Final Report

Identification and Demonstration of a Technology Adaptable to Locating Water in Post-tensioned Bridge Tendons

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Dr. R. Edward Minchin Jr., PE

The University of Florida

Department of Civil and Coastal Engineering

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16. Abstract

The research team has identified a technology with great potential for identifying and locating water in post-tensioned bridge members. This project called for the identification of a technology that can be developed to find hazardous materials in civil structures – specifically, water in post-tensioned bridge tendons. FDOT needs the ability to locate this water in a reliable, non-destructive way. Currently, FDOT spends time and energy checking the condition of individual strands and reacting to any troubled strand by searching for bleed water at its most likely location. The search, however, has been conducted using destructive methods that are not as reliable as desired. By using non-destructive methods to locate the water early, the water can be removed before damage is done to the strands. Also only those locations where state engineers are certain of the location of water will be disturbed. The days of blind, destructive searches will be over. The research team tested four technologies for their potential to provide a non-destructive, accurate, and efficient method for identifying and locating this harmful bleedwater. These technologies were ultrasonic sound waves, ground-penetrating radar, impact echo, and gamma-ray spectroscopy. Gamma-ray spectroscopy shows, by far, the most potential for development.

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EXECUTIVE SUMMARY

The purpose of the research was to determine if there exists technologies that can be developed to identify and locate bleedwater water in the conduits of post-tensioned bridge members.

Every year, millions of dollars are spent nationwide in the rebuilding, repairing, re-engineering, and maintaining of post-tensioned bridges that have had their structural integrity compromised, and in some cases ruined, by bleedwater in the conduits housing their structural strands. The Florida Department of Transportation (FDOT) recently finished an $11,000,000 project to repair the Mid-Bay Bridge in Okaloosa County, and are currently in the midst of a $15,000,000 contract to repair damage done to the state's flagship bridge, the Sunshine Skyway. Both post-tensioned bridges had been severely damaged by bleedwater in the conduits housing their structural strands.

The objectives of the research were to 1) generate a Short List of technologies that have the possibility to locate and identify the problem water, 2) test the technologies on the list to determine their potential for development, and 3) analyze the data and identify the single technology that holds the most promise for meeting the challenge.

After completion of the research, it is apparent that the technology with the greatest potential in this area is Gamma-ray Spectroscopy. In fact, this technology is the only one

showing appreciable potential, for development into a system that can be utilized to locate and identify the problem water.

There are great benefits to implementing the results of this research. For a relatively low level of funding, the results of this research could be developed into a system that could locate and identify the problem water in real time in existing or newly-constructed bridges. Such a system could be made safe and usable for technicians.

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Chapter 1: INTRODUCTION

There is great need for a non-destructive method for identifying and locating the water that gathers in post-tensioned bridge members and causes great damage to bridges. The research team has successfully identified a technology with great potential for use in developing such a system.

BACKGROUND

Every year, millions of dollars are spent nationwide in the rebuilding, repairing, re-engineering, and maintaining of post-tensioned bridges that have had their structural integrity compromised, and in some cases ruined, by water in the conduits housing their structural strands. The Florida Department of Transportation (FDOT) recently finished an $11,000,000 project to repair the Mid-Bay Bridge in Okaloosa County, and a $15,000,000 contract to repair damage done to the state's flagship bridge, the Sunshine Skyway. Both post-tensioned bridges had been severely damaged by water in the conduits housing their structural strands.

The source of the water is the grout used to secure the structural steel strands inside a sheet metal or polyurethane conduit. As the grout hardens, water that failed to properly mix with the grout separates and rises to the highest elevation possible as it is lighter than the bulk of the grout. This "bleedwater" gathers in these "high spots" in volumes that can range from six ounces to as much as 13 liters. The quality of the water produced by this process is much more corrosive than pure water, as the ingredients of the grout become increasingly concentrated as time goes along due to evaporation. Thus the grout actually harms the very strands it is placed to aid. In fact, in the most severe cases, FDOT reports that a bridge's structural integrity can be severely compromised in as little as thirty days of exposure to this bleed water.

Bridge owners such as FDOT need to be able to locate this water in a reliable, non-destructive way. Currently, FDOT spends time and energy checking the condition of individual strands and reacting to any troubled strand by searching for bleedwater at its most likely location. The search for the water, however, has been conducted using destructive methods that are not as reliable as desired.

The proposed system will allow FDOT to move from a reactive position to a proactive one. By locating the water early, the water can be removed before damage is done to the strands. Also, since the test conducted will be non-destructive, only those locations where state engineers are certain of the location of water will be disturbed. The days of blind, destructive searches will be over.

STATEMENT OF HYPOTHESIS

The hypothesis of the research project was that there is one best technology that can be used to develop a method for identifying and locating bleedwater in post-tensioned bridge members. Each technology tested had its own hypothesis. Since the Gamma-ray Spectroscopy was the only method that showed promise, the hypothesis of that portion of the research will be shared here.

This research will examine innovative nondestructive methodologies based on neutron activation followed by Gamma-ray spectroscopy, neutron back-scattering, and/or transmission. It is envisioned that these methodologies will ultimately provide the means of developing portable devices, which can identify target isotopes in orders of minutes.

The proposed nuclear technique will investigate a combination of neutron sources of various spectra (through the use of different source types and different neutron moderation thicknesses) and detection systems. Neutrons, because they are not charged, can penetrate materials, and therefore provide valuable information about material compositions through by-products of their interactions with nuclei of different elements and isotopes. For instance, if the search is for water, the technique relies on the detection of hydrogen, the main constituent of H_20. A particular nuclear reaction can be leveraged in which a thermal neutron is captured by the nucleus of a hydrogen atom, converting it into deuterium. This reaction is commonly shown symbolically as H(n,)D, meaning a neutron reacts with an H atom generating deuterium and a gamma ray. The gamma ray comes from an excited state of deuterium that has energy of 2.223 MeV (million electron volts). A gamma-ray spectrometer (GRS) (e.g., High Purity Germanium, HPGe) is used to measure the intensity of the gamma rays. This intensity is proportional to the amount of H, and hence water, in the structure.

Note that besides the nuclei in target materials, similar nuclei in other materials would also be activated, and hence, it is essential that these unwanted components (considered as background/noise) are significantly low or could be suppressed. For example, in the case of civil structures, much of a structure is comprised of members, such as steel-reinforced concrete, bricks and mortar, or other components that naturally contain small amounts of water. Since the interest is in identification of large pockets of water, the sensor could be designed to effectively distinguish such regions from the intrinsic water. Part of the modeling and testing of the technique will be to determine exactly how sensitive the system is to the concentrated water in the conduit over normal background amounts of water naturally present in the members composing the structure itself.

Objectives

The objective of this project is to identify and demonstrate a technology that is capable of or adaptable to reliably locating accumulated bleedwater in post-tensioned bridge tendons. The technology should be capable of detecting water residing in plastic ducts, steel ducts, and steel anchors, each of which may be encased in concrete for depths of up to several feet.

Chapter 2: LITERATURE REVIEW

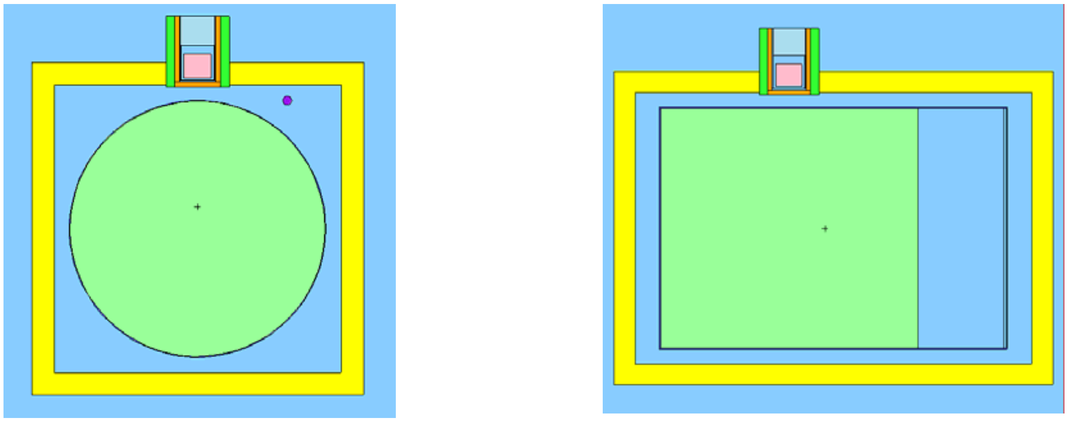
The Literature Review conducted for this project was limited to a review of previous research into attempts to locate harmful elements embedded in structures or containers, and a comprehensive review of all technologies used for non-destructive evaluation of all types to determine their limitations and strengths regarding the intended purpose.

REVIEW OF PREVIOUS RESEARCH

Previous research was conducted by a research team funded by Westinghouse to find harmful elements inside 55-gallon drums**.** The main focus of the work was to analyze and optimize Westinghouse's PGNAA (pulsed gamma neutron activation analysis) device (Dullee et al. 1998a) (Dullee et al. 1998b) (Dullee et al. 1999) (Petrovic et al. 1999). Thus far, PGNAA has been successfully used for detection of various hazardous metals such as Cd, Pb, and Hg in a concrete matrix.

Figures 1a and b show different views of the PGNAA physical model. As shown in the figures, the waste drum (light green; PCC matrix) is placed inside the polyethylene chamber (yellow color; used for nuclear thermalization) with the source (purple small circle) located at the side and the detector located at the top of the drum.

In order to improve the accuracy and performance of the PGNAA device, a detailed particle transport methodology was developed based on a combination of time-dependent 3-D Monte Carlo and time-independent deterministic discrete ordinates calculations. Besides simulating the as-built device, a series of sensitivity studies were performed to examine the interference effects from ^{235}U, ^{238}U, ^{239}Pu, ^{241}Am, chlorine and boron, and to estimate the effect of waste density variations on the performance of the device.



a. Cut through the detector mid-plane, perpendicular to the drum axis.

b. Cut through the detector mid-plane, along the drum axis.

Figure 1. MCNP Model of the 55-Gallon System.

LEGEND: waste matrix = light-green; drum steel = blue; air = sky-blue; polyethylene = yellow; germanium = pink; aluminum = gray-blue; tungsten = green; ^{6}LiF = orange; Source position = purple

Moreover, in order to enhance system performance, special detector shielding was developed (orange and green layers shown in Figures 1a and b), and the positioning of the detector and source assembly relative to the waste drum was tested. Finally, the response of the PGNAA system to non-uniform axial distribution of contaminants was examined.

An accurate and efficient three-step transport theory methodology was developed to estimate the HPGe response due to an activated waste drum. The three-step methodology is described below:

Step 1) Gamma field throughout the waste was determined by performing time-dependent Monte Carlo calculations to simulate neutron transport, moderation, and gamma generation throughout the waste;

Step 2) Gamma field over the surface of the HPGe detector was determined by using the adjoint methodology that folds the adjoint function distribution with the gamma field obtained in Step 1. For this, time-independent deterministic Sn adjoint calculations were performed;

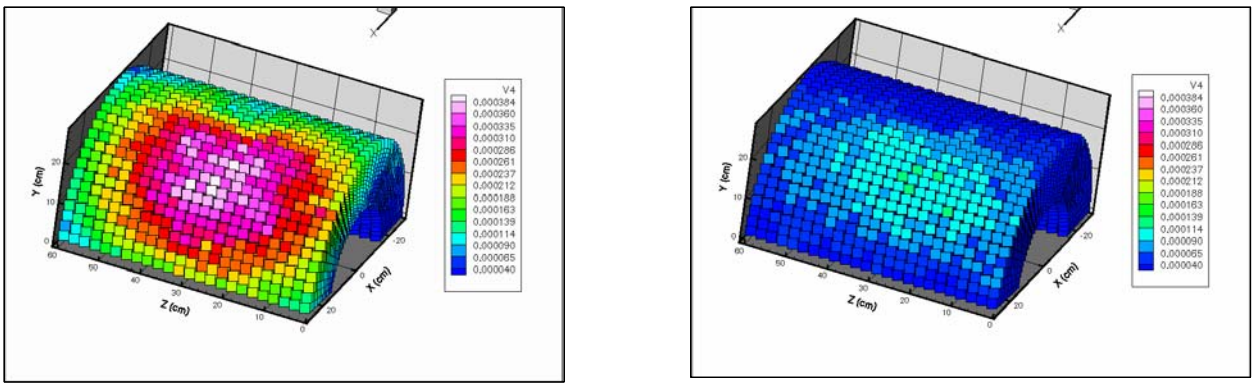
Step 3) HPGe detector response was estimated by transporting the surface gamma source into the detector volume. For this, time-independent Monte Carlo calculations were performed.

For time-dependent and time-independent "forward" Monte Carlo calculations, the MCNP (Monte Carlo N-particle) Monte Carlo code was used. (Briesmeister, 1993) For the time-independent adjoint transport calculations, the PENTRAN (Parallel Environment Neutral-particle TRANsport) 3-D parallel Sn code was utilized (Sjoden, Haghighat, 1997).

Time-dependent Monte Carlo MCNP simulations were performed to obtain the generation rate and spatial distribution (i.e., gamma source) of the signature gamma rays within the waste matrix. To improve the efficiency of these simulations, they were performed in the neutron-only mode and resulted in a time-dependent thermal neutron flux distribution. The gamma source was then inferred based on the captured cross section for the corresponding RCRA (Resource Conservation and Recovery Act) metal, i.e., cadmium, mercury, and lead.

As a sample, Figures 2a and b depict the thermal neutron flux distributions at the drum surface for two mercury concentrations of 200 ppm and 20,000 ppm. It is clear that the higher contaminant concentration leads to a higher neutron absorption rate, and consequently to lower thermal neutron fluxes. This observation indicates that besides the lower limit of detection, there is a maximum limit of detection that has to be determined. In order to determine the detector response, PENTRAN was used to calculate three different adjoint function distributions corresponding to gamma lines of interest, i.e., energy groups 10 (1. -1.5 MeV), 14 (0.4 -0.6 MeV), and 15 (0.2 - 0.4 MeV) of the gamma cross sections of the BUGLE-96 library.

Results indicate that the response-generating volume is more shallow for increasing concentrations (due to neutron self-shielding), and consequently spread over a large area close to the surface. This information was used to optimize the system performance, i.e., measuring a spectrum which closely represents the material content within the waste drum. Figure 3 shows a set of spectra measured for examination of the mercury content of a 55-gallon drum.



(a) 200 ppm Hg **(b) 20,000 ppm Hg**

Figure 2. Thermal Neutron Flux Distribution (Arbitrary Units) for Different Mercury Concentrations.

Table 1 gives the predicted mass of mercury along with its deviation from the true concentration for different heights of drum scanned. These results indicate that the PGNAA device can predict material concentrations accurately.

Review and Analysis of Existing Technologies

Every technology known to be used in non-destructive evaluation was analyzed. Results of this effort can be seen in Table 2. A more detailed analysis of these and other technologies can be found in Appendix A.

Effect of ^{235}U on 368-keV Hg Prompt Gamma Peak

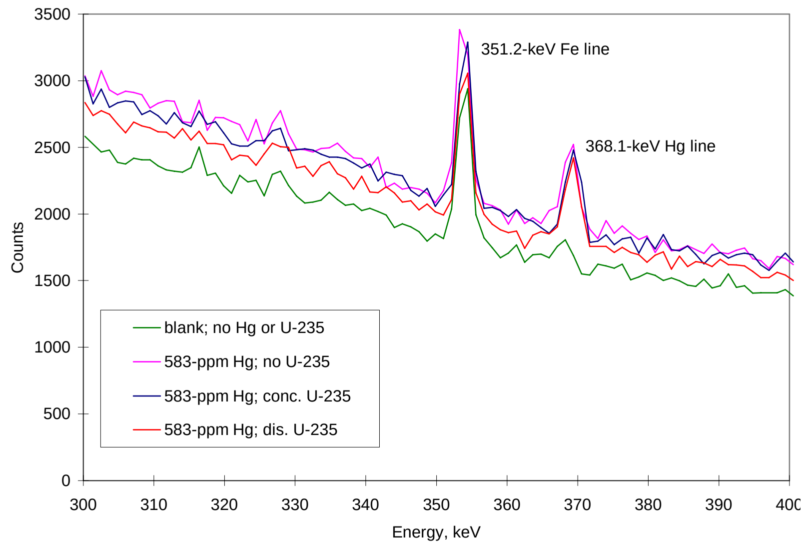


Figure 3. PGNAA Spectra from Blank Drum and from Drum.

Table 1. Hg Concentration values from simulation runs for different number of axial locations along the height of a 55-gallon drum containing a waste matrix with a Non-uniform Distribution of Hg.

Scan Height, cm	No. of axial positions	Average Hg concentration based on detector response, ppm	Deviation from true average Hg concentration of 250, ppm
5.08	12	249.8	-0.08%
10.16	6	250.2	0.08%
15.24	4	247.0	-1.2%

Table 2. Applications, Advantages, and Limitations of Technologies Reviewed.

Technology	Past Applications/Advantages	Apparent Limitations
X-Ray	Probed and pictured the inside of a PCC slab	Has had problems functioning at the kind of depths necessary for this application
Electrical	Used to measure moisture content of PCC	1) May not be able to differentiate bleed-water from normal PCC water content. 2) Most tests are partially destructive
Gamma Rays	1) Used to find water pockets on Mars 2) Used to find toxins in waste drums	Any system must be properly shielded for protection of operator
Capacitance	Health monitoring of PCC structures by detecting corrosion initiation in rebar	1) Does not actually find water 2) Requires embedded sensors
Microwave	1) Moisture determination in soils – non-contact 2) Can move and measure in real-time	1) More expensive than most technologies 2) No history with PCC 3) May not be able to differentiate bleed-water from normal PCC water content
Ground Penetrating Radar	1) Fast 2) Real-time measurement 3) System already in advanced state	Has shown poor performance in dealing with metal shells/containers
Laser	1) Can detect any liquid or paste containing water molecules. 2) Non-contact – can operate up to 800 mm from container surface	Only success to date is with clear or translucent containers
Multiring Electrode	Used to measure moisture content of PCC	1) May not be able to differentiate bleed-water from normal PCC water content. 2) Requires embedded sensors
Infrared Thermometry	Non-contact	Claims of ability to detect moisture are unsubstantiated
Supersonic Soundwaves	1) Non-contact More applications than can be listed	1) May not be able to differentiate between pockets of bleed-water and simple voids
1) Passive Microwave 2) Psychrometers (Peltier) 3) Time-domain Reflectometry 4) Wide-band Radiometry 5) Basic Infrared	Various	For various reasons, these show less promise than those listed above

Chapter 3: METHODOLOGY

Six reinforced concrete slabs containing a conduit full of grout and steel tendons were formed in the University of Florida Civil Engineering Structures Laboratory and poured under the supervision of Corrosion Laboratory personnel in the Florida Department of Transportation

State Materials Office on November 14. The details of the slabs, constructed per design by the FDOT Central Structures Design Office, can be seen in Appendix B.

Two of the slabs contained conduits with an 8-ounce plastic bottle of water embedded within, two contained an empty 8-ounce plastic bottle, and two contained nothing but the strands and grout. The slabs were 30"L x 9.5" h x 11.5" w and weighed approximately 280 pounds per slab. The construction of the slabs can be seen in Figures 4 and 5.

Figure 4. FDOT and UF Personnel Pour Concrete into Slab Forms

The explanation of the testing methodology will be broken up into sections for each of the four technologies.

GROUND-PENETRATING RADAR AND IMPACT ECHO

Four of the sample bridge deck slabs were transported to the campus of Worcestor Polytechnic Institute (WPI), and after a three-day delay due to a blizzard and a weekend, tests

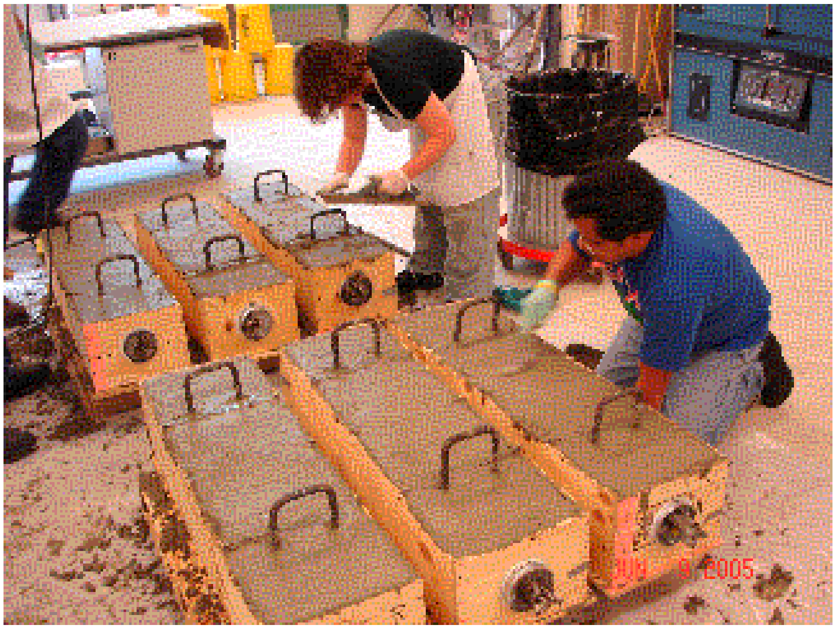


Figure 5. FDOT and UF Personnel Finish Concrete in Slab Forms.

were performed using GPR and IE technology on December 12. The capacity of the truck used to transport the slabs precluded taking all six slabs as planned, so the two slabs that contained no plastic bottle were left behind. The GPR tests (see Figure 6) were executed during the morning and the IE tests were performed in the afternoon. Figure 7 shows the IE transducer and Figure 8 shows the test being conducted.

Ultrasonic Sound Waves

The slabs were then transported to State College, PA, to the testing laboratory of The Ultran Group, a group of engineers and scientists specializing in exploration of innovative uses for ultrasonic sound waves and the manufacture of transducers for these purposes. Figure 9

Figure 6. GPR Testing.

shows the slab being tested. The tests were conducted using non-contact (air-coupled) ultra-sound scanning. The scanning was accomplished using 100 kHz transducer pairs. Note the transponder on the right and the receiver on the left. The readings of the receiver were shown on a remote computer screen.

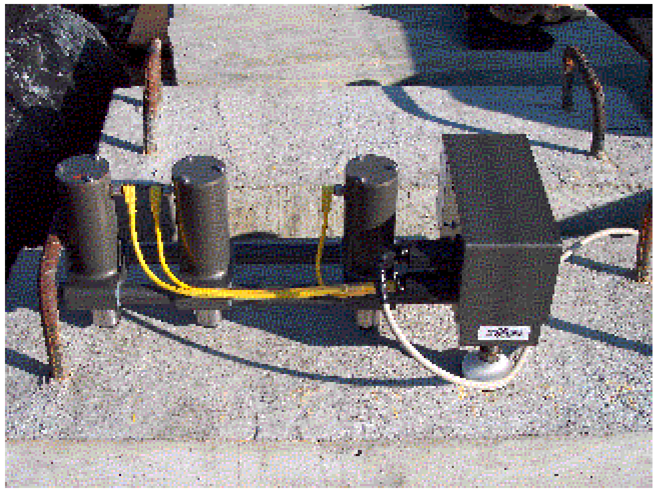


Figure 7. IE Transducer.

Figure 8. IE Testing in Progress.

A very unfortunate thing happened the night before the ultrasonic tests were conducted. The temperature dropped to -2° Fahrenheit and the two slabs containing the water split down the middle of the slab as seen in Figure 10. The crack down the middle of the top slab in the figure was similar to the one in the second slab containing water.

Figure 9. Ultrasonic Testing.

Figure 10. Crack Down the Middle of Top Slab.

Gamma-ray Spectroscopy

Additional test slabs true to the original design were constructed for the Gamma-ray Spectroscopy tests. An example of the experimental setup is shown in Figure 11. The concrete block was lifted into position using a pneumatic table. A combination of lead and borated paraffin blocks were used to provide some shielding from scattered gamma-ray and neutrons, respectively. The Pb blocks were positioned such that a 3 x 3 in^2 (approximate) column was produced from which the detector would collect gamma-ray spectra. This "collimated beam" extended to the approximate height of the water bottle (near the centerline of the concrete block). The detector used for this experiment was a high purity germanium (HPGe) detector that has an approximate diameter of 3 in and a height of 3 in. A 1-Ci PuBe source producing approximately 10^6 neutrons/s was placed on the top of the concrete block. The source, shielding, and detector were moved in tandem across the detector to measure each block in five positions, labeled A-E. The gamma-ray spectra were recorded from the HPGe detector using standard nuclear instrument modules (NIMs), the Ortec TRUMP-PCI multichannel analyzer card, and Ortec's MAESTRO spectroscopy software. Each measurement took approximately 30 minutes after accounting for detector dead time and signal processing time.

Figure 11. The Experimental Setup for Measuring the 2.22 MeV Gamma-ray from Neutron Capture with Hydrogen.

In order to perform a complete Gamma-ray Spectroscopy, it is necessary to generate simulated images of the object being analyzed. This requires a complete summary of the chemical makeup of the concrete slab, including conduit, concrete, steel, and grout. Tables 3-5 show the information fed into the software in order to generate the needed simulations. The results of the simulation can be seen in Appendix C.

Table 3. Materials for Prestressed Concrete.

Material	Source	Specs 1	Specs 2	Notes
Cement	Portland, Type II	ASTM C-150	AASHTO M85	
Air entrainer	Darex AEA	ASTM C-260	AASHTO M154	
Water reduction	WRDA 60	ASTM C-494	AASHTO M194	
Water Reduction	ADVA 120	ASTM C-494	AASHTO M194	
Fine aggregate	76-137			silika sand
Coarse aggregate	AL-149			limerock
Water				
Rebars		ASTM A-615		
Grout	SikaGrout 300PT	ASTM C-1152 (C)		125 lbs per cf
	SikaGrout 328	ASTM C-1107 (B,C)	CRD C-621	
Plastic bottle				
Strands		ASTM A-416 (grade 270)	ASTM A-416M (grade 1860)	
Conduit	Metal			
	Plastic			Polyurethane
Source: Florida DOT Standard Specifications for Highway and Bridge Construction				
Source: Manual from manufacturer				

Table 4. Density of Components, Concrete Sample.

		Diameter		Area		Weight		Density			Source
		inch	mm	sq.in.	cm^2	kg/ft	lb/ft	kg/m	lb/cf	g/cm^3	
Strands	7-wire, No. 9, Grade 270	0.375	9.53	0.085	0.548		0.290	0.432		7.88	ASTM A416/ A416M
	7-wire, No. 15, Grade 270	0.600	15.24	0.217	1.400		0.740	1.102		7.87	ASTM A416/ A416M
	7-wire, Grade 270	0.563	14.29	0.191	1.232		0.650	0.967		7.85	FL Specs, 933-1
Rebar	5/8”	0.625	15.9	0.31	1.99	0.473	1.043	1.552		7.80	ASTM A615/A615M
Grout	Sika Grout 300PT								125	2.00	Manufacturer
	Sika Grout 328								130	2.08	
Concrete									150	2.40	
Conduit	Metal									7.80	
	Plastic									0.95	
Water										1.00	
Air										0.00	

Table 5. Chemical Composition of Materials

Strands	Source:	Caleb Hornbostel, "Construction Materials: Type, Uses, and Applications",		
		John Wiley & Sons, 1978. ISBN: 0-471-40940-5. p.635		
	Ref.	ASTM A441		
	Material type:	High-strength, low-alloy steel		
Element		**List**	**Used**	
Fe	Iron		97.64	
C	Carbon	0.22	0.20	
Mn	Manganese	0.85-1.25	1.05	
P	Phosphorus	0.04	0.04	
Si	Silicon	0.30 max	0.27	
Cu	Copper	0.20 min	0.30	
Ni	Niobium		0.50	
Cr	Chromium			
Mo	Molybdenum			
Sum			*100*	
Rebars	Source:	ASTM A706/A706M		
Element		**max [%]**	**Used (90% of max)**	
Fe	Iron		98.715	
C	Carbon	0.30	0.270	
Mn	Manganese	1.50	0.900	exception
P	Phosphorus	0.035	0.030	
S	Sulfur	0.045	0.040	
Si	Silicon	0.50	0.045	
Sum			*100.0*	
Concrete	Source:	Worksheet of "Comp-A"		
Element		Percent		
Ca		25.44		
Si		17.03		
Al		0.46		
S		0.13		
H		0.60		
O		49.88		
C		5.41		
Mg		0.49		
Fe		0.57		
Sum		*100.00*		

Water	Atom mass	Wt. pct.						
H	1.008	11.19%						
O	15.9994	88.81%						
Grout	Source:	Worksheet of "Comp-A"						
	Note: % of cement or silica within SikaGrout 300PT is unknown. Assume 75% cement and 25% silica							
Element		**Wt. pct.**						
Ca		27.31						
Si		15.84						
Al		1.26						
S		0.42						
H		2.24						
O		49.98						
C								
Mg		1.11						
Fe		1.84						
Sum		*100.00*						
Duct: Metal								
Material type: steel, galvanized								
Notes: assume Galvanized coating 1.00 oz/ft (385 g/m2), pipe thick 0.8mm								
Element	**Wt pct**		**Adj wt pct**					
C	0.3		0.28					
Mn	0.75		0.71					
Si	0.5		0.47					
P	0.45		0.42					
S	0.45		0.42					
Fe	97.55		91.88					
Zn		100	5.81					
Weight	*6240*	*385*	*100.00*					
Duct: Plastic								
Material type: Polyurethane								
Element	**Wt pct**							
C	22							
H	36							
O	8							
N	2							

Chapter 4: FINDINGS

As with the Methodology, the Findings will be offered in Sections for each Technology.

Ground-penetrating Radar

Infrasense Inc., in cooperation with Worcestor Polytechnic Institute, performed these experiments, with help from the research team. Infrasense did submit a formal report of sorts, but the conclusions were very vague. The PI asked the researcher at Infrasense to specifically address the results of the tests in light of the technology's potential for development for the purposes of this application and the response was equally vague.

The observation of the PI was that the performance of this technology was worse than expected. From the literature, and from observing GPR in other application, the PI expected some promise, at least when testing polyeurethane conduits. However, after many hours of testing, the figures on the screen showed nothing of significance. Several attempts were made to reposition sensors, etc., but there was never a good result. It is the opinion of the PI that, regarding this technology, more research for further development not be conducted until all other possibilities have been exhausted.

Impact Echo

The lead researcher for the Impact Echo testing stated that the results of those tests are fairly conclusive that IE is not a good fit as a technology for this application.

Ultrasonic Sound Waves

Because frigin temperatures in the Northeast caused the water-containing samples to crack, this experiment was compromised. The sound waves, then could not make the necessary trip from one side of the sample to the other. However, it ended up not being a factor, since the very advances ultrasonic sound wave system could not even locate the voids in the samples containing only entrapped air (empty 8-ounce water bottle).

It should be noted that the engineers conducting these ultrasonic sound wave experiments expressed the belief before the testing commenced that a special sensor needed to be developed that would give a much better result than what they had to use. The sensor would cost between $11,000 and $15,000 and would be attached to their existing system.

As the tests were conducted, however, there was no patent evidence that the system was detecting any difference between the section of the sample that contained the empty 8-ounce plastic bottle and the other solid concrete sections of the sample. Literature and past experience of the PI and the FDOT project manager indicate that this technology may have significant difficulty in differentiating between air voids and voids filled with water.

The testing engineers, members of the testing laboratory, the Ultran Group, submitted a very brief report on the testing that was very vague. Repeated attempts by the PI to get the group to elaborate on or specifically address the results of the tests in light of the technology's potential for development for the purposes of this application proved fruitless.

While there may be potential for this technology, none was apparent from the experiments and it is recommended that more research for the development of this technology not be conducted until all other possibilities have been exhausted.

Gamma-ray Spectroscopy

In order to find the water bottle within the concrete block, the height of the 2.22 MeV prompt gamma-ray due to neutron capture must be compared with hydrogen at several locations along the block. The excellent energy resolution of HPGe allows for easy distinction of the 2.22 MeV gamma-ray. This experiment was also attempted with a NaI(Tl) scintillation detector, but the results were unsatisfactory due to the poor energy resolution of NaI(Tl) detectors.

An example of the recorded gamma-ray spectra is shown in Figure 12. The 2.22 MeV gamma-ray line is clearly visible. Note: these results are background subtracted, meaning gamma-rays due to background radiation sources, cosmic rays, and atmospheric neutrons are removed from the gamma-ray spectra. Other gamma-rays are also visible, due to neutron interactions with other elements in the concrete structure, HPGe detector, and shielding material. It may be of interest to examine these other gamma-ray lines to locate salt deposits within the concrete itself. By recording the peak area of the 2.22 MeV gamma-ray line at each of the five positions, a relative strength of the hydrogen capture line (percentage of water) was recorded and shown in Table 6 below.

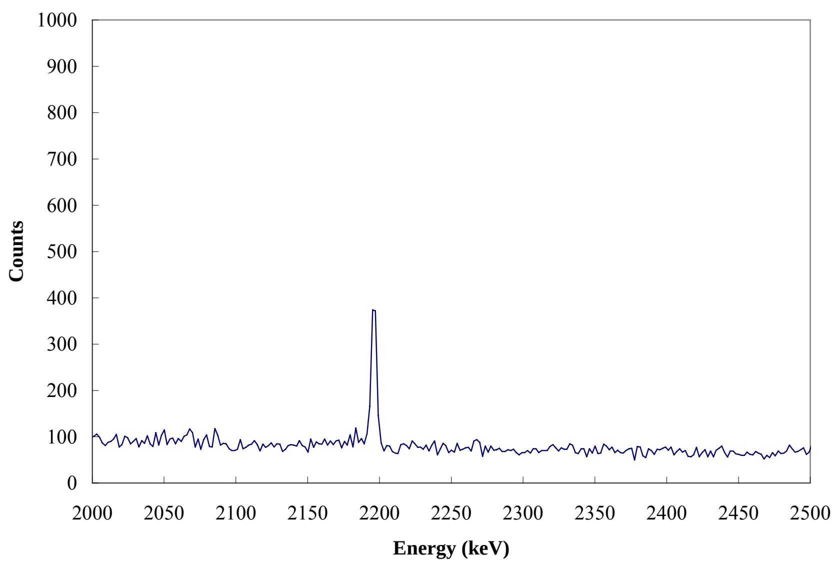


Figure 12. Sample gamma-ray spectrum from one of the concrete structures (P04, Location C), where a small bottle of water was imbedded in the middle of the sample. A large 2.22 MeV gamma-ray line can be clearly seen. Note: the energy location indicates the gamma-ray line was at 2.197 MeV; this was due to a slight error in the energy calibration of the HPGe detector and spectroscopy system.

Table 6. Net Photopeak Area of the 2.22 MeV Gamma-Ray Line as a Function of Position for Concrete Samples Containing a Bottle of Water.

Plastic Conduit				Metal Conduit			
Location	**Peak Area**	**% Error**	**Relative Area**	**Location**	**Peak Area**	**% Error**	**Relative Area**
A	659	5.77	0.887	A	700	6.00	0.913
B	667	6.15	0.898	B	644	6.37	0.840
C*	743	5.11	1.000	C	620	6.61	0.808
D	586	6.31	0.789	D*	767	5.48	1.000
E	761	5.26	1.024	E	748	5.75	0.975

*Represents Location of Bottle

There are two things to note from these measurements. First, locations A and E are at the edges of the concrete blocks and edge effects may be a significant factor in these measurements. Therefore, these can be disregarded for the time being (shielding and collimation had to be altered at the edges due to the size of the table. Locations B, C, and D are within the concrete structure themselves (no edge effects) and are a better representation of the true experiment. As can be seen in Table 6, the locations of the water bottle showed a net 2.22 MeV photopeak area increase of approximately 10-20% over the other locations. This was also significantly above the error in the measurement (~ 5-6% in most cases). Thus, the prompt gamma-ray neutron activation analysis technique seems able to detect water pockets in concrete structures (i.e., bridge components) where increased hydrogen levels suggest an increased concentration of water.

Chapter 5: DISCUSSION

Since only Gamma-ray spectroscopy proved to hold any promise based on the tests, the discussion will be centered on this technology.

VALIDITY OF HYPOTHESIS

Two hypotheses offered by the research team before the commencement of this research were borne out by the results of the study. First, the general hypothesis that a technology exists which, under rigorous analysis, will show potential for development into a system that can identify and locate water in post-tensioned bridge members. That technology is Gamma-ray Spectroscopy, and it shows undeniable and enormous potential for such use.

Therefore, the hypothesis dealing with that particular technology, "the proposed nuclear technique will investigate a combination of neutron sources of various spectra (through the use of different source types and different neutron moderation thicknesses) and detection systems. Neutrons, because they are not charged, can penetrate materials, and therefore provide valuable information about material compositions through by-products of their interactions with nuclei of different elements and isotopes," has been validated.

The hypotheses dealing with the other three technologies, ground-penetrating radar, impact echo, and ultrasonic sound waves proved unverifiable in the controlled environment in which they were tested.

Factors Affecting the Results

Except for the Impact Echo tests, every technology tested was carried out with sensors not perfectly suited for this application. Obviously, the budget did not allow for the production or purchase of sensors customized for working with this set of materials or for this purpose. The experts in each field were left to use the sensors at their disposal best suited for this purpose, which they did.

The water-containing samples cracking disqualified them from use in the ultrasonic testing. However, the fact that this technology could not find the empty water bottled (simulating large air voids) in the solid samples meant that this technology, at least with the sensors used, can not find water in a conduit filled with grout, covered by four inches of steel-reinforced portland cement concrete.

The success of gamma-ray spectroscopy was realized despite many obstacles to overcome that will be solved when, in future research, the team is able to use sensors suited for this application. In other words, while the results described above show that it is possible to detect pockets of water within a concrete structure, these results were far from ideal.

In particular, it would be advantageous to improve the detector system design to optimize the system for use as a field instrument for scanning a variety of concrete structures. This can be accomplished by combining a number of complex simulations with laboratory experiments. For example, specific shielding designs for the detector may enhance the signal by eliminating sources of gamma-ray/neutron scatter. The PuBe source used in the experiments could be replaced by a mono-energetic neutron source, such as a D-T gun. This new source would allow one to optimize source strength and moderation in order to "peer" into different depth of concrete. Finally, the detector used was a HPGe detector, which requires liquid nitrogen cooling (77 K). This is not ideal for a fielded instrument as one may be required to also transport liquid nitrogen. A better gamma-ray detector may be newly design compound semiconductor radiation detectors (e.g., CdZnTe and HgI_2) that can operate at room temperature (or higher) without any necessary cryogenic or mechanical cooling.

Implications

The implications of the research are that a system to accurately identify and locate water in the conduits of post-tensioned bridge members is there for the taking if the equipment necessary to build a prototype can be procured. The prototype would then be tested in a laboratory, and finally in a field (actual bridges) setting.

Chapter 6: CONCLUSIONS

The conclusions to this small but important study are simple.

1. Gamma-ray spectroscopy shows great potential as a technology for use in the development of a system to accurately identify and locate pockets of water in the conduits of post-tensioned bridge structures.
2. Impact echo, ground-penetrating radar, and ultrasonic sound waves do not show potential as a technology for use in the development of a system to accurately identify and locate pockets of water in the conduits of post-tensioned bridge structures.
3. None of the technologies were tested under ideal conditions. None of the experts were fortunate enough to have sensors that were well-suited for this application and the funds for the research were not sufficient to purchase or develop better-suited sensors.
4. To have access to a system to accurately identify and locate water in the conduits of post-tensioned bridge members is there for the taking given the equipment necessary to build a prototype and test it in a laboratory, and finally in a field (actual bridges) setting..

APPENDIX A

Review of Potential Technologies

for Locating Water in Post-tensioned Bridge Conduits

TECHNOLOGY

Infrared Thermometry

PRINCIPLE OF OPERATION

The infrared spectral falls between the visible light and radio waves, extending from 0.7 micron to 1000 microns. Infrared thermometers sense emitted infrared energy from an object and convert it to an electrical signal at the detector.

ADVANTAGES

- Non-contact
- Lightweight, compact, and easy to use

LIMITATIONS

- IR measurement is affected by an object’s emissivity. Many materials and surfaces have similar emissivity. Inaccurate reading may result.
- The IR thermometer takes an average temperature of the target area. If the temperature varies across a given surface, the measurement may be less inaccurate.

APPLICATIONS

Infrared thermometry is widely used to measure surface temperature of objects. The most popular uses include: monitor steam systems, boiler operations, and engine cooling systems performance; detect hot spots in electrical systems, panels and motor bearings; monitor agricultural plant temperature for stress.

Bridge: Detect delaminations in concrete slabs. (SHRP-S-323)

Infrared Solutions Inc. claims to be able to detect moisture present in roofs and walls using its portable infrared imagers. (Infrared thermography)

POTENTIAL FOR LOCATING WATER

Not likely. IR thermometer takes average temperature of the target area, and may not tell the detail of structurally complicated objects. Probably not suitable for testing component deep inside the concrete.

TECHNOLOGY

Ultrasonic (Pulse Echo)

PRINCIPLE OF OPERATION

An ultrasonic inspection system consists of several function units, including pulser, transducer, and receiver. A pulser is a device that can produce high voltage electrical pulse. This electrical pulse further causes the transducer to generate ultrasonic wave. The ultrasonic wave is introduced and propagated through the object. The change in acoustic impedance at the various interfaces (discontinuity) within the object causes a portion of the ultrasonic energy to be reflected (echo) back to the surface. The reflected wave signal is detected and transformed into electrical signal by the receiver. Signal travel time, which is directly related to the distance that the signal traveled, is also measured. Information about the reflector location, size, and other features can also be gained.

ADVANTAGES

- Non-contact
- Sensitive to both surface and subsurface discontinuities
- The depth of penetration to flaw measurement is superior to other NDT methods
- Only one-side access is needed
- High accuracy in determine reflector position, size and shape
- Instantaneous results available

LIMITATIONS

- Materials not homogeneous are difficult to inspect
- Reference standards are required for both equipment calibration, and characterization of discontinuities

APPLICATIONS

Flaw detection

Thick measurement

Underwater detection and ranging

POTENTIAL FOR LOCATING WATER

Maybe, since it is sensitive to subsurface discontinuities and can penetrate a deep object. But may not be able to differentiate between pockets of water and simple voids.

TECHNOLOGY

Ground Penetrating Radar (GPR)   Radio Pulse Echo

PRINCIPLE OF OPERATION

A GPR system includes a radio transmitter and a receiver, connected to a pair of antennas. The antennas transmit short pulses of radio wave energy to the ground. As the radio wave penetrating the ground, part of the energy is reflected back at the boundaries of dissimilar materials. The strength of the echoes and the signal travel time are measured to calculate the depth of the boundaries and other properties.

ADVANTAGES

Fast test

Real-time data collection

System already in advanced state

LIMITATIONS

- Spurious radar echoes (clutter echoes)
- Manual data processing
- Broad antenna beamwidth makes it difficult to discriminate between closely spaced components
- Attenuation of radar signal (metal)

APPLICATIONS

pipes and utilities
landfill and burial trenches
cemetery and grave sites
archaeological studies
Soil stratigraphy and water content

POTENTIAL FOR LOCATING WATER

Maybe. Has been proposed/used on mars subsurface water detection

<u>TECHNOLOGY</u>

Nuclear (neutron, gamma ray)

PRINCIPLE OF OPERATION

(a) ability of hydrogen to slow down, or moderate, neutrons
(neutron scattering: multiple elastic collisions)
(b) H(n,γ)D
neutron + hydrogen = deuterium + γ (2.223MeV)

ADVANTAGES

(b) focus on nuclear reaction with hydrogen, less "noise signal".

reactions occur when neutrons slow down to thermal neutron. This makes it sensitive to material beneath the surface.

LIMITATIONS

Radiation exposure

APPLICATIONS

Both (a) and (b) are successfully used on Marian water detection

POTENTIAL FOR LOCATING WATER

a) possible, not sure. Neutron interacts with nuclides of all types of atoms in the concrete. The interaction with hydrogen maybe not significant enough to identify water.

b) More likely than other technologies. Since H(n,γ)D reaction dominates all other possible reactions, noise should be low.

c) Has been successfully used on mars for subsurface water detection

<u>TECHNOLOGY</u>

Time-Domain Reflectometry (TDR) (electromagnetic)

PRINCIPLE OF OPERATION

TDR method calculated a material's relative dielectric constant by comparing the velocity of an electromagnetic signal propagated through that material to one propagated through free space.

Electromagnetic signals are sent to a TDR probe. The time for the signal to travel down the length of the probe and to reflect back to its source is measured to calculate the signal velocity.

Signal velocity is affected by the dielectric constant of the materials surrounding the probe. Water, with a high dielectric constant, affect signal velocity much more greatly than do most other materials.

ADVANTAGES

(Not identified)

LIMITATIONS

embedded probes needed

APPLICATIONS

Detect water content in PCC

POTENTIAL FOR LOCATING WATER

No.
No probes were instrumented at the time of construction.

TECHNOLOGY

x-ray, gamma radiography

PRINCIPLE OF OPERATION

x-ray from a radioactive element can induce fluorescent x-rays from other non-radioactive materials. The energies of the fluorescent x-rays emitted can identify the elements present in the material, and their intensity can indicate the quantity (concentration) of each element present.

Gamma radiography is similar.

ADVANTAGES

Known technology

Easier to transport than gamma-ray equipment

LIMITATIONS

X-ray:

- x-ray may not be able to penetrate the necessary depth for this application
- x-ray equipment usually immobile
- high-energy x-ray are very expensive

Both:

- Radiation exposure
- Access required to both sides of sample
- Exposure time?

APPLICATIONS

x-ray screen luggage at airport

x-ray medical examination

x-ray flaw detection: cracks, porosity, corrosion

x-ray and gamma ray: concrete deterioration inspection

gamma ray: detect aircraft internal flaws

Gamma: detect void in prestressed cable ducts (system name: SCORPION)

POTENTIAL FOR LOCATING WATER

Very possible if water is close to the surface. Depth is a real issue. Gamma ray possible.

SCORPION (by France) is able to detect void in prestressed cable ducts

(Source: SHRP-S/FR-92-103)

<u>TECHNOLOGY</u>

Passive microwave remote sensing

PRINCIPLE OF OPERATION

Detect microwave radiation emitted directly from objects.

ADVANTAGES

LIMITATIONS

Limited penetration depth

May not detect the complex structure within the concrete

APPLICATIONS

Near surface soil volumetric water content

POTENTIAL FOR LOCATING WATER

Definitely NO

Penetration limit

<u>TECHNOLOGY</u>

Laser

PRINCIPLE OF OPERATION

Non-contact water detection sensors (SA1W) developed by IDEC.

Using a laser beam tuned to the resonant frequency of an H2O molecule, the SA1W sensor is able to detect any liquid or paste containing water molecules - without any contact

Capable of detecting liquids through clear or translucent containers of any color, the SA1W uses a small diameter laser beam for precise detection and has a visible red spot for easy targeting and alignment.

ADVANTAGES

Non-contact

LIMITATIONS

Successful only with clear or translucent containers

APPLICATIONS

Detect liquid in container

POTENTIAL FOR LOCATING WATER

No. Laser can not penetrate the concrete

APPENDIX B

DESIGN OF TEST SLABS

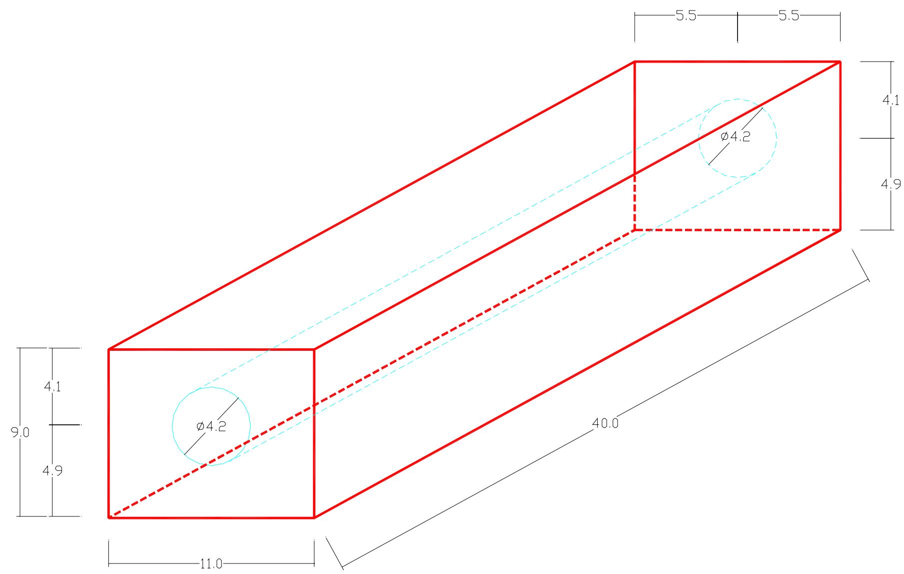


Figure B1. Concrete Sample.

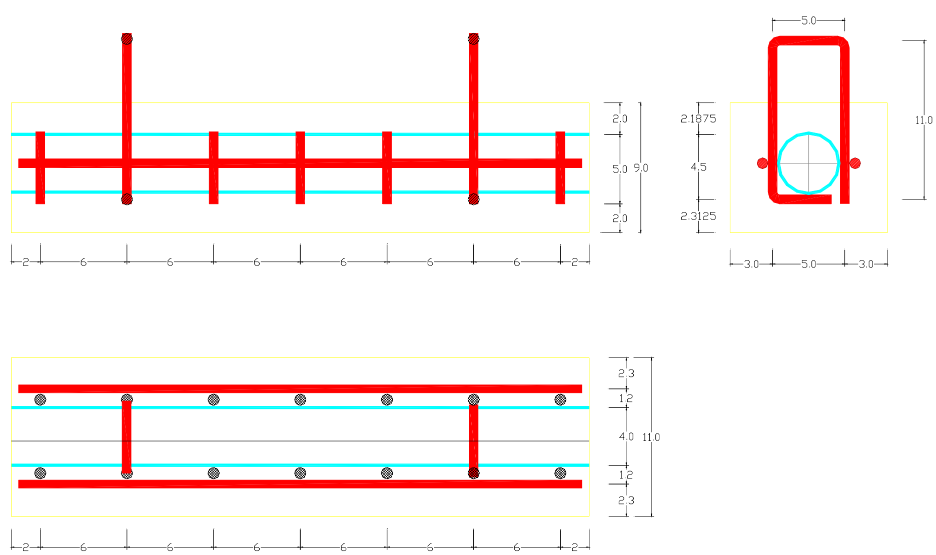


Figure B2. Rebars

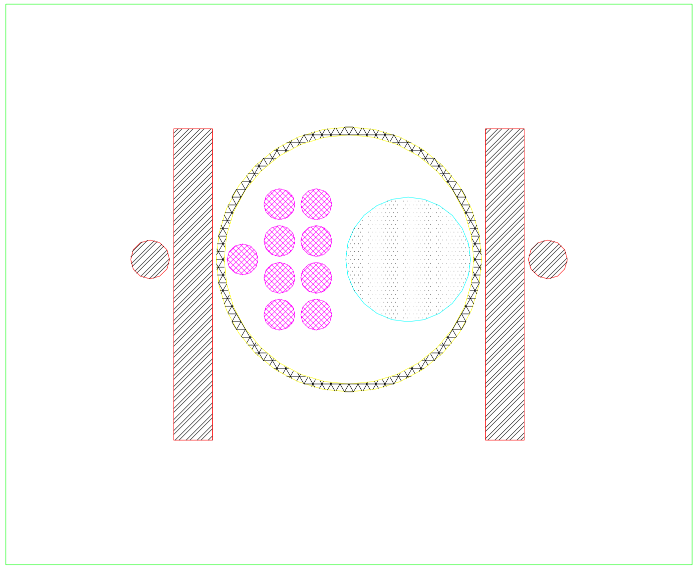
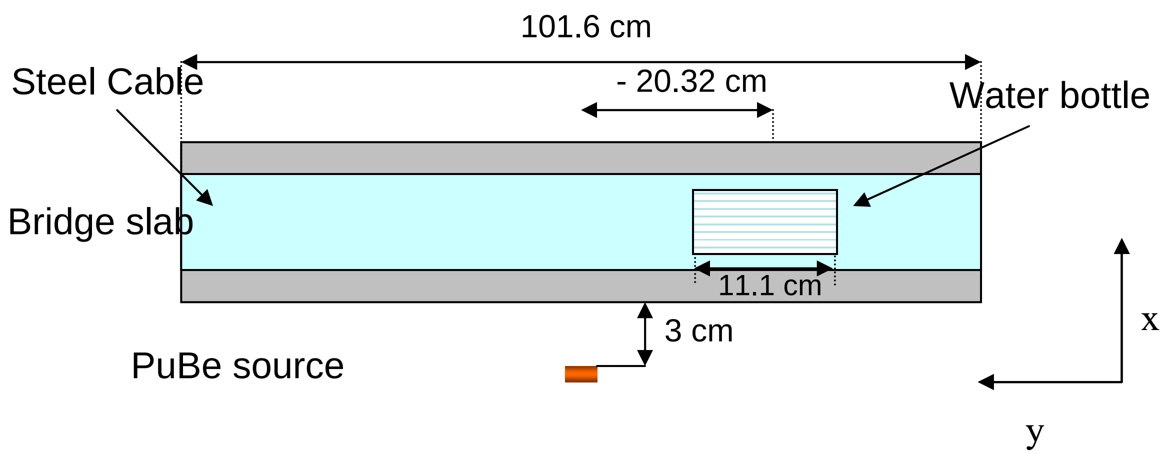


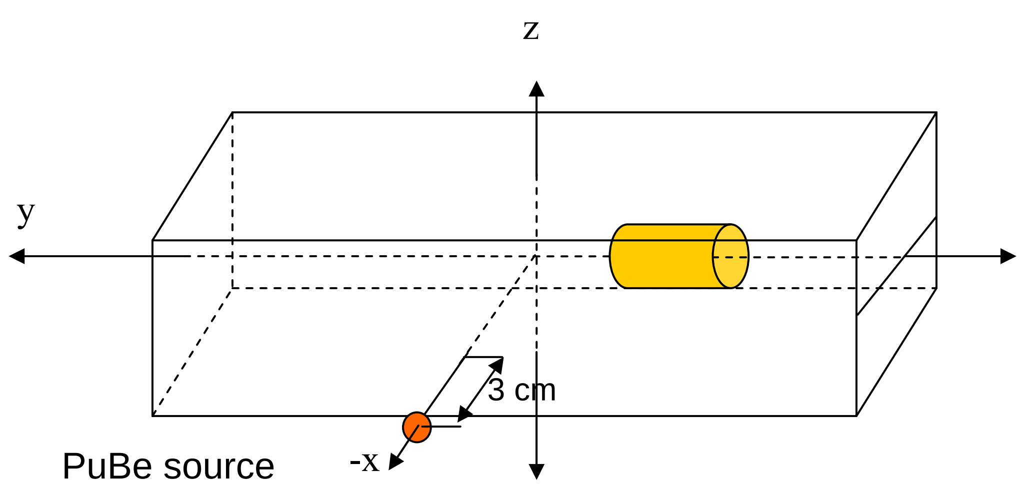
Figure B3. Concrete Cross Section (for simulation only).

Appendix C

Preliminary Results of Computer Simulation of Gamma-ray Spectroscopy



a) Top view of the concrete bridge slab (at z = 0.0 cm)



b) The concrete bridge slab and the neutron source

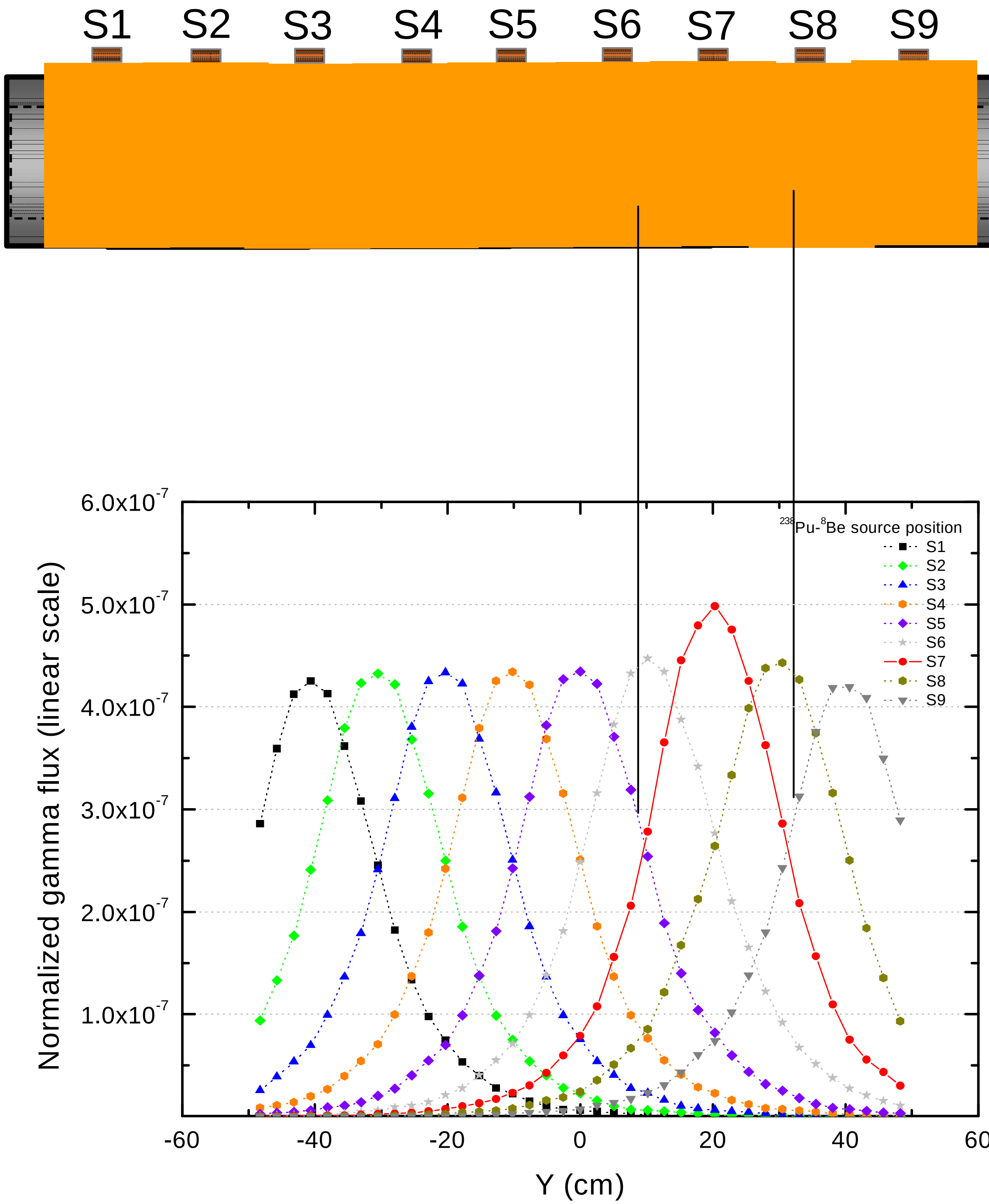


Figure C2. Spectrograph of Sensor Matrix.

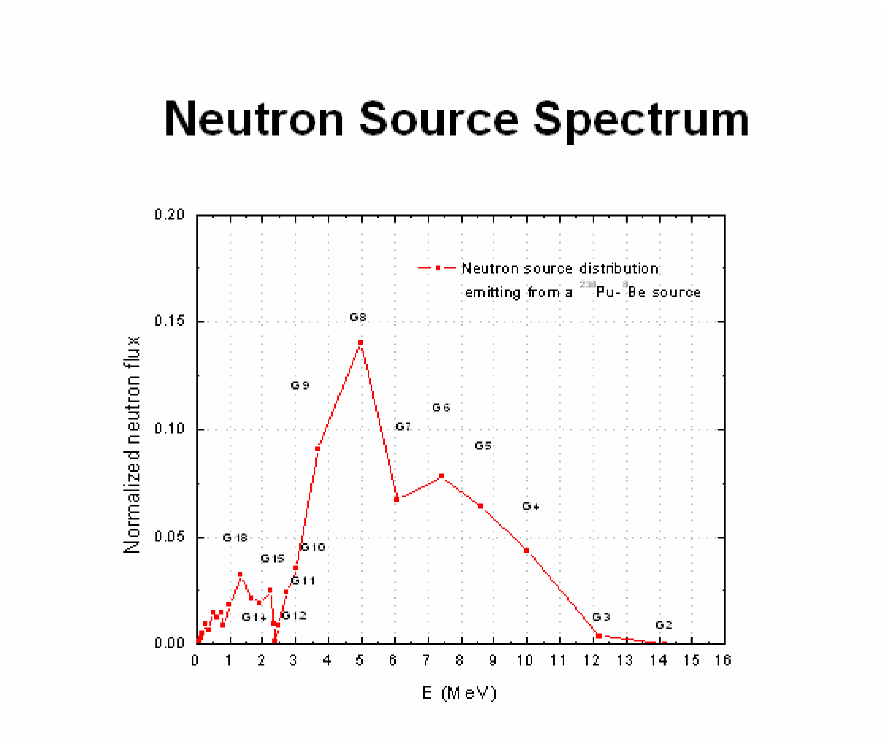


Figure C3. Neutron Source Spectrum.