NDE2002 predict. assure. improve.
National Seminar of ISNT
Chennai, 5. – 7. 12. 2002
www.nde2002.org

Determining the Moisture Content in Limestone Concrete by Gamma Scattering Method: A Feasibility Study

Shivaramu
Health and Safety Division, SHINE Group
Indira Gandhi Centre for Atomic Research, Kalpakkam - 603 102, e- mail: shiv@igcar.ernet.in

R. Vijayakumar, L. Rajasekaran and N. Ramamurthy
Department of Physics, Annamalai University,
Annamalainagar- 608 002

Abstract

The use of a theoretical model based on the concept of the isolated atom has facilitated the study of the relationship between coherent and incoherent scattered gamma radiation and chemical composition, leading to the application of the measurement of scattered intensity ratio as a means of determining the moisture content of concrete. From the typical mixing proportions and oxide composition of the main constituents of limestone concrete the fractional weights of the constituent elements are obtained. The coherent, incoherent, coherent-to-incoherent intensity and the effective atomic number (Z_{eff}) of limestone concrete for 0%, 2%, 4%, 6% and 8% of water have been calculated at different scattering angles of 36.40°, 49.40°, 62.74°, 77.4°, 93.60° and 112.81° for 59.54 keV gamma energy and at two scattering angles of 21.60 and 43.60 degrees for 661.6 keV. The experimental set- up consists of a collimated ^{137}Cs radioactive source and a collimated planar HPGe detector coupled to a PC based plug-in-card multichannel analyser providing energy dispersive analysis of the scattered spectrum. The scattered intensity and effective atomic number found to vary linearly with the amount of water present in the concrete specimen and the results show that the scattering method is highly sensitive to changes in moisture content in limestone concrete and < 1% change can be easily detected using this method.

1. Introduction

The Nuclear Power Plant (NPP) concrete structures are composed of several constituents that, in concert, perform multiple functions (i.e., load- carrying capacity, radiation shielding and leak tightness). Primarily these constituents can include concrete, conventional steel reinforcement, prestressing steel, and steel or non- metallic liner materials. These structures are required to function safely and reliably in challenging, demanding, and varying environments**.** The NPP concrete structures are exposed to a variety of damaging influences and degradation of concrete is an extremely complex subject and can be age-related phenomena. In most cases, concrete damage will be the result of more than one mechanism (degradation factor). However, given the basic understanding of the various damage- mechanisms, it should be possible, in most cases, to determine the primary cause or causes of damage to a particular concrete structure. The physical causes of damage are Moisture changes, Freeze/ Thaw cycling, Thermal exposure/ Thermal cycling, Irradiation. Abrasion/ Erosion/ Cavitation, Fatigue/ Vibration, Creep and degradation of mild steel reinforcing and prestressing steel systems. The chemical causes of damage are Alkali-Aggregate reactions, Sulfate attack, Efflorescence and Leaching, Bases and Acids and Salt Crystallization

In design of reactor shields concrete is a widely used and versatile shielding material primarily because of its special attenuating properties for neutrons and relatively new cost. It also has the required structural integrity and mechanical properties. Concrete is effective for neutron shielding because of its aggregates of low atomic number and hydrogen content- which are desirable to thermalise the fast neutrons within the shield. Neutron transmission through concrete is very much dependent on its water content. However, over a period of time water content of the concrete slowly decreases due to the inherent porosity of the material and also due to varied weather conditions with different degree of humidity. Moreover, in addition to being exposed to external heat, concrete accumulates heat generated due to absorption of radiation within the shield. At elevated temperatures, the process of evaporation of water takes place rapidly resulting in larger neutron transmission and therefore, more dose outside the shield. Long- term dehydration process can also influence thermal conductivity of the concrete and consequently temperature distribution and thermal stress in a shield. Thus the water content of the concrete is an important consideration while choosing the shielding material. The reduction in water content of the concrete has a very significant effect in calculation of radiation shielding thickness

Water, although important for concrete hydration and hardening, can also play a role in decreased durability. Water can transport harmful chemicals to the interior of the concrete leading to various forms of deterioration. As pointed out by Mehta etal [1] that water is "at the heart of the most of the physical and chemical causes underlying the deterioration of concrete structures". Among other effects the moisture levels determine the risk of corrosion attack on cast- in -steel and reinforcement, deleterious mechanisms such as alkali- aggregate reactions (AAR). At the same time a long- term ageing effect caused by drying- out of the cement matrix in concrete will be evident and the result will be reduced strength. A combination of dry and wet concrete may cause differential shrinkage, which in turn may well lead to cracking. A balanced and stable moisture levels would seem to be desirable, but cannot be achieved since the structural members are usually massive and are subjected to different environments. Moisture variations affect testing performance as the speed and penetration ability of acoustic and electromagnetic pulses used in modern techniques are strongly dependent on this factor. The criteria used in evaluating electrochemical test results are similarly affected by moisture content (oxygen availability). It may be said that any advances in non- destructive methods will be dependent on the ability to determine the moisture condition of massive concrete members on site and ability to use this information in processing measurement data [2]. An overview on the applications of various non destructive testing techniques for assessment of concrete structures is given by Baladev Raj and Jayakumar [3]

Concrete is a living material and in terms of durability and structural ageing is governed by moisture content. The concrete comprehensive strength is influenced not only by the moisture content but also, significantly by the moisture distribution in the concrete specimen and the knowledge of moisture content as a function of time and position allows one to extract information on the permeability of the porous body. Compton scattering of gamma radiation has been considered for the inspection of concrete structures [4] and the concept is based on the detection of scattered radiation produced from a collimated beam aimed at the object. This paper proposes and demonstrates the use of a gamma scattering method to determine the moisture content of limestone concrete

2. Theoretical calculations

The use of a theoretical model based on the concept of the isolated atom has facilitated the study of the relationship between coherent and incoherent scattered gamma radiation and chemical composition, leading to the application of the measurement of scattered intensity as a means of determining the moisture content of concrete. From the typical mixing proportions and oxide composition of the main constituents of limestone concrete the fractional weights of the constituent elements such as hydrogen, carbon, oxygen, sodium, magnesium, aluminium, silicon, sulfur, potassium, calcium, and iron are obtained. Typical composition of main constituents of limestone concrete in % mass for 0%, 2%, 4%, 6% and 8% of water are given in Tables 1-3. The coherent, incoherent, coherent-to-incoherent intensity and the effective atomic number (Z_{eff}) of limestone concrete for 0%, 2%, 4%, 6% and 8% of water have been calculated at different scattering angles of 36.40^o, 49.40^o, 62.74^o, 77.4^o, 93.60^o and 112.81^o for 59.54 keV and at two scattering angles of 21.60 and 43.60 degrees for 661.6 keV. The calculated scattered intensity and effective atomic number for different amount of water present in the concrete specimen are given in Tables 4 and found to vary linearly with the amount of water present in the concrete specimen and are shown in Figures 3- 6.

Table 1
Typical composition of main constituents of limestone concrete in % mass for 0%, 2%, 4%, 6% and 8% of water

Constituents	% Mass	% Mass	% Mass	% Mass	% Mass	Density g / cc at 25°C
Water	8.0000	6.0000	4.0000	2.0000	0.0000	1.0000
Limestone	54.0000	54.2963	54.5926	54.8889	55.1852	2.7100
Natural sand	21.0000	21.7619	22.5238	23.2857	24.0476	2.6500
Portland Cement	17.0000	17.9412	18.8824	19.8235	20.7647	3.1500
Concrete	100.0000	99.9994	99.9988	99.9981	99.9975	---------

Table 2.
Typical oxide composition of each constituents in % mass

Oxide	Limestone	Natural sand	Ordinary portland cement	Concrete 8%water	Concrete 6%water	Concrete 4%water	Concrete 2%water	Concrete 0%water
CaO	48.1000	0.57	62.86	36.7799	37.5184	38.2569	38.9954	39.7338
MgO	1.7200	1.09	5.74	2.1335	2.2009	2.2683	2.3358	2.4032
SiO2	7.2800	87.92	21.84	26.1072	27.0042	27.9012	28.7982	29.6952
Fe2O3	0.2500	0.80	4.06	0.9932	1.0382	1.0833	1.1283	1.1734
Al2O3	1.3900	9.18	2.06	3.0306	3.1220	3.2155	3.3089	3.4024
Na2O	0.2800	0.04	0.30	0.2106	0.2146	0.2185	0.2225	0.2264
K2O	0.2200	0.04	0.28	0.1753	0.1820	0.1858	0.1895	0.1933
CO2	39.2300	-------	---------	21.1842	21.3004	21.4167	21.5329	21.6491
SO3	--------	--------	1.14	0.1938	0.2045	0.2153	0.2260	0.2367
H2O	--------	--------	---------	8.0000	6.0000	4.0000	2.0000	0.0000

Table 3
Limestone concrete fractional weights of individual elemental constituents for 0%, 2%, 3%, 4%, 6% and 8% of water

Element	0 % Water	2 % Water	4 % Water	6 % Water	8 % Water
Hydrogen	0.0000000	2.23808E-03	0.4476E-02	6.71424E-03	8.9523E-03
Carbon	0.0590846	0.0587673	0.5845E-01	0.0581331	0.0578157
Oxygen	0.4603189	0.4694195	0.4785E+00	0.4877452	0.4967657
Sodium	1.6797891 E-03	1.6506341 E-03	0.1621E-02	1.5920273 E-03	1.5623529 E-03
Magnesium	0.0144938	0.0140873	0.1368E-01	0.0132737	0.0128672
Aluminium	0.0180072	0.0175134	0.1702E-01	0.0165237	0.0160394
Silicon	0.1388067	0.1346051	0.1304E+00	0.1262281	0.1220352
Sulfur	9.4803756 E-04	9.0550563 E-04	0.8621E-03	8.1940049 E-04	7.7614768 E-04
Potassium	1.5704196 E-03	1.5407788 E-03	0.1542E-02	1.4810072 E-03	1.4551062 E-03
Calcium	0.2839781	0.2787005	0.2734E+00	0.2683888	0.2628663
Iron	8.2070769E-03	7.892402E-03	0.7577E-02	7.2622128E-03	6.9467686E-03

Table 4

Coherent (R), Incoherent (C), R/C and Zeff of Limestone concrete for 0%, 2%, 3%, 4%, 6% and 8% of water at various scattering angles (θ) and momentum transfer (X= sin (θ/2) /λ)

θ=49.40°, X=2.0				
% of Water	R	C	Rscat (R/C)	Zeff
8.0	0.4696E-01	0.4308E+00	0.1090	11.0612
6.0	0.4963E-01	0.4485E+00	0.1107	11.2154
4.0	0.5257E-01	0.4679E+00	0.1124	11.3782
2.0	0.5579E-01	0.4891E+00	0.1141	11.5506
0.0	0.5935E-01	0.5126E+00	0.1158	11.7336
θ=62.74°, X=2.5				
% of Water	R	C	Rscat (R/C)	Zeff
8.0	0.2168E-01	0.3592E+00	0.0604	10.7012
6.0	0.2298E-01	0.3740E+00	0.0615	10.7900
4.0	0.2441E-01	0.3902E+00	0.0626	10.8820
2.0	0.2598E-01	0.4081E+00	0.0637	10.9739
0.0	0.2771E-01	0.4277E+00	0.0648	11.0675
θ=77.40°, X=3.0				
% of Water	R	C	Rscat (R/C)	Zeff
8.0	0.1188E-01	0.3001E+00	0.0396	11.2983
6.0	0.1263E-01	0.3125E+00	0.0404	11.3843
4.0	0.1345E-01	0.3261E+00	0.0412	11.4713
2.0	0.1435E-01	0.3411E+00	0.0421	11.5595
0.0	0.1534E-01	0.3576E+00	0.0429	11.6479
θ=93.60°, X=3.5				
% of Water	R	C	Rscat (R/C)	Zeff
8.0	0.7786E-02	0.2748E+00	0.0283	12.0500
6.0	0.8292E-02	0.2862E+00	0.0290	12.1372
4.0	0.8848E-02	0.2987E+00	0.0296	12.2269
2.0	0.9457E-02	0.3125E+00	0.0303	12.3164
0.0	0.1013E-01	0.3276E+00	0.0309	12.4056
θ=112.81°, X=4.0				
% of Water	R	C	Rscat (R/C)	Zeff
8.0	0.6302E-02	0.2978E+00	0.0212	12.7725
6.0	0.6719E-02	0.3102E+00	0.0217	12.8618
4.0	0.7176E-02	0.3238E+00	0.0222	12.9506
2.0	0.7678E-02	0.3388E+00	0.0227	13.0388
0.0	0.8232E-02	0.3552E+00	0.0232	13.1285

3. Experiment

We have developed a gamma scattering method of determining the moisture content of concrete by measuring the intensity of scattered radiation in limestone concrete using an indigenously built goniometer and an HPGe spectrometer. The experimental set- up, shown in Fig.1 consists of a collimated ^{137}Cs radioactive source with a lead shielding mounted on a fixed arm of about 100 cm length, which could be rotated around the target centre and a collimated detector providing energy dispersive analysis of the scattered spectrum. The limestone concrete blocks of density 2.71 g / cc and dimensions 230 x 160 x 50 mm have been fabricated according to standard mix ratios and cured for 28 days. The concrete mix for the specimen comprised ordinary Portland cement, limestone (coarse aggregate), limestone sand and water in the proportion of 1: 3.121: 1.830: 0.484 respectively. By knowing the quantity of water added to the concrete mix, the water content in the concrete block was evaluated and the water content was computed as a function of percentage of the weight. After the normal curing period, the loss in weight was assumed to be due to loss of water only. The concrete block was then subjected to uniform heating in an oven at 130^{O} C for varying periods up to a maximum of 47 hours. The block was then placed in water for a few days to help regain the water lost. The concrete blocks were mounted on a mild steel target frame of dimensions 35.3 x 10.3 x 2.0 cm. The scattered beam was further collimated and detected using a high- purity germanium planar detector and the photo peaks of the scattered spectrum were analysed using a PC based plug-in-card multichannel analyser. A typical incoherent scattered spectrum is shown in Fig.2.

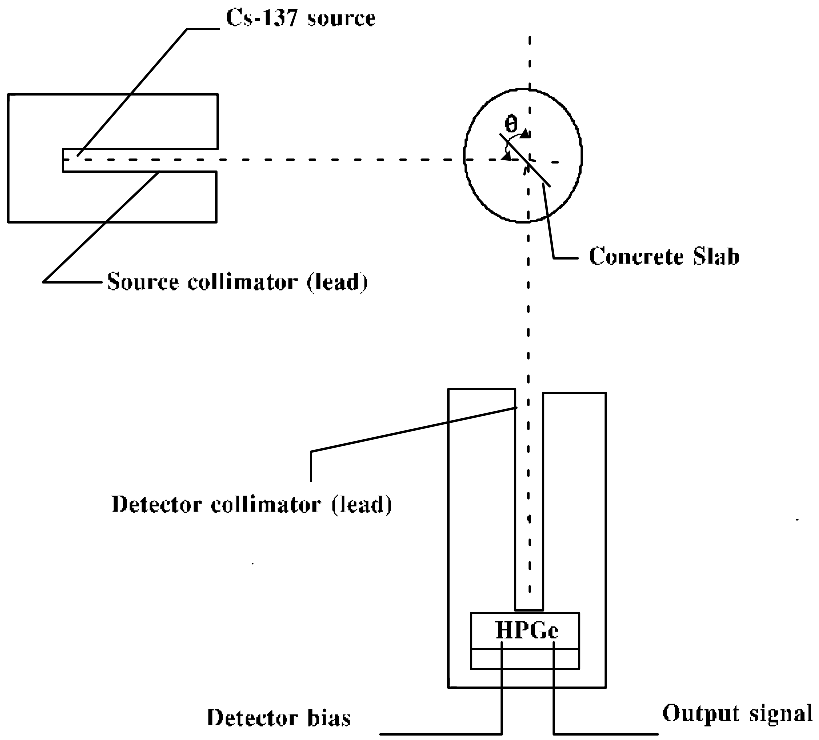

Figure 1. Experimental Setup

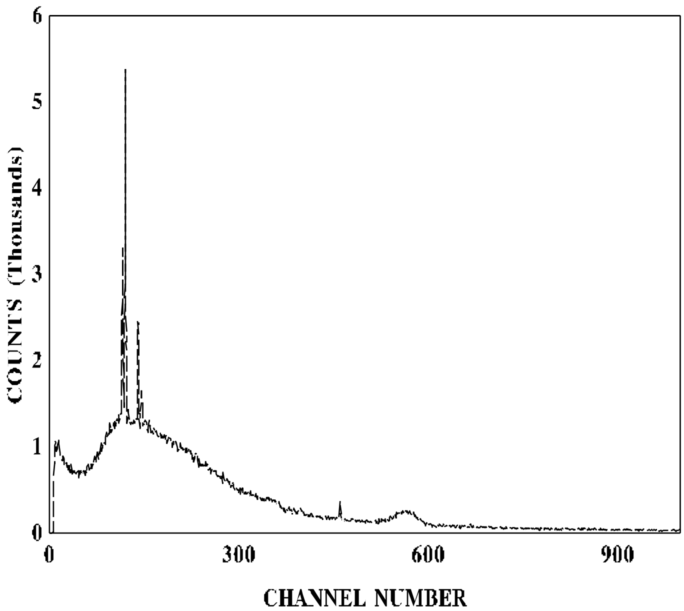

Fig. 2. A typical spectrum of 661.6 keV photons scattered by concrete block at an angle of 90^O and detected using a planar HPGe detector

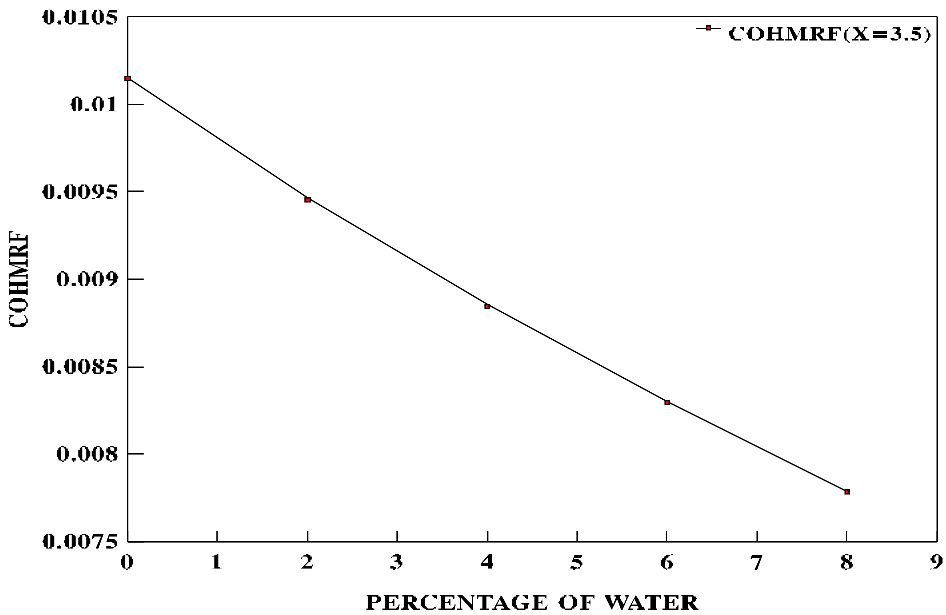

Fig.3. The calculated coherent scattering cross sections in barns/ atom based on Modified Relativistic Form Factors (COHMRF) as a function of water content of limestone concrete in % for 59.54 keV gamma rays at $\theta=93.60^o$

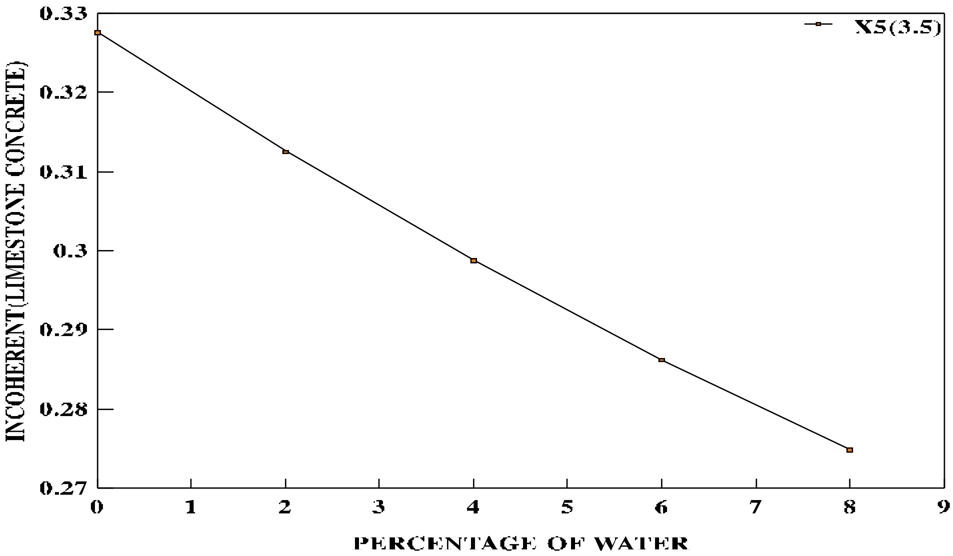

Fig.4. The calculated incoherent scattering cross sections in barns/ atom as a function of water content in % for 59.54 keV gamma rays at θ=93.60°

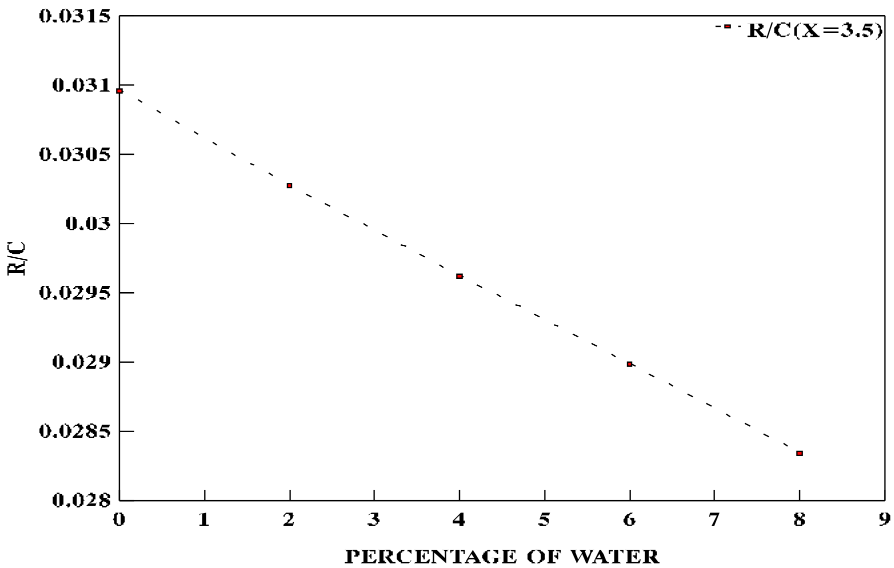

Fig.5. The calculated Ratio of coherent to incoherent scattering cross sections (R/C) in barns/ atom as a function of water content in % for 59.54 keV gamma rays at θ =93.60°

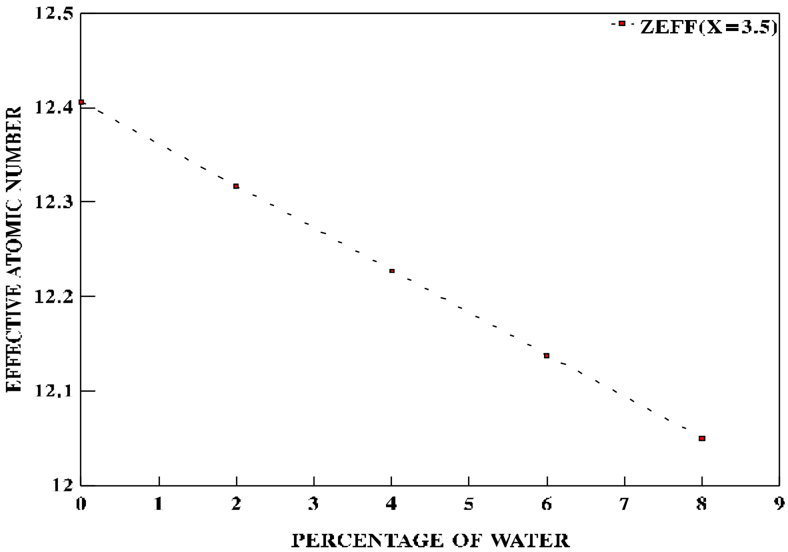

Fig.6. The effective atomic number (Z_{eff}) as a function of water content in % for 59.54 keV gamma rays at θ=93.60^{O}

The scattered counts were taken at several times during the heating and cooling, each time weighing the sample and evaluating the water content. The horizontal and vertical scanning of the concrete block was achieved by lateral movement of the concrete brick across the source and detector collimators in steps of 57 mm and the scattered spectra was recorded at different positions of the concrete block.

The calculated and experimental results show that the scattering method is highly sensitive to changes in moisture content in limestone concrete and < 1% change can be easily detected using this method

References

1. Mehta, P.K., Schiessl, P. and Raupach, M., "Performance and Durability of Concrete Systems", Proceedings of the 9th International Congress on the Chemistry of Cement, New Delhi, 1992, Vol. 1. pp. 597-659

2. Peter Shaw., "Assessment of the Deterioration of Concrete in NPP– Causes, Effects and Investigative Methods" , NDT NET 1998 February, Vol. 3 No.2

3. Baladev Raj and T. Jayakumar, "Semi destructive and Non Destructive testing of Concrete Structures- An Overview", Journal of Non Destructive Evaluation, 3 (2001) 29-44

4. Hussein, E.M.A., and Whynot, T.M. "A Compton Scattering Method for Inspecting Concrete Structures", Nucl. Instrum. Methods Phys. Res. A283 (1989) 100- 106