion date of September 30, 2012.

2. Funds obligated hereunder are available for program expenditures for the estimated period: September 30, 2010 – September 30, 2012.

A. GENERAL

1. Total Estimated NRC Amount:	$300,000
2. Total Obligated Amount:	$40,000
3. Cost-Share/Other Agency Support:	$0
4. Activity Title:	Ultrasonic Guided Wave Sensor for Gas Accumulation Detection in Nuclear Emergency Core Cooling Systems
5. NRC Project Officer:	Zeechung Wang
6. DUNS NO.	111310249

B. SPECIFIC

RFPA No.:	04-10-155
FFS:	RES-C10-861
Job Code:	K6002
BOC:	4110
B&R Number:	060-15-111-195
Appropriation #:	31X0200.060
Amount Obligated:	$40,000

A.3 BUDGET

Revisions to the budget shall be made in accordance with Revision of Grant Budget in accordance with 2 CFR 215.25.

	Year 1	Year 2
Direct Costs	$107,545	$106,179
F&A Costs	$42,455	$43,821
Total Costs	$150,000	$150,000

All Travel must be in accordance with the South Carolina Research Foundation's Travel Regulations or the US Government Travel Policy in absence of grantee's regulations.

A.4 AMOUNT OF AWARD AND PAYMENT PROCEDURES

1. The total estimated amount of this Award is $300,000 for two years.

2. NRC hereby obligates the amount of $40,000 for program expenditures during the period set forth above and in support of the Budget above. The grantee will be given a written notice by the Contracting Officer when additional funds will be added. NRC is not obligated to reimburse the grantee for the expenditure of amounts in excess of the total obligated amount.

3. Payment shall be made to the grantee in accordance with procedures set forth in the Automated Standard Application for Payments (ASAP) Procedures set forth below.

Attachment B – Program Description

PROGRAM DESCRIPTION

Objectives

The proposed research will seek a fundamental breakthrough for system wide detection, localization and evaluation of gas accumulation in nuclear emergency core cooling pipeline systems. The proposed research is characterized by (a) a novel sensing technique with ultrasonic guided waves to perform long term long range in-situ nuclear pipes inspection for gas accumulation, and (b) an advanced signal processing technique such as time-frequency analysis for an intelligent processing of the sensory data. Ultimately, the proposed research will provide an overall in-depth solution for a timely detection, localization and evaluation of the amount of the gas accumulation in the subject piping systems.

Technical Approach

The proposed technique to detect, locate and measure gas voids is a nondestructive reflectometry technique, which is based on the same principle as radar. The concept of reflectometry utilizes a relatively low-energy ultrasonic pulse in order to transmit the pulse down a waveguide, and any impedance discontinuity generates a reflection that one can detect. The impedance discontinuity can be located and characterized from this reflected signal. In this application, the pipeline filled with fluid corresponds to the waveguide, and the gas accumulation causes the impedance discontinuity as shown in Figure 1. Like other reflectometry techniques, the amplitude of the reflected waveform can be used to measure the impedance discontinuity, and the time delay of the reflected waveform can be used to locate it. Furthermore, the measurement of phase differences in the reflected signal will enable us to measure the size of impedance discontinuity, which is related with volume of the gas accumulation in the pipeline.

Although ultrasonic guided wave technique using Piezoelectric Wafer Active Sensors (PWAS) has been successfully used to detect cracks and other types of common defects on plate-like aero structures, the application of PWAS on piping structures is a new approach. Problems such as the interaction between PWAS and the pipe/tube structures, with air and water on each side, have not been thoroughly studied. Additionally, the guided waves have multiple modes and are dispersive in nature, which complicates data analysis when used for pipe inspection. However, our previous study on pipeline corrosion detection showed that time-frequency analysis is feasible for the study of dispersive guided waves [3].

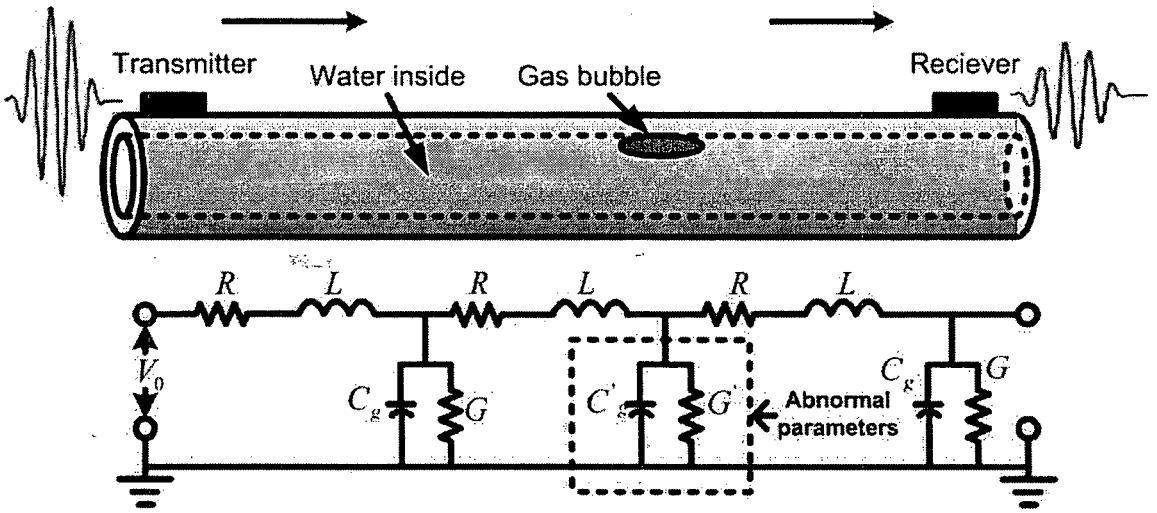

Figure 1 A transmission line model of a gas accumulation in a pipe.

In-situ Sensing Using Piezoelectric Wafer Active Sensors Although guided waves have been widely used in pipeline corrosion detection, their application to detect gas voids is new. In this proposed study, we will perform the gas void detection using the ultrasonic guided wave excited and generated by PWAS.

Piezoelectric wafer active sensors (PWAS) transducers are non-intrusive piezoelectric wafer transducers that can be permanently affixed to the structure and can actively interrogate the structure over long time spans without interfering with system operation [4], [5]. Being small and low-cost, a large number of PWAS can be embedded into a structure and wired to local data concentrators. For example, in a piping system, the PWAS can be embedded into the piping system by mounting them directly on the outside surface of a pipe, under the protective shielding and insulation, and left in place to perform their gas void detection task (Such thing would be unthinkable with conventional ultrasonic transducers, which are bulky, obtrusive, and expensive). The physical geometry/dimensions of PWAS are similar to a strain gage and can be glued to the structural surface easily. These can operate at elevated temperatures up to 260°C. PWAS are non-resonant devices with wide band capabilities, which make them suitable for guided-wave (Lamb wave) ultrasonic inspection (Figure 2).

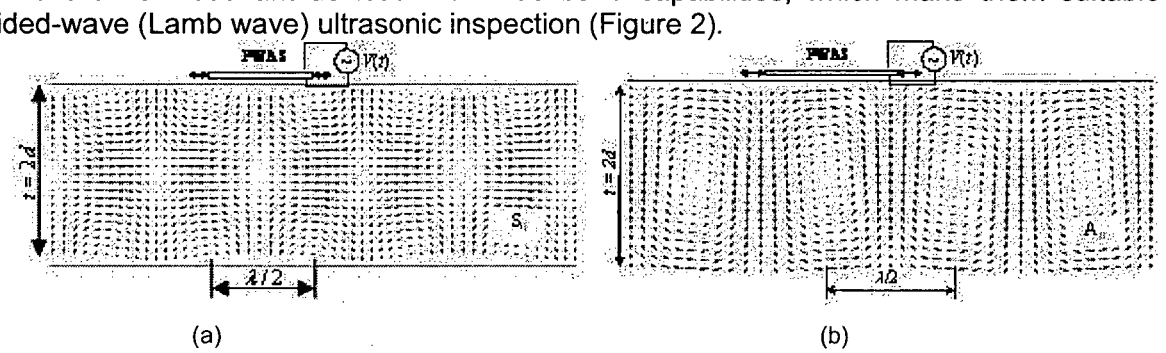

Figure 2 Piezoelectric wafer active sensors for Lamb wave generation. (a) typical structure of S0 Lamb wave modes and the interaction in between; (b) typical structure of S0 Lamb wave modes and the interaction in between

PWAS guided wave generation

PWAS have been used to generate guided Lamb waves in a thin plate structures. Eleven PWAS were placed in a rectangular grid (Table 1). Guided waves were transmitted, in a round-robin fashion, from one PWAS and received at the other PWAS (as well as at the transmitter). Figure 4a shows the waves received at the PWAS #1 through #10 when a tone-burst wave

pulse was applied at #11. Correlation between of flight and distance was used to determine the group velocity. Both symmetric (S0) and antisymmetric (A0) guided-wave modes could be excited. Figure 3b shows the group velocity values measured during these experiments and their comparison with the theoretical dispersion curves. Very good agreement between theory and experiment was observed over a wide frequency band.

Table 1 Locations of sensors on a thin rectangular plate specimen

Sensor #	1	2	3	4	5	6	7	8	9	10	11
x (mm)	100	100	100	100	100	450	450	450	800	800	800
y (mm)	100	175	250	325	400	100	250	400	100	250	400

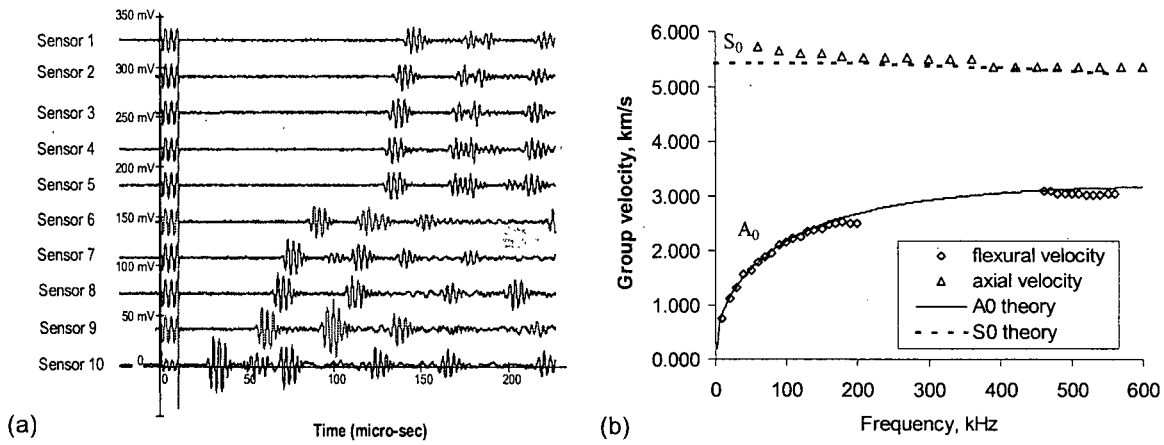

Figure 3 (a) Ultrasonic guided-waves recorded during the rectangular plate experiments: (a) raw reception signals received at active sensors 1 through 10 when sensor 11 was excited with a 300 kHz smoothed tone burst; (b) group velocity dispersion curves for Lamb-wave A0 and S0 modes

PWAS guided wave corrosion detection on pipe structures

We have successfully applied the propagating Lamb waves (a.k.a. plate guided waves) to detect and monitor simulated corrosion development as thickness loss on an aluminum plate specimen. The waves were generated by the embedded PWAS network operating in pitch-catch mode. When the plate thickness is changed by the corrosion development, velocity of the highly dispersive A0 mode is changed as well; thus allowing us to detect the presence of corrosion and quantify the thickness change accordingly with appropriate time-frequency analysis [3].

The corrosion test has also been initiated on actual pipe structure (Figure 4). The same sensor network was installed on the pipe where the corrosion was simulated by chemical erosion. The dispersive A0 mode was successfully excited in the pipe using PWAS as shown in Figure 4. Damage index study on the corrosion data yielded a good indication of corroded path detection (path 0-4).

Time-frequency analysis in guided wave detection

Guided waves are dispersive and contain multiple modes. Experimental work has shown that it is possible to obtain a plate's dispersion relationship by using two dimensional Fourier transform (2D FT) [6], [7], [8]. Cross time-frequency distribution (CTFD) will be adopted in this research to analyze the guided wave signals from PWAS in a pitch-catch mode to detect the existence of and quantify the volume of the gas void(s). The phase difference of the incident signals and reflected signals in the pitch-catch mode is believed to be directly related with the size of the gas accumulation in the pipe. These signals are transient signals which have a time-variant

frequency spectrum. Traditional techniques that work in the time domain only or in the frequency domain only are unable to measure time- and frequency- varying phase differences accurately. CTFD is motivated by traditional energy based time-frequency distribution and capable of preserving the time- and frequency- varying phase difference while traditional time-frequency distribution cannot. CTFD has been shown to be able to measure time- and frequency- varying phase differences accurately.

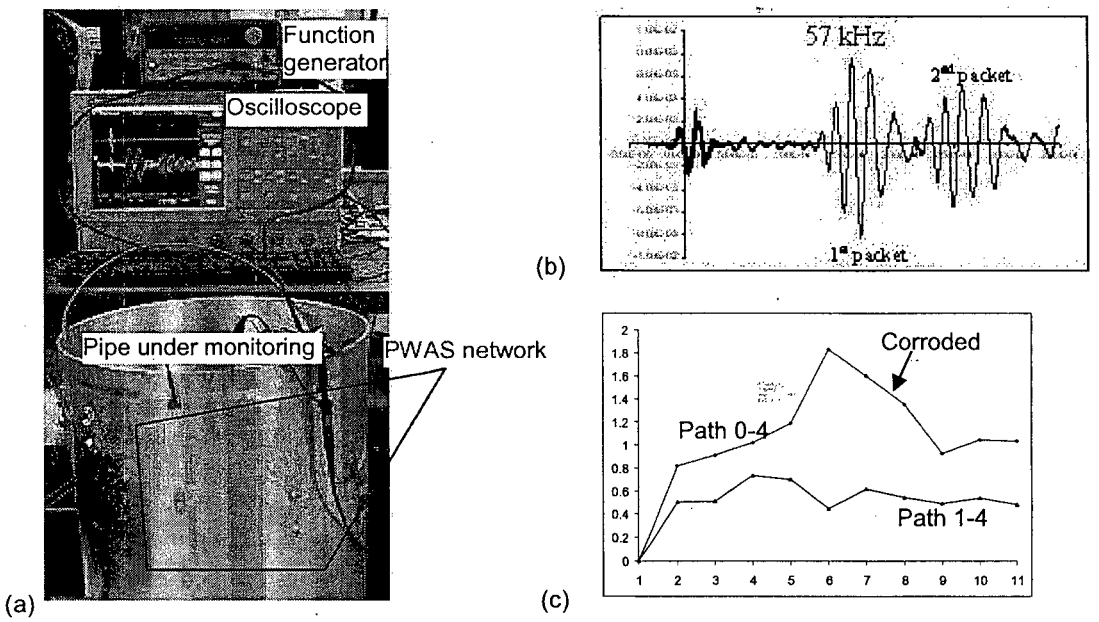

Figure 4 (a) PWAS network installed on a pipe and experimental setup; (b) typical A0 guided wave modes used in the detection; (c) signal analysis in corrosion detection

As shown in Figure 5(a), a PWAS sensing system has been instrumented on a 500 mm x 500 mm x 3.229 mm rectangular plate. The sensor network consists of five 7-mm round PWAS sensors. The corrosion is located exactly at the same position of PWAS #2 on the other side of the plate. A 5 mm x 3.8 mm area is used to simulate the corrosion by machine cutting material from the plate. 7 records are taken at different depths where materials are removed. The theoretical phase difference and phase difference against corrosion depth evaluated with traditional cross spectral analysis which works in frequency domain only and CTFD analysis are all plotted in Figure 5(b). It can be observed that cross spectral analysis fails to measure the phase difference accurately while CTFD closely followed the theoretical value at all corrosion depths.

Figure 6 shows the CTFD of two sets of incident and received signal pairs: 1) with corrosion in the metal along the signal path (Pair 04) and 2) without corrosion on the signal path (Pair 14). The different records shown in the figure correspond to different level of corrosions with the larger record number having more serious corrosion. The red portion of the plots indicates high energy density of similar frequency content and small phase difference, while the blue portion indicates that both signals either have no frequency content or have frequency content that is out of phase. For Pair 14, the cross time-frequency distributions have similar shapes to the baseline, and they are located almost at the same time-frequency coordinates. This implies that the two signals have very small phase differences because there is corrosion located on the path of Pair 14. For Pair 04, which has corrosion in the path, obvious changes can be observed corresponding to the growth of corrosion. In this case, the signals are all dispersive and have

time a varying frequency spectrum, and the example demonstrates that CTFD can provide a direct image of the phase difference at a specific time and frequency.

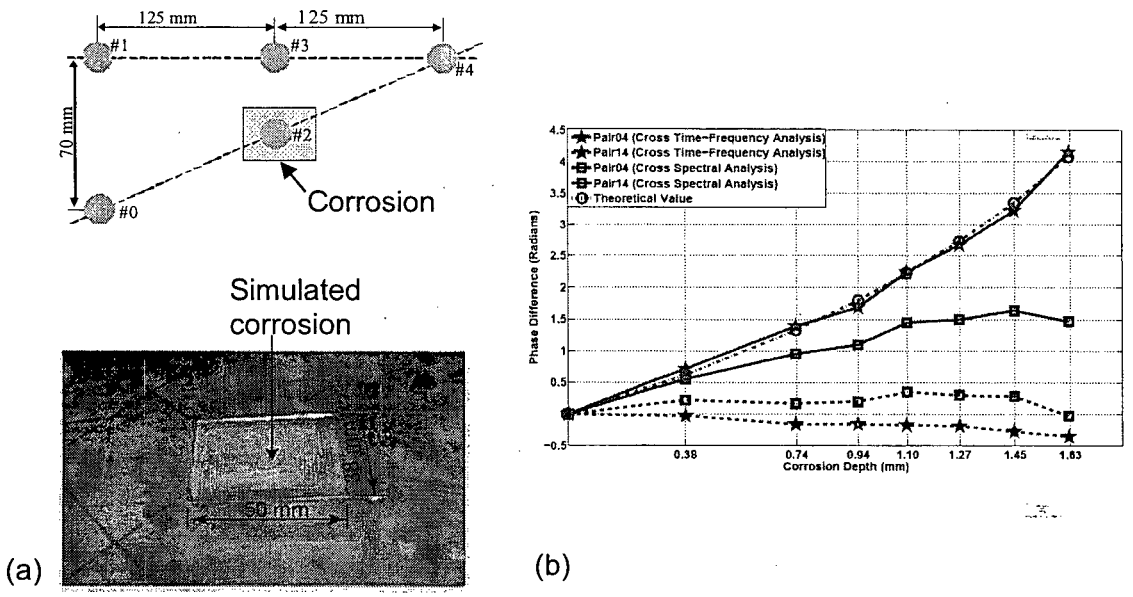

Figure 5 Piezoelectric wafer active sensors corrosion detection on aluminum plate. (a) specimen setup; (b) corrosion detection and quantification using time-frequency analysis

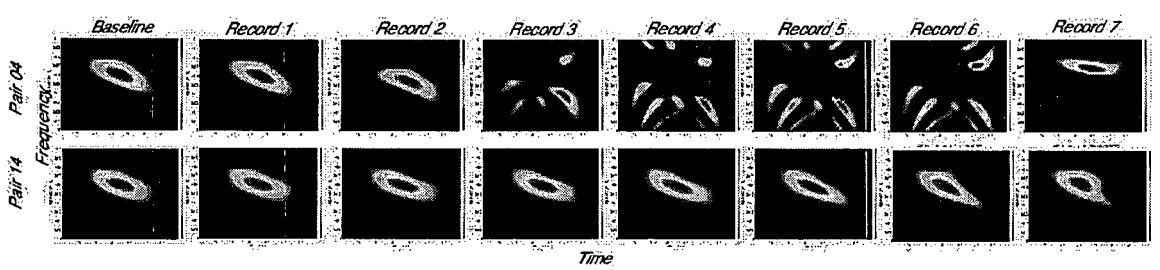

Figure 6 CTFD of two sets of incident and received signal pairs in metallic corrosion experiment: 1) with corrosion on the path (Pair 04); 2) without corrosion on the path (Pair 14).

These methods can be extended to liquid coolant transmission models based around acoustic sensors. Similar time-frequency methods have previously been applied to overhead transmission lines, mechanical systems, and physical materials. Water displays nearly linear variations in dielectric constant at different temperatures with a relative dielectric constant of 88 at 0 ˚C, 76.75 at 30 ˚C, and 55.33 at 100 ˚C based around the permittivity of free space 8.85 pF/m. This variation in dielectric constant could be used to detect differences in electromagnetic wave propagation in vapor, detecting lower dielectric properties reported from embedded sensors. A measure that could detect these slight differences could identify gas voids and provide timely feedback.

Proposed tasks and work plan

The proposed research is built upon two scientific principles:

- The utilization of guided waves in pipes generated and received by permanently installed PWAS.
- The extraction of gas voids related information through time-frequency signal analysis.

The proposed research will be conducted in a two-year time schedule with four tasks summarized in Chart 1.

Chart 1: Time line of proposed research

Key Research Issues	YEAR 1				YEAR 2			
	1	2	3	4	1	2	3	4
Task 1								
Task 2								
Task 3								
Task 4								

Task 1: Studies on the mechanism of ultrasonic guided waves testing for gas voids detection

To correctly detect the presence of gas accumulated in the coolant pipes and quantify the accumulation, it is essential to understand the ultrasonic guided wave excitation and interaction with a solid half space immersed in a fluid. Meanwhile, the optimal sensor locations need to be identified as well in order to detect the voids in a timely fashion. Therefore, it is also needed to study the critical locations in the piping structures where gas voids may most likely happen, the "hot spots".

Subtask 1.1 Analytical solution of guided wave excitation using PWAS in pipe/tube structures

Though previous researchers have separately modeled guided waves in pipe/tube structures, while others have modeled PWAS, none have captured the intimate interaction between these surface-mounted strain transducers and a pipe/tube structure. The modeling and understanding of the wave interaction with curved surface is critical to the successful development of the proposed guided wave detection method. This objective will be pursued with analytical methods that will yield the governing differential equations to be used in subtask 1.2.

Soedel [9] presented a comprehensive modeling and analysis of the vibrations of circular tubes, including pipes and tubes. However, this modeling is not appropriate for describing the high-frequency wave propagation phenomena encountered during ultrasonic inspection. In our proposed research, we will apply theory of ultrasonic guided waves in plates to model the transmission and reception of ultrasonic guided waves in pipes and tubes using surface mounted PWAS. The modeling starts from the equation of motion for an isotropic elastic medium, in invariant form:

$$\mu\Delta\mathbf{u} + (\lambda+\mu)\nabla\nabla\times\mathbf{u} = \rho(\partial^2\mathbf{u}/\partial t^2) \qquad (1)$$

where **u** is the displacement vector, ρ is the density, λ and μ are Lame's constants, and Δ is the three-dimensional Laplace operator. For free motion, the displacement equations of motion are satisfied if the potentials ϕ and **H** satisfy the wave equations

$$c_P^2\Delta\phi = \partial^2\phi/\partial t^2 \qquad (2)$$

$$c_S^2 \Delta \mathbf{H} = \partial^2 \mathbf{H} / \partial t^2 \quad (3)$$

where $c_P^2 = (\lambda + 2\mu)/\rho$ and $c_S^2 = \mu/\rho$ are the pressure and shear wave speeds, respectively. To determine the free vibration conditions, we will impose the free-motion boundary conditions on the tube/pipe.

As shown by Gazis [10], three basic families of guided waves exist: longitudinal, L(0, m); torsional, T(0, m);and flexural, F(0, m). Within each family, an infinite number of modes exist, such that their phase velocities, V_{ph}, for a given frequency-thickness product, *fd*. The index *n* determines the manner in which the fields generated by the guided wave modes vary with angular coordinate θ in the cross-section of the cylinder. The longitudinal modes are good for the location of circumferential crack while for corrosion the torsional modes are recommended. In our study, we will extend Gazis analysis by introducing in the analysis the forcing functions generated by the PWAS transducer, and thus model their interaction. To achieve this, we will develop a normal modes series expansion solution of the form

$$\mathbf{u}(r,\theta) = \left(\sum_i \xi_i \mathbf{\Phi}_i(r,\theta) \right) \quad (4)$$

where $\mathbf{\Phi}_i$ are the normal modes [10].

We will apply the theory of plate ultrasonic guided waves to model the transmission and reception of ultrasonic guided waves in pipes/tubes using surface mounted PWAS. The model will be built in the wavenumber domain using space domain Fourier transform. The inverse Fourier transform is used to return into the physical space. A general solution will be obtained with a reduced close-form expression for the case of ideal bonding of the interfacial shear stress. We will then use the general solution to solve the three basic families of pipe/tube guided waves: longitudinal, torsional, and flexural. These conclusions will serve as the theoretical basis for choosing the right wave modes for gas accumulation detection.

Subtask 1.2 Model ultrasonic field of a solid half-space immersed in a fluid

When the pipe is immersed half-space into fluid, the air-air boundary condition is changed and the wave propagation features will be modified accordingly. A lot of work has been done for plate structures immersed into fluid. Distributed point source method (DPSM) is a semi-analytical technique that can be used to calculate the ultrasonic field such as pressure, velocity, and displacement in a fluid or solid. It has been used to model ultrasonic fields near a fluid-solid interface when a solid half-space is immersed in a fluid [11].

In this subtask, we will use the DPSM method to study the ultrasonic fields generated by PWAS when the pipe structures is immersed in a fluid. Using this method, two layers are placed near the solid-air or solid-fluid interface (Figure 7). The interaction between two transducers in both solid and fluid will be studied. Particularly in our case, we study the ultrasonic fields in a solid pipe structure with solid-air and solid-fluid interface on each side. We will find out how the energy leaks into the surrounding fluid, how the symmetric and anti-symmetric guided wave modes are formed in the structure, and how different modes vary as the gas gets in between the transmitter-receiver. A prediction model will be yielded under this study to show how the guided wave propagation will be changed and compared to the experimental results obtained in task 4.

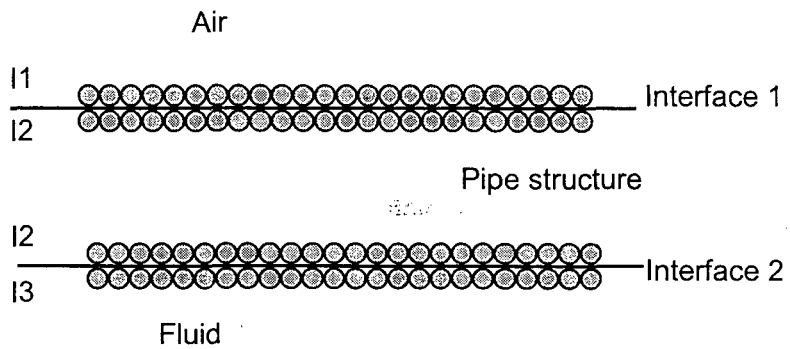

Figure 7 Distribution of the point sources at the solid-air solid-fluid interfaces of the pipe structure

Task 2: Optimal excitation signal

The PowerIT group at the University of South Carolina will explore the optimal excitation signal for implementing the ultrasonic guided wave inspection. Typically guided wave inspection uses wave packets generated through an energy burst. A 5-count hanning window smoothed tone burst signal with a center frequency at 10 MHz and its spectrum is shown in Figure 8.

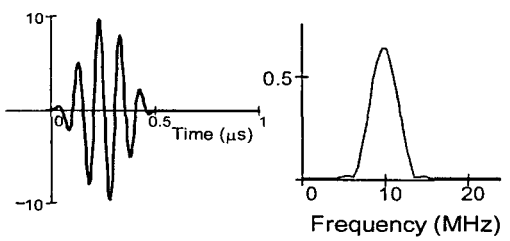

Figure 8 A 5-count tone-burst signal and its spectrum

The principal advantage of the time-frequency domain analysis is its ability for time and frequency localization and its flexibility in using a signal form that fits the physical characteristics of the waveguide. Successful detection and location of defects via the proposed technique depends on the design of the reference signal. Consequently, successful detection and location of defects via time-frequency method depends on the design of the reference signal. The parameters of the reference signal (time duration, center frequency, and frequency bandwidth) are to be selected with prior knowledge of the testing distance, attenuation characteristics of the piplines, and signal-to-noise ratio of the data acquisition. In order to apply time-frequency analysis to more realistic scenarios, we must consider the following questions:

- From what distance do we need to be able to detect the gas accumulation?
- How accurate should our findings be for each type of gas accumulation?
- How sensitive and accurate is the detection?
- Is it possible to measure size of the gas accumulation?

The correct answer to all these questions is: "**it depends**", specifically on the reference signal of JTFDR. In order to address these issues, the first step is to design the optimized reference signal for JTFDR. In that process, we must keep in mind the uncertainty principle and the trade-off relation between frequency and attenuation: higher frequency enables smaller space resolution, but a higher frequency will suffer higher attenuation that prohibits propagation over longer distances.

Thus, we need to find the optimal reference signal with the time duration and frequency bandwidth that "fits" the defect on the gas accumulation. Within the frequency band of interest,

the frequency band of the reference signal should match the resonant frequency of the faulty impedance (frequency-localization). Also, the time duration of the reference signal should match the length of the local defect (time-localization), so that one can maximize the reflection from the defects using time and frequency localization within the uncertainty principle.

In Figure , a new, dynamic signaling strategy is depicted on the time-frequency plane. This dynamic signaling idea is based on the scaling relation between the time and frequency domains. The following basis function is a chirp signal with a Gaussian envelope, and its maximum frequency sweeping rate will be limited and determined by the performance of the signal generator. (Recall that one cannot achieve arbitrary small resolution in the joint time-frequency domain due to the uncertainty principle.)

$$\phi_0(t) = s(t; t_0, \omega_0) = (\alpha/\pi)^{1/4} e^{-\alpha(t-t_0)^2/2 + j\beta(t-t_0)^2/2 + j\omega_0(t-t_0)} \qquad 6)$$

Then, we define a sequence of the basis functions by the scaling factor *a*:

$$\phi_{i+1}(t, a) = \phi_i(at) \qquad 7)$$

$$\Phi_{i+1}(\omega, a) = \frac{1}{|a|} \cdot \Phi_i(\frac{\omega}{a}), \quad \text{where} \quad \Phi_i(\omega) = \mathfrak{F}\{\phi_i(t)\} \qquad 8)$$

Each basis function can be characterized by its time duration and frequency bandwidth based on the scaling property of the time and frequency domains, as follows (see also Figure):

$$T_{i+1,a} = a \cdot T_i \quad \text{(Time Duration)} \qquad (9)$$

$$B_{i+1,a} = \frac{1}{|a|} \cdot B_i \quad \text{(Frequency Bandwidth)} \qquad 10)$$

As the iteration progresses, if *a*>0, the time and frequency localization of individual basis will be characterized by the scale factor, *a*. The time duration increases, while the frequency bandwidth decreases. Similar iteration process of basis function can be found in the theory of time-scale analysis. But it is a new idea to adopt the time-scale feature of wavelet to time-frequency analysis for the optimization of the reference signal.

Each basis function is delayed in the time domain and modulated in frequency so that each basis function occupies a unique time and frequency on the plane. Then, we can define a two-dimensional dynamic reference signal on the time-frequency plane, which is a collection of these scaled basis functions:

$$S(t; a) = \sum_{i=0}^{N} \phi_i(t - T_{i,a}; a) \cdot e^{j(\omega - B_{i,a}) \cdot t}, \quad N = \arg_i \max\{\omega_i > 2\pi f_r \qquad 11)$$

Note that the dynamic reference signal is characterized by time and scale. On the time-frequency distribution of the signal *S(t,a)* is another chirp signal whose instantaneous frequency decreases with time. If we transmit the dynamic reference signal in equation (11) to the cable of interest, a defect presenting on the cable will generate a reflection and it will be processed by time-frequency cross correlation function. By tracking the highest value of time-frequency cross correlation between the reference and reflection on time and scale, we can determine the time duration and frequency bandwidth that optimally fit the unknown defects on the cable. The defect will be more responsive to a particular frequency band and a particular pulse time duration.

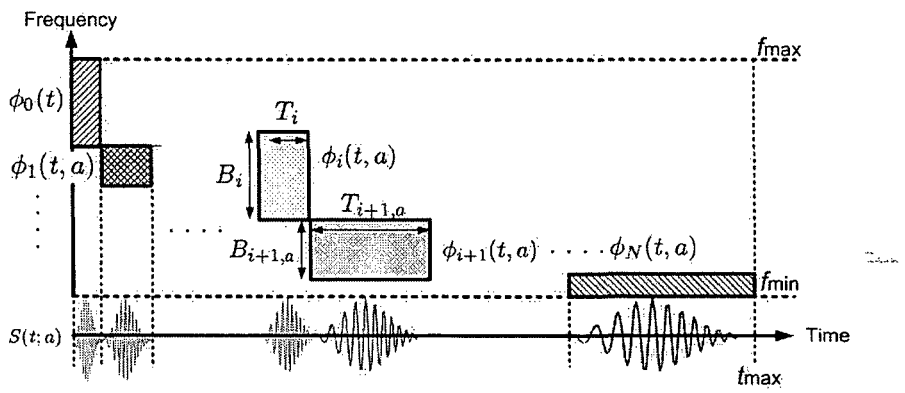

Figure 9. Dynamic JTFDR signaling and reference signals in time-frequency domain

Task 3: Signal processing approach

Subtask 3.1 Cross time-frequency distribution

The signals generated by PWAS are characterized by transient signals in which the frequency contents change over time. Furthermore, due to the dispersive propagation, the spectral characteristics of the signal will be changed after the propagation. Therefore, time-frequency analysis can provide an effective tool for non-stationary signal analysis in PWAS applications by a time- and frequency- localized signal representation. Motivated by Cohen's definition for time-frequency distribution, the cross time-frequency distribution of a pair of complex analytic signals $x_1(t)$ and $x_2(t)$ *is* defined as follows:

$$\mathrm{J}_{x_1x_2}(t,\omega;\emptyset) = \frac{1}{4\pi^2}\iiint x_1\left(u+\frac{\tau}{2}\right)x_2^*\left(u-\frac{\tau}{2}\right)\emptyset(\theta,\tau)e^{-j\theta t-j\tau\omega+j\theta u}d\theta d\tau du$$

The cross time-frequency distribution is a complex distribution and, thus, provides phase difference information. In general, a cross time-frequency distribution can be rewritten in following format:

$$\mathrm{J}_{x_1x_2}(t,\omega;\emptyset) = \left|\mathrm{J}_{x_1x_2}(t,\omega;\emptyset)\right|e^{j\vartheta_{x_1x_2}(t,\omega;\emptyset)}$$

Where $\vartheta_{x_1x_2}(t,\omega;\emptyset)$ is the phase difference spectrum of the signal $x_1(t)$ and $x_2(t)$.

$$\vartheta_{x_1x_2}(t,\omega;\emptyset) = \tan^{-1}\left[\frac{\mathrm{Im}(\mathrm{J}_{x_1x_2}(t,\omega;\emptyset))}{\mathrm{Re}(\mathrm{J}_{x_1x_2}(t,\omega;\emptyset))}\right]$$

Therefore, cross time-frequency distribution reveals phase difference between two signals as a function of time and frequency. Take following two transient signals as example:

$$x_1(t) = \left(\frac{\alpha}{\pi}\right)^{\frac{1}{4}}e^{-\frac{\alpha(t-t_1)^2}{2}+j\left[\frac{\beta(t-t_1)^2}{2}+\omega_1(t-t_1)+\varphi_1\right]}$$
$$x_2(t) = \left(\frac{\alpha}{\pi}\right)^{\frac{1}{4}}e^{-\frac{\alpha(t-t_2)^2}{2}+j\left[\frac{\beta(t-t_2)^2}{2}+\omega_2(t-t_2)+\varphi_2\right]}$$

Using the definition of the cross time-frequency distribution, we have:

$$\vartheta_{x_1x_2}(t,\omega;\emptyset) = \Delta t(\omega-\omega_0) - \Delta\omega t + \omega_2 t_2 - \omega_1 t_1 + (\varphi_1-\varphi_2)$$

Where

$$t_0 = (t_1 + t_2)/2, \quad \Delta t = t_2 - t_1$$

$$\omega_0 = (\omega_1 + \omega_2)/2, \quad \Delta\omega = \omega_2 - \omega_1$$

The equation above shows that the phase difference between the two signals is a function of both time and frequency, which means the phase difference of any specific time and frequency can be evaluated with cross time-frequency distribution.

Subtask 3.2 Cross time-frequency correlation

The main difference between different reflectometry techniques lies in their different incident signals, TDR uses a pulse with fixed time duration which has it energy spread over infinite frequency range, FDR uses a set of sinusoidal signals with fixed frequency bandwidth which has infinite time duration. Therefore JTFDR utilizes an incident signal that is localized in both the time and frequency domains simultaneously. This incident signal is composed of a Gaussian envelope applied to a linear chirp signal as below:

$$s(t) = (\frac{\alpha}{\pi})^{\frac{1}{4}} e^{-\frac{\alpha(t-t_0)^2}{2} + j[\frac{\beta(t-t_0)^2}{2} + \omega_0(t-t_0)]}$$

A distinct advantage of this incident signal is its configurability. The user can properly select the parameters of the incident signal, including center frequency, frequency bandwidth, and time duration, by considering the frequency characteristics of the wire being tested. After obtaining the signals reflected by defects in the cable under test, JTFDR uses a predetermined kernel (the Wigner distribution is used in this proposal) to find the time-frequency distributions of the incident signal and the reflected signal. The Wigner distribution of the time signal, s(t), is obtained by the following transformation:

$$W(t,\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} s^*(t - \frac{1}{2}\tau) \cdot s(t + \frac{1}{2}\tau)\, e^{-j\tau\omega} d\tau$$

JTFDR computes the time-frequency cross correlation between the incident signal and the reflected signal
with the following equation:

$$C_{sr}(t) = \frac{1}{E_s E_r(t)} \int_{t'=t-Ts}^{t'=t+Ts} \int_{-\infty}^{\infty} W_r(t',\omega) W_s(t'-t,\omega) d\omega dt'$$

where $W_r(t,\omega)$ is the Wigner distribution of the reflected signal; $W_s(t,\omega)$ is the Wigner distribution of incident signal; and *Es* and *Er(t)* are normalization factors. The time-frequency cross correlation is actually a measure of the similarity between time-frequency distribution of the reflected signal and time-frequency distribution of the incident signal. The peaks of the time-frequency cross correlation usually means high similarity between the reflection and incident signals and are used to detect the gas accumulations and determine their locations. Cross time-frequency correlation function has already been verified to be successful in the detection and location of incipient defects along electric cable, it should also be able to detect the gas accumulations in the pipe based on the transmission line model in Figure 1.

Task 4: Proof-of-concept experiments

Simple controlled proof-of-concept small scale tests will be conducted to evaluate the efficiency of the proposed ultrasonic guided wave method and initiate the relationship between the reflected wave characteristic and gas void volume. The test will also validate the PWAS guided wave excitation derived in Task 1 and time-frequency studies proposed in Task 3.

Subtask 4.1 Study on gas accumulation mechanism

To guarantee the timely and correct detection of gas accumulation in the nuclear coolant pipe, it is important to place the sensors near the locations where it may mostly happen. Therefore, a brief study on the gas accumulation mechanism will be performed under Task 4 to establish the optimal sensor placement combing literature review and fluid mechanism.

Subtask 4.2 PWAS guided wave gas detection

Two types of fundamental ultrasonic guided wave types will be used for the testing in the pipe/tube structures, the axial wave and the circumferential wave. Pipes will be filled with water first, then the water level will be decreased gradually at 10% pace until the pipe is drained of water. For axial wave detection, an inclined pipe setup as illustrated in Figure 10 (a) will be used with the transmitter and receiver aligned along the pipe axis. For circumferential wave detection, pipe setup as illustrated in Figure 10 (b) will be used with the transmitter and receiver aligned around the pipe circumference. PWAS guided wave inspection then will be conducted at each stage and measurements will be processed by appropriate signal processing algorithms. Through the data interpretation, a relationship between the signal feature, such as amplitude, energy, or phase, and the air amount will be established.

Subtask 4.3 Gas detection and evaluation algorithm development

Once the gas is successfully detected, pulse-echo mode can be used to locate the air accumulation along the pipe, that is, find out the distance between the air accumulation and the sensors. In this case, a single PWAS will work as both transmitter and receiver. The guided-wave will be generated and any reflections from air accumulation will be received by the same sensor. By multiplying the time difference between transmitting of reference and receiving of reflection and the wave propagation speed, the location of the air accumulation can be obtained. In this case, the reflection signals from air accumulation could be very weak to be discerned in time domain due to the attenuation of propagation. So another time-frequency analysis technique time-frequency cross correlation will be adopted and it can locate the air accumulation by amplifying the likeness of the frequency content of incident signal and reflected signal.

Subtask 4.4 Proof-of-concept experimental demonstration

Under this subtask, a network of PWAS sensors will be mounted on a pipe structure. Setup tested in subtask 4.2 will be repeated. In this demonstration, a gas void will be injected into the pipe to simulate the real gas accumulation condition in the coolant pipe. The measurements will be repeated and the change caused gas void will be characterized. The experiments will be used to understand the effects of gas voids on wave propagation and to demonstrate that gas voids can be detected.

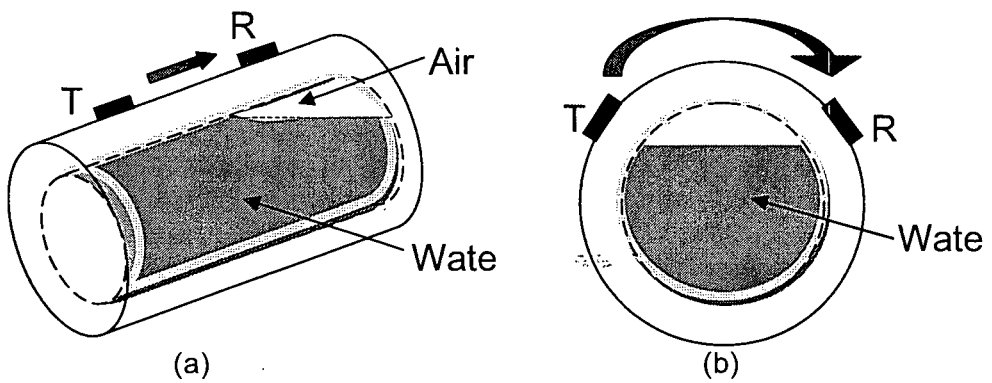

Figure 10 (a) Axial wave gas accumulation detection, (b) Axial wave gas accumulation detection

Benefit to NRC Mission

The proposed research effort will set a framework for development of an ultrasonic guided wave gas accumulation testing systems that will eventually (1) detect the presence of gas bubbles in the subject systems; (2) locate and quantify the gas accumulation; and (3) provide actionable information by identifying potentially significant accumulation in the subject systems. Such a framework is the basis for developing gas accumulation detection technique that can significantly help NRC when evaluating the design, operability, testing, and corrective actions for gas accumulation concerns in emergency core cooling, DHR, and containment sprays systems.

Attachment C – Standard Terms and Conditions

The Nuclear Regulatory Commission's
Standard Terms and Conditions for U.S. Nongovernmental Cooperative Agreements/Grants

Preface

This award is based on the application submitted to, and as approved by, the Nuclear Regulatory Commission (NRC) under the authorization 42 USC 2051(b) pursuant to section 31b and 141b of the Atomic Energy Act of 1954, as amended, and is subject to the terms and conditions incorporated either directly or by reference in the following:

- Cooperative Agreement program legislation and program regulation cited in this Notice of Cooperative Agreement/Grant Award.
- Restrictions on the expenditure of Federal funds in appropriation acts, to the extent those restrictions are pertinent to the award.
- Code of Federal Regulations/Regulatory Requirements - 2 CFR 215 Uniform Administrative Requirements for grants and cooperative agreements with Institutions Of Higher Education, Hospitals, And Other Non-Profit Organizations (OMB Circulars), as applicable.

To assist with finding additional guidance for selected items of cost as required in 2 CRF 220, 2 CFR 225, and 2 CFR 230 these URLs to the Office of Management and Budget Cost Circulars are included for reference:

A-21 (now 2CFR 220): http://www.whitehouse.gov/omb/circulars/a021/print/a021.html
A-87 (now 2CFR 225): http://www.whitehouse.gov/omb/circulars/a087/print/a087-all.html

A-122 (now2 CFR 230): http://www.whitehouse.gov/omb/circulars/a122/print/a122.html
A-102, SF 424: http://www.whitehouse.gov/omb/circulars/a102/print/a102.html
Form 990: http://www.irs.gov/pub/irs-pdf/i990-ez.pdf

Any inconsistency or conflict in terms and conditions specified in the award will be resolved according to the following order of precedence: public laws, regulations, applicable notices published in the Federal Register, Executive Orders (EOs), Office of Management and Budget (OMB) Circulars, the Nuclear Regulatory Commission's (NRC) Mandatory Standard Provisions, special award conditions, and standard award conditions.

By drawing funds from the Automated Standard Application for Payment system (ASAP), the recipient agrees to the terms and conditions of an award.

Certifications and representations. These terms incorporate the certifications and representations required by statute, executive order, or regulation that were submitted with the SF424B application through Grants.gov.

I. Mandatory General Requirements
The order of these requirements does not make one requirement more important than any other requirement.

1. Applicability of 2 CFR Part 215

a. All provisions of 2 CFR Part 215 and all Standard Provisions attached to this cooperative Agreement/grant are applicable to the recipients and to the sub-recipients which meet the definition of "Recipient" in Part 215, unless a section specifically excludes a sub-recipient from coverage. The Recipient and any sub-recipients must, in addition to the assurances made as part of the application, comply and require each of its sub-awardees employed in the completion of the project to comply with Subpart C of 2 CFR 215 Part 180 and include this term in lower-tier (subaward) covered transactions.

b. Recipient must comply with monitoring procedures and audit requirements in accordance with OMB Circular A-133. < http://www.whitehouse.gov/omb/circulars/a133_compliance/08/08toc.aspx >

2. Award Package

§ 215.41 Recipient's responsibilities.
The Recipient is obligated to conduct such project oversight as may be appropriate, to manage funds with prudence, and to comply with the provisions outlined in 2 CFR 215.41 Within this framework, the Principal Investigator (PI) named on the award face page, Block 11, is responsible for the scientific or technical direction of the project and for preparation of the project performance reports. This award is funded on a cost reimbursement basis not to exceed the amount awarded as indicated on the face page, Block 16 and is subject to a refund of unexpended funds to NRC.

The standards contained in this section do not relieve the Recipient of the contractual responsibilities arising under its contract(s). The Recipient is the responsible authority, without recourse to the NRC, regarding the settlement and satisfaction of all contractual and administrative issues arising out of procurements entered into in support of an award or other agreement. This includes disputes, claims, and protests of award, source evaluation or other

matters of a contractual nature. Matters concerning violation of statute are to be referred to such Federal, State or local authority as may have proper jurisdiction.

Sub Agreements
Appendix A to Part 215—Contract Provisions

Sub-recipients, sub-awardees, and contractors have no relationship with NRC under the terms of this Cooperative Agreement/Grant. All required NRC approvals must be directed through the Recipient to NRC. See 2 CFR 215.180 and 215.41.

Nondiscrimination
(This provision is applicable when work under the Cooperative Agreement/Grant is performed in the U.S. or when employees are recruited in the U.S.)

No U.S. citizen or legal resident shall be excluded from participation in, be denied the benefits of, or be otherwise subjected to discrimination under any program or activity funded by this award on the basis of race, color, national origin, age, religion, handicap, or sex. The Recipient agrees to comply with the non-discrimination requirements below:

Title VI of the Civil Rights Act of 1964 (42 USC §§ 2000d et seq)
Title IX of the Education Amendments of 1972 (20 USC §§ 1681 et seq)
Section 504 of the Rehabilitation Act of 1973,as amended (29 USC § 794)
The Age Discrimination Act of 1975, as amended (42 USC §§ 6101 et seq)
The Americans with Disabilities Act of 1990 (42 USC §§ 12101 et seq)
Parts II and III of EO 11246 as amended by EO 11375 and 12086.
EO 13166, "Improving Access to Services for Persons with Limited English Proficiency."
Any other applicable non-discrimination law(s).

Generally, Title VII of the Civil Rights Act of 1964, 42 USC § 2000e et seq, provides that it shall be an unlawful employment practice for an employer to discharge any individual or otherwise to discriminate against an individual with respect to compensation, terms, conditions, or privileges of employment because of such individual's race, color, religion, sex, or national origin. However, Title VII, 42 USC § 2000e-1(a), expressly exempts from the prohibition against discrimination on the basis of religion, a religious corporation, association, educational institution, or society with respect to the employment of individuals of a particular religion to perform work connected with the carrying on by such corporation, association, educational institution, or society of its activities.

Modifications/Prior Approval
NRC prior written approval may be required before a Recipient makes certain budget modifications or undertakes particular activities. If NRC approval is required for changes in the Cooperative Agreement or Grant, it must be requested of, and obtained from, the NRC Grants Officer in advance of the change or obligation of funds. All requests for NRC's prior approval must be made, in writing (which includes submission by e-mail), to the designated Grants Officer and Program Office no later than 30 days before the proposed change. The request must be signed by both the PI and the authorized organizational official. Failure to obtain prior approval, when required, from the NRC Grants Officer may result in the disallowance of costs, termination of the award, or other enforcement action within NRC's authority.

Lobbying Restrictions

The Recipient will comply, as applicable, with provisions of the Hatch Act (5 U.S.C. §§1501-1508 and 7324-7328) which limit the political activities of employees whose principal employment activities are funded in whole or in part with Federal funds.

The Recipient shall comply with provisions of 31 USC § 1352. This provision generally prohibits the use of Federal funds for lobbying in the Executive or Legislative Branches of the Federal Government in connection with the award, and requires disclosure of the use of non-Federal funds for lobbying.

The Recipient receiving in excess of $100,000 in Federal funding shall submit a completed Standard Form (SF) LLL, "Disclosure of Lobbying Activities," regarding the use of non-Federal funds for lobbying within 30 days following the end of the calendar quarter in which there occurs any event that requires disclosure or that materially affects the accuracy of the information contained in any disclosure form previously filed. The Recipient must submit the SF-LLL, including those received from sub-recipients, contractors, and subcontractors, to the Grants Officer.

§ 215.13 Debarment And Suspension.

The Recipient agrees to notify the Grants Officer immediately upon learning that it or any of its principals:

(1) Are presently excluded or disqualified from covered transactions by any Federal department or agency;

(2) Have been convicted within the preceding three-year period preceding this proposal been convicted of or had a civil judgment rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (Federal, State, or local) transaction or contract under a public transaction; violation of Federal or State antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, tax evasion, receiving stolen property, making false claims, or obstruction of justice; commission of any other offense indicating a lack of business integrity or business honesty that seriously and directly affects your present responsibility;

(3) Are presently indicted for or otherwise criminally or civilly charged by a governmental entity (Federal, State, or local) with commission of any of the offenses enumerated in paragraph (1)(b); and

(4) Have had one or more public transactions (Federal, State, or local) terminated for cause or default within the preceding three years.

b. The Recipient agrees that, unless authorized by the Grants Officer, it will not knowingly enter into any subagreement or contracts under this Cooperative Agreement/Grant with a person or entity that is included on the Excluded Parties List System (http://epls.arnet.gov).

The Recipient further agrees to include the following provision in any subagreements or contracts entered into under this award:

'Debarment, Suspension, Ineligibility, and Voluntary Exclusion

The Recipient certifies that neither it nor its principals is presently excluded or disqualified from participation in this transaction by any Federal department or agency. The policies and procedures applicable to debarment, suspension, and ineligibility under NRC-financed transactions are set forth in 2 CFR Part 180.'

Drug-Free Workplace
The Recipient must be in compliance with The Federal Drug Free Workplace Act of 1988. The policies and procedures applicable to violations of these requirements are set forth in 41 USC 702.

Implementation of E.O. 13224 -- Executive Order On Terrorist Financing
The Recipient is reminded that U.S. Executive Orders and U.S. law prohibits transactions with, and the provision of resources and support to, individuals and organizations associated with terrorism. It is the legal responsibility of the Recipient to ensure compliance with these Executive Orders and laws. This provision must be included in all contracts/sub-awards issued under this Cooperative Agreement/Grant award. Recipient must comply with Executive Order 13224, Blocking Property and Prohibiting Transactions with Persons who Commit, Threaten to Commit, or Support Terrorism. Information about this Executive Order can be found at: www.fas.org/irp/offdocs/eo/eo-13224.htm.

Procurement Standards. § 215.40
Sections 215.41 through 215.48 set forth standards for use by Recipient in establishing procedures for the procurement of supplies and other expendable property, equipment, real property and other services with Federal funds. These standards are furnished to ensure that such materials and services are obtained in an effective manner and in compliance with the provisions of applicable Federal statutes and executive orders. No additional procurement standards or requirements shall be imposed by the Federal awarding agencies upon Recipient unless specifically required by Federal statute or executive order or approved by OMB.

Travel
Travel is an appropriate charge to this award and prior authorization for specific trips are not required, as long as the trip is identified in the Recipient's original program description and original budget. All other travel, domestic or international, must not increase the total estimated award amount. Trips that have not been identified in the approved budget require the written prior approval of the Grants Officer.

Travel will be in accordance with the US Government Travel Regulations at: www.gsa.gov/federaltravelregulation and the per diem rates set forth at: www.gsa.gov/perdiem.

Travel costs to the Recipient must be consistent with provisions as established in Appendix A to 2 CFR 220 (J.53)

Property Management Standards
Property standards of this award shall follow provisions as established in 2 CFR 215.30.

Equipment procedures shall follow provision established in 2 CFR 215.34.

Procurement Standards
Procurement standards of this award shall follow provisions as established in 2 CFR 215.40.

Intangible and Intellectual Property

Intangible and intellectual property of this award shall generally follow provisions established in 2 CFR 215.36.

Inventions Report - The Bayh-Dole Act (P.L. 96-517) affords Recipient the right to elect title and retain ownership to inventions they develop with funding under an NRC Cooperative Agreement award ("subject inventions"). In accepting an award, the Recipient agrees to comply with applicable NRC policies, the Bayh-Dole Act, and its Government-wide implementing regulations found at Title 37, Code of Federal Regulations (CFR) Part 401. A significant part of the regulations require that the Recipient report all subject inventions to the awarding agency (NRC) as well as include an acknowledgement of federal support in any patents. NRC participates in the trans-government Interagency Edison system (http://www.iedison.gov) and expects NRC funding Recipients to use this system to comply with Bayh-Dole and related intellectual property reporting requirements. The system allows for Recipient to submit reports electronically via the Internet. In addition, the invention must be reported in continuation applications (competing or non-competing).

Patent Notification Procedures- Pursuant to EO 12889, NRC is required to notify the owner of any valid patent covering technology whenever the NRC or its financial assistance Recipients, without making a patent search, knows (or has demonstrable reasonable grounds to know) that technology covered by a valid United States patent has been or will be used without a license from the owner. To ensure proper notification, if the Recipient uses or has used patented technology under this award without license or permission from the owner, the Recipient must notify the Grants Officer. This notice does not necessarily mean that the Government authorizes and consents to any copyright or patent infringement occurring under the financial assistance.

Data, Databases, and Software - The rights to any work produced or purchased under a NRC federal financial assistance award are determined by 2 CFR 215.36. Such works may include data, databases or software. The Recipient owns any work produced or purchased under a NRC federal financial assistance award subject to NRC's right to obtain, reproduce, publish or otherwise use the work or authorize others to receive, reproduce, publish or otherwise use the data for Government purposes.

Copyright - The Recipient may copyright any work produced under a NRC federal financial assistance award subject to NRC's royalty-free nonexclusive and irrevocable right to reproduce, publish or otherwise use the work or authorize others to do so for Government purposes. Works jointly authored by NRC and Recipient employees may be copyrighted but only the part authored by the Cooperative Agreement is protected because, under 17 USC § 105, works produced by Government employees are not copyrightable in the United States. On occasion, NRC may ask the Recipient to transfer to NRC its copyright in a particular work when NRC is undertaking the primary dissemination of the work. Ownership of copyright by the Government through assignment is permitted under 17 USC § 105.

Records retention and access requirements for records of the Recipient shall follow established provisions in 2 CFR 215.53.

Organizational Prior Approval System

In order to carry out its responsibilities for monitoring project performance and for adhering to award terms and conditions, each Recipient organization shall have a system to ensure that appropriate authorized officials provide necessary organizational reviews and approvals in advance of any action that would result in either the performance or modification of an NRC

supported activity where prior approvals are required, including the obligation or expenditure of funds where the governing cost principles either prescribe conditions or require approvals.

The Recipient shall designate an appropriate official or officials to review and approve the actions requiring NRC prior approval. Preferably, the authorized official(s) should be the same official(s) who sign(s) or countersign(s) those types of requests that require prior approval by NRC. The authorized organization official(s) shall not be the principal investigator or any official having direct responsibility for the actual conduct of the project, or a subordinate of such individual.

Conflict Of Interest Standards of this award shall follow provisions as established in 2 CFR 215.42 Codes of Conduct.

Dispute Review Procedures

a. Any request for review of a notice of termination or other adverse decision should be addressed to the Grants Officer. It must be postmarked or transmitted electronically no later than 30 days after the postmarked date of such termination or adverse decision from the Grants Officer.

b. The request for review must contain a full statement of the Recipient's position and the pertinent facts and reasons in support of such position.

c. The Grants Officer will promptly acknowledge receipt of the request for review and shall forward it to the Director, Office of Administration, who shall appoint a review committee consisting of a minimum of three persons.

d. Pending resolution of the request for review, the NRC may withhold or defer payments under the award during the review proceedings.

e. The review committee will request the Grants Officer who issued the notice of termination or adverse action to provide copies of all relevant background materials and documents. The committee may, at its discretion, invite representatives of the Recipient and the NRC program office to discuss pertinent issues and to submit such additional information as it deems appropriate. The chairman of the review committee will insure that all review activities or proceedings are adequately documented.

f. Based on its review, the committee will prepare its recommendation to the Director, Office of Administration, who will advise the parties concerned of his/her decision.

Termination and Enforcement. Termination of this award by default or by mutual consent shall follow provisions as established in 2 CFR 215.60,

Monitoring and Reporting § 215.51

a. Recipient Financial Management systems must comply with the established provisions in 2 CFR 215.21

- Payment – 2 CFR 215.22
- Cost Share – 2 CFR 215.23
- Program Income – 2 CFR 215.24

- Earned program income, if any, shall be added to funds committed to the project by the NRC and Recipient and used to further eligible project or program objectives.

- Budget Revision – 2 CFR 215.25
  - In accordance with 2 CFR 215.25(e), the NRC waives the prior approval requirement for items identified in sub-part (e)(1-4).
  - The Recipient is not authorized to rebudget between direct costs and indirect costs without written approval of the Grants Officer.
  - Allowable Costs – 2 CFR 215.27

b. **Federal Financial Reports**

Effective October 1, 2008, NRC transitioned from the SF–269, SF–269A, SF–272, and SF–272A to the Federal Financial Report (SF-425) as required by OMB:
http://www.whitehouse.gov/omb/fedreg/2008/081308_ffr.pdf
http://www.whitehouse.gov/omb/Cooperative Agreements/standard_forms/ffr.pdf
http://www.whitehouse.gov/omb/Grants/standard_forms/ffr_instructions.pdf

The Recipient shall submit a "Federal Financial Report" (SF-425) on a quarterly basis for the periods ending 3/31, 6/30, 9/30 and 12/31or any portion thereof, unless otherwise specified in a special award condition. Reports are due no later than 30 days following the end of each reporting period. A final SF-425 shall be submitted within 90 days after expiration of the award.

Period of Availability of Funds 2 CFR § 215.28

a. Where a funding period is specified, a Recipient may charge to the Cooperative Agreement/Grant only allowable costs resulting from obligations incurred during the funding period and any pre-award costs authorized by the NRC.

b. Unless otherwise authorized in 2 CFR 215.25(e)(2) or a special award condition, any extension of the award period can only be authorized by the Grants Officer in writing. Verbal or written assurances of funding from other than the Grants Officer shall not constitute authority to obligate funds for programmatic activities beyond the expiration date.

c. The NRC has no obligation to provide any additional prospective or incremental funding. Any modification of the award to increase funding and to extend the period of performance is at the sole discretion of the NRC.

d. Requests for extensions to the period of performance shall be sent to the Grants Officer at least 30 days prior to the Cooperative Agreement/Grant expiration date. Any request for extension after the expiration date may not be honored.

Automated Standard Application For Payments (ASAP) Procedures

Unless otherwise provided for in the award document, payments under this award will be made using the Department of Treasury's Automated Standard Application for Payment (ASAP) system < http://www.fms.treas.gov/asap/ >. Under the ASAP system, payments are made through preauthorized electronic funds transfers, in accordance with the requirements of the Debt Collection Improvement Act of 1996. In order to receive payments under ASAP, Recipients are required to enroll with the Department of Treasury, Financial Management Service, and Regional Financial Centers, which allows them to use the on-line method of withdrawing funds from their ASAP established accounts. The following information will be

required to make withdrawals under ASAP: (1) ASAP account number – the award number found on the cover sheet of the award; (2) Agency Location Code (ALC) – 31000001; and Region Code. Recipients enrolled in the ASAP system do not need to submit a "Request for Advance or Reimbursement" (SF-270), for payments relating to their award.

Audit Requirements

Organization-wide or program-specific audits shall be performed in accordance with the Single Audit Act Amendments of 1996, as implemented by OMB Circular A-133, "Audits of States, Local Governments, and Non-Profit Organizations." http://www.whitehouse.gov/omb/circulars/a133/a133.html Recipients are subject to the provisions of OMB Circular A-133 if they expend $500,000 or more in a year in Federal awards.

The Form SF-SAC and the Single Audit Reporting packages for fiscal periods ending on or after January 1, 2008 must be submitted online.

1. Create your online report ID at http://harvester.census.gov/fac/collect/ddeindex.html
2. Complete the Form SF-SAC
3. Upload the Single Audit
4. Certify the Submission
5. Click "Submit."

Organizations expending less than $500,000 a year are not required to have an annual audit for that year but must make their Cooperative Agreement/Grant -related records available to NRC or other designated officials for review or audit.

III. Programmatic Requirements

Performance (Technical) Reports

a. The Recipient shall submit performance (technical) reports electronically to the NRC Project Officer and Grants Officer as specified in the special award conditions in the same frequency as the Federal Financial Report unless otherwise authorized by the Grants Officer.

b. Unless otherwise specified in the award provisions, performance (technical) reports shall contain brief information as prescribed in the applicable uniform administrative requirements 2 CFR §215.51 which are incorporated in the award.

Unsatisfactory Performance

Failure to perform the work in accordance with the terms of the award and maintain at least a satisfactory performance rating or equivalent evaluation may result in designation of the Recipient organization as high risk and assignment of special award conditions or other further action as specified in the standard term and condition entitled "Termination".

Failure to comply with any or all of the provisions of the award may have a negative impact on future funding by NRC and may be considered grounds for any or all of the following actions: establishment of an accounts receivable, withholding of payments under any NRC award, changing the method of payment from advance to reimbursement only, or the imposition of other special award conditions, suspension of any NRC active awards, and termination of any NRC award.

Other Federal Awards With Similar Programmatic Activities

The Recipient shall immediately provide written notification to the NRC Project Officer and the Grants Officer in the event that, subsequent to receipt of the NRC award, other financial assistance is received to support or fund any portion of the program description incorporated into the NRC award. NRC will not pay for costs that are funded by other sources.

Prohibition Against Assignment By The Cooperative Agreement

The Recipient shall not transfer, pledge, mortgage, or otherwise assign the award, or any interest therein, or any claim arising thereunder, to any party or parties, banks, trust companies, or other financing or financial institutions without the express written approval of the Grants Officer.

Site Visits

The NRC, through authorized representatives, has the right, at all reasonable times, to make site visits to review project accomplishments and management control systems and to provide such technical assistance as may be required. If any site visit is made by the NRC on the premises of the Recipient or contractor under an award, the Recipient shall provide and shall require his/her contractors to provide all reasonable facilities and assistance for the safety and convenience of the Government representative in the performance of their duties. All site visits and evaluations shall be performed in such a manner as will not unduly delay the work.

IV. Miscellaneous Requirements

Criminal and Prohibited Activities

a. The Program Fraud Civil Remedies Act (31 USC §§ 3801-3812), provides for the imposition of civil penalties against persons who make false, fictitious, or fraudulent claims to the Federal government for money (including money representing Cooperative Agreement/cooperative agreements, loans, or other benefits.)

b. False statements (18 USC § 287), provides that whoever makes or presents any false, fictitious, or fraudulent statements, representations, or claims against the United States shall be subject to imprisonment of not more than five years and shall be subject to a fine in the amount provided by 18 USC § 287.

c. False Claims Act (31 USC 3729 et seq), provides that suits under this Act can be brought by the government, or a person on behalf of the government, for false claims under federal assistance programs.

d. Copeland "Anti-Kickback" Act (18 USC § 874), prohibits a person or organization engaged in a federally supported project from enticing an employee working on the project from giving up a part of his compensation under an employment contract.

American-Made Equipment And Products

Recipients are hereby notified that they are encouraged, to the greatest extent practicable, to purchase American-made equipment and products with funding provided under this award.

Increasing Seat Belt Use in the United States

Pursuant to EO 13043, Recipient should encourage employees and contractors to enforce on-the-job seat belt policies and programs when operating company-owned, rented or personally-owned vehicle.

Federal Employee Expenses

Federal agencies are generally barred from accepting funds from a Recipient to pay transportation, travel, or other expenses for any Federal employee unless specifically approved in the terms of the award. Use of award funds (Federal or non-Federal) or the Recipient's provision of in-kind goods or services, for the purposes of transportation, travel, or any other expenses for any Federal employee may raise appropriation augmentation issues. In addition, NRC policy prohibits the acceptance of gifts, including travel payments for Federal employees, from Recipient or applicants regardless of the source.

Minority Serving Institutions (MSIs) Initiative

Pursuant to EOs 13256, 13230, and 13270, NRC is strongly committed to broadening the participation of MSIs in its financial assistance program. NRC's goals include achieving full participation of MSIs in order to advance the development of human potential, strengthen the Nation's capacity to provide high-quality education, and increase opportunities for MSIs to participate in and benefit form Federal financial assistance programs. NRC encourages all applicants and Recipients to include meaningful participations of MSIs. Institutions eligible to be considered MSIs are listed on the Department of Education website: http://www.ed.gov/about/offices/list/ocr/edlite-minorityinst.html

Research Misconduct

Scientific or research misconduct refers to the fabrication, falsification, or plagiarism in proposing, performing, or reviewing research, or in reporting research results. It does not include honest errors or differences of opinions. The Recipient organization has the primary responsibility to investigate allegations and provide reports to the Federal Government. Funds expended on an activity that is determined to be invalid or unreliable because of scientific misconduct may result in a disallowance of costs for which the institution may be liable for repayment to the awarding agency. The Office of Science and Technology Policy at the White House published in the Federal Register on December 6, 2000, a final policy that addressed research misconduct. The policy was developed by the National Science and Technology Council (65 FR 76260). The NRC requires that any allegation be submitted to the Grants Officer, who will also notify the OIG of such allegation. Generally, the Recipient organization shall investigate the allegation and submit its findings to the Grants Officer. The NRC may accept the Recipient's findings or proceed with its own investigation. The Grants Officer shall inform the Recipient of the NRC's final determination.

Publications, Videos, and Acknowledgment of Sponsorship

Publication of the results or findings of a research project in appropriate professional journals and production of video or other media is encouraged as an important method of recording and reporting scientific information. It is also a constructive means to expand access to federally funded research. The Recipient is required to submit a copy to the NRC and when releasing information related to a funded project include a statement that the project or effort undertaken was or is sponsored by the NRC. The Recipient is also responsible for assuring that every publication of material (including Internet sites and videos) based on or developed under an award, except scientific articles or papers appearing in scientific, technical or professional journals, contains the following disclaimer:

> "This [report/video] was prepared by [Recipient organization name] under award [number] from [name of operating unit], Nuclear Regulatory Commission. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the view of the [name of operating unit] or the US Nuclear Regulatory Commission."

CONTRACT, ORDER, AND MODIFICATION DISTRIBUTION LIST

(To Be Filed with Contract in Basic Contract File [red], Left Side)

Senior Grants Specialist: Usha Ganti_____ Date: 9/21/2010_____

Contract/Order/Contract No.: NRC-04-10-155 _____ Mod No.: _____

Action Required	Action Completed (Date)	
(X)		Contractor – Original (with cover letter and attachments, if any) shinjune@engr.sc.edu danielc@mailbox.sc.edu
(X)		DC Contract File – Original
(X)		DC Grants Specialist – Electronic Copy **Usha Ganti**
NA		Director, Requiring Program Office _____, - Hard Copy
(X)		Project Officer, Requiring Program Office: Zeechung Wang – Electronic Copy
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