Chapter 2: LITERATURE REVIEW

General

This Chapter contains a comprehensive survey and review carried out on the literature of relevance to the study, and is split into four sections as follows:

2.1 Concrete as Radiation Shielding Material
2.2 Current Developments in Self-Compacting Concrete (SCC)
2.3 Neutron Activation and Gamma Spectroscopic Analysis
2.4 Studies on Neutron Transmission through Concrete

2.1 Concrete as Radiation Shielding Material

Radiation shields are usually fabricated using materials like lead, graphite, steel, polyethylene, concrete, etc., depending on the radiation type and energy. Of all the materials, concrete is considered to be the most suitable material that can be gainfully employed in fabricating shields that possess not only adequate attenuation property but also the required mechanical strength. Further, concrete can be cast into moulds of any required shape, and by varying the constituents, high densities can be achieved. Since concrete shields require almost no maintenance, they have an additional advantage of being economical too.

In this section, the outcome of a comprehensive survey of the literature available on the topic “Concrete as Radiation Shielding Material” is presented.

Abo-El-Enein, S.A., et al. (2014), in their work concluded that heavy weight high performance concrete (HPC) can be prepared with the use of ilmenite (FeTiO₃) and hematite coarse aggregates when properties such as high strength and good radiation shielding are required. Such concretes have higher densities than those made with
dolomite and air-cooled slag aggregates. The study showed that ilmenite coarse aggregate gives better mechanical properties than the other aggregates. The study also revealed that crushed air-cooled slag can be used to make high-strength concrete with better mechanical properties than concrete made with crushed hematite and ilmenite. Also, high density concrete made with fine aggregates of ilmenite and air-cooled slag were found to be suitable for shielding against gamma rays.

Akkurt, I. and Akyıldırım, H. (2012), carried out investigation on radiation shielding properties of pumice concrete. It was concluded that using pumice stone as aggregate in concrete does not give any better results in terms of gamma radiation shielding properties.

Akkurt, I., et al. (2010), measured the linear attenuation coefficient for concrete containing zeolite (Na$_2$Al$_2$Si$_3$O$_{10}$·2H$_2$O) as aggregates in different concentrations (0%, 10%, 30% and 50%). The linear attenuation coefficient, measured on four concrete blocks, decreased with increasing quantity of zeolite. It was concluded that zeolite was not suitable for preparing radiation shielding concrete.

Akkurt, I., et al. (2006), carried out investigation on barite concrete, and their findings show that concrete with barite (BaSO$_4$) as coarse aggregate exhibits higher linear attenuation coefficient (both calculated and measured results), and therefore the barite-loaded concretes would be advantageous in building construction against radiation.

Al-Humaidani, M.M., et al. (2013), carried out an experimental study on the gamma ray shielding properties of normal and heavy high performance concretes (HPCs). HPCs were produced with different low water-to-cementitious materials ratios (w/cm) and tested for 0.663 MeV γ-rays energy of $^{137}$Cs radioactive source. It was observed that the compressive strength of heavy HPCs plays a significant role in increasing the attenuation of gamma rays. The compressive strength and attenuation of gamma rays in heavy weight HPCs had
nearly a linear relation. The study revealed that for HPCs with the increase in the density, 
the attenuation coefficient increased linearly.

Amirabadi, E.A., et al. (2013), observed that nuclear radiation protection shields are 
fabricated using materials like lead, iron, graphite, water, polyethylene, concrete, etc., 
among which, concrete is one of the best and most widely used materials for manufacture 
of gamma and neutron radiation shields. This is because in addition to having the adequate 
strength and structural properties, concrete can be fabricated into any shape, having 
different densities, at relatively low cost.

Azeez A.B., et al. (2013), assessed the shielding properties of samples of concrete 
containing iron particulates, steel balls, and slags. The attenuation measurements were 
made using gamma spectrometer of NaI (Tl) detector. The maximum linear attenuation 
coefficient (LAC) was attained for concrete having iron filing wastes of 30 % by weight. 
Considerable enhancement in attenuation performance by 20% -25% was achieved for 
concrete samples with iron filings as compared to those having of steel balls. The samples 
having steel balls and steel slags exhibited the least LAC.

Basu P.C. (2001), worked with engineered high performance concrete (HPC) of grade 
M60 using silica fumes, using it for the construction of the inner containment dome of the 
Kaiga Atomic Power Project-2, in the state of Karnataka. It was observed that for silica 
fume quantity of about 7.5% by weight of cement, the mix attains maximum strength, and 
beyond 10% the strength of the mix reduces.

Basyigit, C., et al. (2011), used heavyweight aggregates of different mineral origin 
(Limonite, Siderite) to investigate the radiation shielding properties of concrete mixes 
prepared using them. It was found that the concrete prepared with heavyweight aggregates 
of different mineral origin can make good radiation shields.
Bouzarjomehri, F., et al. (2006), produced heavy concrete samples using barite mineral. The samples they made had densities in the range 3180-3550 kg/m$^3$, and proved to be good radiation barriers.

El-Khayatt, A.M. (2010), studied the shielding of $\gamma$-rays and fast neutrons by concretes containing different lime/silica ratios. The total mass attenuation coefficients ($\mu/\rho$) were computed and it was found that the lime/silica ratio of concrete has significant effects on $\mu/\rho$ values.

Fillmore, D.L. (2004), studied the detrimental effects of radiation on concrete and documented the following observations:

i. In some concretes it is found that neutron radiation greater than $10^9$ neutron/cm$^2$ may cause some reduction in compressive and tensile strength. The extent of reduction, however, depends on the properties of the concrete mix.

ii. Neutron radiation causes more pronounced decrease of tensile strength than compressive strength.

iii. It appears that resistance of concrete to neutron radiation depends on the energy spectrum.

iv. Factors like concrete mix proportion, type of cement and aggregate used in the mix determine the resistance of concrete to neutron radiation.

v. The temperature rise resulting from irradiation causes very little deterioration of concrete properties.

vi. Coefficients of thermal expansion and conductivity of irradiated concrete differ little from those that would result from temperature-exposed concrete.

vii. It is found that the modulus of elasticity of concrete exposed to neutron irradiation decreases with increasing neutron fluence.

viii. High levels of radiation exposure can increase the creep of concrete.
ix. Neutron radiation with fluence greater than $10^{19}$ neutron/cm$^2$ can cause marked increase in volume in some concretes.

x. In general, as the irradiation resistance of aggregate increases the irradiation resistance of concrete also increases.

Gencel O., et al. (2011), conducted experimental measurements to study the gamma and neutron attenuation characteristics of hematite-aggregate concrete. It was found that there was no effect of hematite inclusion in concrete with respect to the neutron absorption capability. However, the gamma-ray attenuation capability and the mechanical strength of concrete increased with increasing quantity of hematite.

Gencel, O., et al. (2010), state that the type of coarse aggregate used in concrete can alter the shielding properties of the material. They experimented on the effect of colemanite on physical and mechanical properties of concrete. Properties of concrete like slump, air content, compressive strength, split tensile strength, hardness, modulus of elasticity, freeze–thaw durability, unit weight and pulse velocity were investigated. It was reported that the properties of concrete were affected by the quantity of colemanite. Up to 30% colemanite was recommended to be used as a replacement of aggregate.

Gencel, O., et al. (2010), studied the effects of different concentrations of hematite on the properties of concrete. A water-to-cement ratio of 0.42 and 400 kg/m$^3$ cement content was selected. It was found that the addition of hematite increases the unit weight so that a smaller thickness of concrete is adequate for radiation shielding. It was also found that after 30 freeze-thaw cycles while plain concrete lost 21.3 % of its compressive strength the concrete containing 10 % hematite lost only 7.8 % of the strength. It was also established that concrete having hematite composites display lower drying shrinkage than plain concrete.
Ichikawa, T., and Koizumi, H. (2002), examined the effect of Ar ion irradiation to check whether radiation from nuclear reactors accelerates the degradation of concrete by inducing alkali-silica reaction in aggregates. The degradation of concrete by alkali-silica reaction is possible to be induced by nuclear radiation even when the aggregates are inert to alkali before the irradiation. The critical radiation doses for the degradation of aggregates containing crystalline quartz were estimated to be $5 \times 10^{19}$ n/cm$^2$ for fast neutrons with energy $>0.1$ MeV, and $5 \times 10^{11}$ Gy for beta and gamma rays. They were found to be $1 \times 10^{19}$ n/cm$^2$ and $0.5 \times 10^{11}$ Gy, respectively for aggregates containing amorphous quartz.

Kansouh W.A. (2013), in his study has found that as compared to basalt concrete, magnetite concrete has better attenuation properties for not only slow and fast neutrons, but also for gamma rays.

Kansouh W.A. (2012), studied the shielding properties of serpentine concrete, hematite-serpentine concrete, ilmenite-limonite concrete, and ordinary concrete. The results showed that ilmenite-limonite concrete is a better reactor biological shield than the other three concretes. Serpentine concrete investigated was found to be a better reactor fast neutrons shield than ordinary and hematite-serpentine concretes.

Kharita, M.H., et al. (2011), studied the effects of addition of three boric compounds (boric acid, boric frit, and borax) on the properties of two types of concretes, made using carbonate and hematite as coarse aggregates. The test results exhibited that boric acid ($H_3BO_3$) and its frit have detrimental effect on the setting of cement in ratios 0.5-1% of the total weight of the concrete mix. The results also revealed that the addition of borax ($Na_2B_4O_7$) has no significant effect on strength of concrete in the range of up to 1% by weight, but it has considerable effects on shielding efficiency in thick concrete shields (100 cm).
Kharita, M.H., et al. (2009), studied the effect of carbon powder addition on the properties of hematite radiation shielding concrete. It was found that the addition of 6% (by weight) carbon powder to the concrete increased its strength by about 15%. However, the shielding characteristics decreased for both gamma and neutrons with increasing carbon powder content.

Kharita, M.H., et al. (2008), studied two types of concretes commonly used in Syria and four other types of concretes, using aggregates from different regions. The shielding properties of these six types of mixes were examined for gamma rays and for neutrons. A reduction of about 10% in the half value layer (HVL) was obtained for the concrete from Damascus as compared to that from Aleppo (both in Syria), for both neutrons and gammas. One of the other four types of concretes (from Rajo site, having hematite) was found to further reduce the HVL thickness by about 10% for both neutrons and gamma rays.

Korkut, T., et al. (2012), studied the neutron shielding property of colemnite, ulexite and tincal ores that contain different percentages of boron as mineral. It was found that the increased concentrations of boron atoms can enhance the neutron shielding property.

Maslehuddin, M., et al. (2013), observed that concrete prepared using heavyweight aggregates or metallic components, is generally used for radiation shielding purposes. A study of the radiation shielding properties of concrete prepared with electric arc furnace slag aggregates (EAFSAs) and steel shots indicated that concrete mixed with 50% EAFSA and 50% steel shots satisfies the weight and radiation requirements. The use of 50% EAFSA results in a decrease in the cost of concrete.

Mortazavi, S.M.J., et al. (2007), in their work on high density concrete found that concrete samples prepared using galena mineral (PbS) showed better shielding properties, and compressive strength in comparison to ordinary concrete. The galena concrete
(density 4800 kg/m$^3$) samples made in this study showed good shielding against $^{60}$Co gamma rays, as well as strength compared to all the other samples made by high-density materials.

**Okuno K., et al. (2009),** investigated the neutron shielding properties of concrete prepared using colemanite and peridotite rock. It was reported that the attenuation length of concrete shield with a colemanite content of 10% by weight is shorter by a factor of 1.7 than that of normal concrete.

**Proshin, A.P., et al. (2005),** produced "Super heavy High-Strength concrete," having densities of 3800-4200 kg/m$^3$, using waste products of heavy silicate-lead glasses. It was found to be a good radiation shield.

**Rezaei-Ochbelagh, et al. (2012),** explored the gamma-ray shielding characteristics of concrete containing varying percentages of lead powder and silica fume. It is reported that there is a slight decrease in the gamma-ray attenuation with the addition of silica fume. The authors recommend 15% silica fume addition to cement concrete containing lead as a gamma shield.

**Rezaei-Ochbelagh, et al. (2011),** studied the effect of addition of lead on the mechanical properties and radiation shielding of concrete. It was found that with the increase in lead percentage in the mix, its strength and also gamma-ray shielding property was enhanced.

**Ristinah S., et al. (2011),** carried out a comparative study on normal concrete (density 2311 kg/m$^3$) and heavyweight concrete having steel slag as fine aggregate (density 3272 kg/m$^3$). The results showed that the attenuation coefficient for heavyweight concrete was 1.5 times higher than that of normal concrete.

**Sharma A., et al. (2009),** explored the mechanical and shielding properties of fiber reinforced concrete containing steel fibers, lead fibers and a combination of the two (hybrid fibers). Compressive strength, split tensile strength and flexural strength were
among the mechanical properties investigated, and radiation shielding to gamma-rays was tested. It was found that the concrete mix having hybrid fibers showed a significant increase in both mechanical and radiation shielding properties.

**Sommers, John F. (1969)**, carried out testing of structural concrete samples for damage due to intense and prolonged gamma radiation exposures. Testing of the samples by breaking them under compression following gamma exposures up to $2 \times 10^{11}$ R indicates a progressive loss of strength with increasing gamma irradiation. Very extensive surface deterioration of the specimens occurred when they were subjected to gamma radiation and when the water in which they were submerged during irradiation was free to circulate away from the concrete samples. The surface deterioration was also progressive with increasing gamma exposures. The study arrived at a general conclusion that 50% loss of strength can occur with gamma exposures of up to $2 \times 10^{11}$ R.

**Zhefu Li, et al. (2011)**, investigated three kinds of shielding materials using boron-containing ores and epoxy. The test results revealed that boron-rich slag as neutron absorber had relatively good slow neutron shielding ability. Boron-containing iron ore concentrate/epoxy composite exhibited relatively good gamma ray shielding ability, and its linear attenuation coefficient ($\mu$) was found to be $0.0772$ cm$^{-1}$. The elements boron and iron that exist as compounds in the ore are the main factors that affect the slow neutron shielding performance. Boron helps in slow neutron shielding, while iron shields the gamma radiation.
2.2 Current Developments in Self-Compacting Concrete (SCC)

General

Self-Compacting Concrete (SCC), also called Self-Consolidating Concrete, as the name itself suggests, is a type of concrete that is capable of flowing and compacting all by itself. Unlike the normal vibrated concrete (NVC), it does not need any external vibration to be consolidated into the forms. The development of SCC is regarded as an important breakthrough in concrete technology due to its several advantages like: high flowability and segregation resistance, low porosity, high strength and durability, etc.; wider applications in structural components having complicated shape and highly congested reinforcements; economical in terms of increased work speed and reduced costs for energy, equipment and labour; enhancement towards modernization of construction process; environmental friendly due to high consumption of industrial wastes and improved working conditions with less noise and reduced health risks.

In the paragraphs that follow a comprehensive review of the literature that is available on SCC, like the different materials used in its production, its performance in fresh and hardened conditions, and other features is documented.

ACI 237R-07 (2007), The American Concrete Institute in its report, “Self-Consolidating Concrete”, defines SCC as “a highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation”.

Amit Mittal, et al. (2004), have successfully produced and used SCC in the concreting of walls and other structures at the Tarapur Atomic Power Project 3 and 4 (TAPP 3 & 4) of
NPCIL in the state of Maharashtra. A volume of about 230 m$^3$ of M40 grade SCC has been produced with a cement content of about 300 kg/m$^3$ and successfully used at this site.

Anastasiou E.K., et al. (2014), prepared SCC mixtures with the use of ladle furnace slag as filler, and with the addition of steel fibers. Different contents of ladle furnace slag filler, ranging from 60 to 120 kg/m$^3$, and steel fibers, ranging from 0% to 0.7%, were used. The test results revealed that ladle furnace slag can be used as filler for SCC, as satisfactory consistency and workability were achieved, while compressive strength and durability also were also found to have been enhanced. It was also discovered that ladle furnace slag can be combined with steel fibers, which considerably increases fracture toughness, in order to produce a high performance SCC using a low-cost industrial by-product like ladle furnace slag.

Bapat, S.G., et al. (2004), have made the following observations, “Structures in nuclear installations are designed with higher safety factors, particularly in the case of seismic loadings resulting in higher percentage of steel which, in turn, leads to congestion at the member junctions. SCC is best suited under such circumstances, as it can easily pass and fill into the formwork, without any voids, all by virtue of its own weight, and without the need for any vibration”. At the Kaiga 3 & 4 sites of NPCIL in Karnataka, M30 grade SCC (cement content 225 kg/m$^3$) has been developed and used in a full scale mock-up of concreting the columns of a pump house, by the authors. From the experience gained it is envisaged that SCC may be used in the construction of tunnels, trenches, and also the turbine buildings at the site.

Bingöl, A. F., and Tohumcu, İ. (2013), investigated the effect of air curing, water curing and steam curing on the compressive strength of SCC produced using silica fume replacing cement by 5%, 10% and 15%, and 25%, 40% and 55% of fly ash. It was
observed that the above mineral admixtures have positive effects on the fresh properties. The highest compressive strength was found in the specimens with 15% silica fume for 28 days water curing. Air curing caused compressive strength losses in all groups. Relative strengths of SCC with mineral admixtures were found to be higher than the mixes without admixtures when steam cured.

Bogas J.A., et al. (2012), worked to study the characteristics of SCCs prepared with lightweight aggregates (SCLC) available in the Iberian Peninsula. SCLC of satisfactory stability and self-compactability were produced for compressive strengths between 37.4 and 60.8 MPa were achieved by the mixes.

Boukendakdji O., et al. (2012), carried out investigations to study the effect of granulated blast furnace slag and two types of superplasticizers on the properties of SCC. Cement was replaced with 10%, 15%, 20%, and 25% of blast furnace slag. Two types of superplasticizers: polycarboxylate based superplasticizer and naphthalene sulphonate based superplasticizer were used. The results revealed that polycarboxylate based superplasticizer concrete mixes give more workability and higher compressive strength than those with naphthalene sulphonate based superplasticizer, at all ages of curing. Addition of blast furnace slag as a partial replacement of cement was found to be very advantageous to fresh properties of SCC. An improvement of workability was observed up to 20% of slag content with an optimum content of 15%. Workability retention of about 45 min with 15% and 20% of slag content was obtained using a polycarboxylate based superplasticizer; compressive strength decreased with the increase in slag content, as also for the vibrated concrete (control mix), although at later ages the differences were negligible.
Bouzoubaa, N., and Lachemi, M. (2001), carried out an experimental program aimed at producing and evaluating SCC made with high volumes of fly ash. The content of the cementitious materials was maintained constant (400 kg/m$^3$), while the water/cementitious material ratios ranged from 0.35 to 0.45. The SCC mixes had a cement replacement of 40%, 50%, and 60% by Class F fly ash. The mixes exhibited 28-day compressive strengths ranging from 26 to 48 MPa. It was concluded that an economical SCC could be successfully produced by incorporating high volumes of Class F fly ash.

Brite Euram (2000), a group, constituted with partners drawn from a few European countries viz., Sweden, France, Scotland, Spain and Belgium published a report entitled, “Rational production and improved working environment through using self-compacting concrete”. The aim of the group was to develop a system for quality control for the full production process, e.g. mix design, production at concrete plants or in truck-mixers, transport, formwork, casting, curing and treatment after casting of SCC.

Cuenca J., et al. (2013), studied the characteristics of biomass fly ash to obtain its optimal dosage for use in SCC. The properties of the reference concrete made with conventional filler and the biomass fly ash concrete were compared. The tests showed that the SCC mix having biomass fly ash developed a compressive strength that was equal to or greater than that of the reference concrete. It was concluded that biomass fly ash can be used to manufacture good quality SCC.

Deeb R., et al. (2012), investigated the properties of self-compacting high-and ultra high-performance concrete mixes with and without steel fibres. They found that for the mixes without steel fibres the requirements of the flow and cohesiveness criteria, were adequately met. In the mixes with fibres, it was noticed that the fibres were uniformly distributed in the slump spread right up to the edge. The investigations also showed that
although the mixes with fibres meet the flowability criterion and were resistant to segregation, they may not meet the passing ability criterion. It was concluded that these mixes need to be more flowable than required by the slump flow test, in order to satisfy the passing ability test.

Degussa MBT (2004), opined that while SCC is being extensively used in the construction of structures in the developed countries, in India the use of SCC is still in its initial stages. A few examples where SCC has been introduced in our country are the Delhi Metro; Hotel Taj, Bangalore; Kaiga 3 & 4, Nuclear Power Corporation of India Ltd. (NPCIL), Kaiga, Karnataka; and Tarapur Atomic Power Project 3 and 4 (TAPP 3 & 4), Maharashtra.

EFNARC (2002), The European Federation dedicated to specialist construction chemicals and concrete systems, in its publication titled, “Specifications and Guidelines for Self-Compacting Concrete”, defines SCC as a, ‘Concrete that is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity’.

Elyamany H. E., et al. (2014), carried out a study to evaluate the effect of various filler types on the properties of SCC and Flowable concrete. Two groups of fillers were selected, with the first group having pozzolanic fillers (silica fume and metakaolin), and the second group having non-pozzolanic fillers (limestone powder, granite dust and marble dust). Cement contents of 400 kg/m$^3$ and 500 kg/m$^3$ were considered, while the filler material added was 7.5%, 10% and 15% by weight of cement. The test results showed that addition of non-pozzolanic fillers improve segregation and bleeding resistance. It was found that the filler type and content have considerable effects on unit
weight, water absorption and voids ratio. Also, non-pozzolanic fillers were found to have negligible negative effect on concrete compressive strength.

**Gandage, A. S., et al. (2013)**, carried out an experimental analysis to assess the properties of M40 grade of SCC mixes produced using manufactured sand. While Class C flyash was used as a partial cement replacement material, perlite was used as fine sand replacement material. From the studies, it was observed that 5% perlite dosage gives a maximum 28-day compressive strength of 51.852 MPa. Hence, it was concluded that 5% perlite dosage would be the suitable perlite dosage from the strength perspective. It was also found that the addition of fly ash and perlite brings down the density of the mix, and the thermal conductivity values of the concrete mix decreased at all temperature ranges, with decrease in density.

**Ganesan N., et al. (2013)**, conducted experiments on the flexural fatigue behavior of Self Compacting Rubberized Concrete (SCRC) with and without steel fibers. In this study varied proportions of fine aggregate were replaced by shredded rubber. The results showed significant improvement of 15% and 25% in the fatigue performance of SCRC and Steel Fiber Reinforced SCRC (SFRSCRC) respectively, when compared to normal SCC.

**Gesoglu M., et al. (2014)**, studied the transport properties of SCCs in which natural aggregates were partially replaced with lightweight fine (LWFA) and coarse aggregate (LWCA). The transport properties were investigated via water sorptivity, water permeability, rapid chloride ion permeability, and gas permeability. Mechanical properties of SCCs were also determined. It was found that with increasing volume of LWFA and/or LWCA, the hardened properties reduced for all ages. However, it was found that in spite of lower compressive strength, SCCs with LWFA had better performance in the case of durability related properties compared to the SCCs with LWCA.
Gesoglu M., et al. (2012), studied the feasibility of using marble powder and limestone powder as fillers in the production of SCCs with and without fly ash. Test results revealed that high replacement level of the filler adversely affected the fresh properties of the SCCs. However, the addition of fly ash solved such problems. Further, the fresh and hardened properties of the mixes were found to improve with the use of marble powder and limestone powder as fillers.

Grdici Z. J., et al. (2010), researched the feasibility of using recycled coarse aggregate in SCC. Three types of concrete mixtures were prepared, where the percentage of substitution of coarse aggregate by the recycled aggregate was 0%, 50% and 100%. The test results showed that the properties of these concretes have only a slight difference, and that the recycled coarse aggregate can successfully be used for preparing SCC.

Guneyisi E., et al. (2014), studied the adverse effect of old cement-mortar composite on SCC containing recycled concrete aggregate (RCA). Four types of aggregate surface treatment methods were used, viz., the two-stage mixing approach, pre-soaking in HCl solution, water glass dispersion and cement-silica fume slurry. Test results exhibited that self-compactibility characteristics of the concrete is highly affected by surface treatment of RCAs. It was also found that the treatment methods of two-stage mixing approach and water glass dispersion provide denser and connected microstructures leading to greater strength improvements compared to the control SCC having normal aggregate.

Helincks P., et al. (2013), investigated the bond and shear performance of powder type SCC. About seventy two pull-out specimens were cast and tested with different concrete mixtures and rebar diameters. It was found that SCC showed normalized characteristic bond strength values as high as or higher than normal vibrated concrete (NVC). In addition, as the bar diameter increased, larger bond strengths were measured, with the
highest values for bars with diameter 12 or 16 mm. When larger diameters up to 20 mm were used, a decrease in bond performance was noticed. To study the shear behaviour, four-point bending tests were performed. A slightly decreased shear capacity was observed for SCC specimens.

Herbudiman B., et al. (2013), worked on the use of traditional roof tile powder in self-compacting concrete. Indonesian standard (SNI 03-2834-2000) and the Okamura proportioning method were used to calculate the constituents of SCC. It was found that the optimum dosage of the roof tile powder was 20% at w/p ratio of 0.35, and dosage of super-plasticizer of 1%. The maximum compressive strength of 44.11 MPa and split-tensile strength of 3.25 MPa were achieved. It was also found that washing aggregate before mixing could increase the workability, and also increase compressive and split-tensile strengths by 17.06 % and 42.37 % respectively.

IS 456-2000 (Reaffirmed 2005), Indian Standard Plain and Reinforced Concrete-Code of practice (Fourth Revision), in its Annex J defines SCC as, ‘A concrete that fills uniformly and completely every corner of formwork by its own weight without application of any vibration, without segregation, whilst maintaining homogeneity’.

Kannan, V., and Ganesan, K. (2014), conducted experiments on the durability properties of SCC containing rice husk ash (RHA), metakaolin (MK) and a combination of MK and RHA (1:1). The tests revealed that SCC blended with RHA and a combination of RHA and MK showed a considerable improvement in durability than unblended SCC. Further, the performance of SCC blended with MK was unsatisfactory in an acid environment. In addition, it was found that resistance to acid attack was directly related to the silica ratio.

Khaloo A., et al. (2014), carried out experiments to study the effect of steel fibres on the rheological properties, compressive strength, splitting tensile strength, flexural strength,
and flexural toughness of SCC specimens, using four different steel fibre volume fractions (0.5%, 1%, 1.5%, and 2%). Two mix designs with strengths of 40 MPa (medium strength) and 60 MPa (high strength) were considered. The test results revealed that the workability of medium and high strength SCC mixes reduces with increasing steel fibre volume fraction. However, it was found that the splitting tensile strength, flexural strength, and flexural toughness increase with the increasing percentage of fibres. It was also found that compressive strength decreased with the increase in the percentage of fibres.

Kou S. C., et al. (2009), studied the fresh and hardened properties of SCC prepared using recycled concrete aggregate—both coarse and fine aggregates. Different tests covering fresh, hardened and durability properties of these SCC mixes were carried out. The test results revealed that the properties of the SCCs made from river sand and crushed fine recycled aggregates showed only slight differences.

Kou S.C., et al. (2009), investigated the effects of recycled glass (RG) cullet on fresh and hardened properties of SCC. RG was used to replace river sand (in proportions of 10%, 20% and 30% by weight), and 10 mm granite (5%, 10% and 15%) was used in making the SCC mixes. Fly ash was used in the concrete mixes to reduce the possible alkali-silica reaction. The test results revealed that the slump flow, blocking ratio, air content of the RG-SCC mixes increased with increasing RG content. The compressive strength, splitting tensile strength and static modulus of elasticity of the RG-SCC mixes were found to decrease with an increase in RG aggregate content. It was concluded that SCC can be produced with recycled glass (RG) cullet as aggregate.

Łaźniewska-Piekarczyk, B. (2013), studied the influence of superplasticizers (SP) type, like: air-entraining admixture (AEA), anti-foaming admixture (AFA) and viscosity modifying admixture (VMA) on porosity, workability, cement hydration and
microstructure of very high performance self-compacting concrete (VHPSCC). The results showed that the type of admixture and its interaction significantly influence the investigated properties of non-air entrained and air-entrained VHPSCC.

**Liu M. (2010)**, tested SCC mixes with levels of up to 80% cement replacement by fly ash. The results showed that SCC can be achieved with up to 80% cement replaced by fly ash. It was found that to keep the filling ability constant, replacement of cement with fly ash would require an increase in water/powder ratio, and a reduction in superplasticiser dosage. It was also seen that fly ash had negative effects on passing ability, consistency retention and also strength characteristics.

**Madandoust, R., and Mousavi, S. Y. (2012)**, worked on the fresh and hardened properties of SCC containing metakaolin (MK). A total of fifteen mixes containing different MK contents (0-20% by weight of cement) with three water/binder (W/B) ratios of 0.32, 0.38 and 0.45 were prepared. The fresh concrete test results revealed that by substituting optimum levels of MK in SCC, satisfactory workability and rheological properties can be achieved, without any viscosity modifying agent. Addition of MK significantly increased the compressive strength of SCC up to 27% within the first 14 days. The tensile strength and electrical resistivity of the SCC containing MK were higher than those of the control SCC by a maximum of 11.1% and 26%, respectively. It was also found that a low absorption (below 3% at 30 min) can be achieved for MK mixes. The tests concluded that 10% MK can be considered as a suitable replacement of cement.

**Mathew, G., and Paul, M. M. (2012)**, carried out experiments on materials like laterite aggregate and a mix design procedure for Laterized Self Compacting Concrete (LSCC), and its performance under elevated temperature was studied. Test specimens were heated to 600 deg. Centigrade, and the properties of LSCC at fresh and hardened stages were
observed. It was concluded that the type of aggregate and fly ash content prevented the explosive spalling in LSCC even up to 800 deg. Centigrade, and the development of surface crack was also delayed up to 600 deg. Centigrade. It was concluded that LSCC could be used as a substitute fire protection material for conventional concrete.

**Mohammed M. K., et al. (2013)**, studied various aspects like production, microstructure and hydration characteristics of SCC with two types of fillers namely, fly ash (FA) and limestone powder (LP). The two types of SCC produced had a compressive strength of 50-60 MPa and used the same water to binder ratio. The replacement rate of both limestone powder (LP) and fly ash (FA) was about 33% of the total binder (450 kg/m$^3$). In spite of the equal water to binder ratio and approximately the same compressive strength grade at 28-days, limestone powder self-compacting concrete (LP-SCC) had a different microstructure and hydration products from the fly ash self-compacting concrete (FA-SCC). It was concluded that fly ash would be more suitable for the production of SCC.

**Nanthagopalan, P., and Santhanam, M. (2011)**, explored the possibility of using manufactured sand (Msand) in SCC. Experiments were carried out to understand the influence of paste volume and water to powder ratio on the properties of SCC having Msand. The test results revealed that relatively higher paste volume was essential to achieve the required flow for SCC using Msand, as compared to river sand. Low and medium strength (25-60 MPa) SCCs were achieved by using Msand. It was concluded that it was possible to successfully utilise manufactured sand in producing SCC.

**Nikbin I. M., et al. (2014)**, carried out a comprehensive investigation into the effect of water to cement ratio and powder content on mechanical properties of SCC, and the following are a few of the facts revealed by their study: 1. With increase of w/c ratio from 0.35 to 0.7 the value of compressive strength is decreased by 66%. 2. The relation
proposed by Abrams can predict compressive strength of SCC, based on w/c ratio, with acceptable accuracy. 3. With increase of limestone powder content from 25% to 100% the compressive strength increased 20% and 38% for two w/c ratios of 0.6 and 0.47 respectively. 4. In lower w/c ratios, the effect of limestone powder content on increase of compressive strength was more noticeable. 5. With increase of w/c from 0.35 to 0.7, tensile strength of SCC is decreased by 51%. 6. With increase of limestone powder content from 25% to 100%, tensile strength increased by 17% and 12% for w/c ratios of 0.6 and 0.47 respectively. 7. With increase of w/c ratio from 0.35 to 0.7, modulus of elasticity of SCC is decreased by 44%. 8. With increase of limestone powder content from 25% to 100%, modulus of elasticity increased roughly by 9% for both w/c ratios of 0.6 and 0.47. 9. The effect of w/c ratio on the variation of compressive strength and tensile strength was more noticeable than on modulus of elasticity.

Nuruddin M. F., et al. (2014), carried out research on ductile self-compacting concrete (DSCC). Up to 20% of cement in DSCC was replaced by Microwave Incinerated Rice Husk Ash (MIRHA), silica fume (SF) and fly ash (FA) in different proportions. The fresh and hardened property test results showed that DSCC with replacement of 10% FA and 10% MIRHA achieved the highest compressive strength without compromising on the fresh properties of SCC.

Okamura, H., and Ouchi, M. (2003), observed that the placing of normal vibrated concrete mixes requires adequate compaction which would need the services of skilled manual labour. To overcome this problem, SCC was first proposed in the year 1986 by the authors at the Kochi University of Technology in Japan. Today SCC is seen as a solution for the achievement of durable concrete structures, independent of the quality of the construction work. The prototype of SCC which was first completed in 1988 performed satisfactorily with regards to both fresh and hardened properties. This concrete was named
“High Performance Concrete.” Over the years this concrete has come to be referred to as “Self-Compacting High Performance Concrete”, “Self-Consolidating Concrete”, “Self-Compacting Concrete”, or simply “SCC”.

**Panda, K. C., and Bal, P. K. (2013)**, researched on the influence of recycled coarse aggregate (RCA) on the properties of self-compacting concrete (SCC), and compared the results with normal vibrated concrete (NVC) containing 100% natural coarse aggregate (NCA). NCA was partially replaced with RCA by an amount of 10%, 20%, 30% and 40%. The effects of RCA on the properties of SCC in fresh and hardened states were studied for M25 grade concrete. The test results showed satisfactory fresh properties, and the study concluded that SCC achieved the required compressive strength up to 30% replacement of RCA.

**Parra C., et al. (2011)**, carried out experimental work in which the splitting tensile strength and the modulus of elasticity of SCC were studied, in addition to its porous structure. Eight different concretes were cast, four SCC and four NVC, with different water/cement ratios and different types of cement. The test results showed that in SCCs made with limestone filler the splitting tensile strength was on average 15% less than that of normally-vibrated concretes.

**Pereira-de-Oliveira L.A., et al. (2014)**, studied durability related properties of SCC with the use of coarse recycled aggregates with an objective to verify the influence of recycled aggregates on the permeability properties of SCC. To achieve this end, four different types of concrete mixes were prepared, one of them used as reference with natural coarse aggregates and the others prepared with 20%, 40% and 100% of recycled coarse aggregates. The properties related to the durability of SCC, namely air and water permeability and capillary absorption were determined on concrete specimens. It was
concluded that it is feasible to replace natural coarse aggregates by recycled coarse aggregates since the findings did not show any detrimental effect of their use to the permeability properties of SCC.

**Ponikiewski, T., and Gołaszewski, J. (2014),** carried out investigations on the influence of varying compositions of high calcium fly ash (HCFA) on properties of SCC and high-performance SCC (HPSCC). The research revealed the negative effects of raw calcium fly ash (without grinding) on the rheological properties and workability of the mixes. With the activation of fly ash (by grinding), the properties improved and, as a result, showed a positive effect of the additive to the SCC mixes.

**Pop I., et al. (2013),** carried out investigations on the bond behavior between steel reinforcement and powder-type SCC. A total of 135 pull-out cubes were cast by using four SCC and two vibrated concretes (VC). The parameters analysed were the compressive strength, the reinforcement bar diameter, and the embedded length of bars. The results showed that the ultimate bond strength can be greater in SCC as compared to vibrated concrete. At the same load level it was found that the bars in SCC tend to present a smaller slip than in VC.

**Rahman M.E., et al. (2014),** carried out an experimental study on the preparation of SCC using rice husk ash (RHA) as a partial replacement to cement and blended fine aggregate. RHA was added in dosages of 0%, 20%, 30% and 40% by mass of the total cementitious material in the mix. The test results revealed that when normal strength SCC is required the RHA obtained from uncontrolled burning can be successfully used to replace cement partially.

**Rahman M.K., et al. (2014),** conducted investigations on SCC mixes prepared using mineral admixtures like silica fume, limestone powder and fly ash for a target slump flow
of the order of 700 mm, and minimum static segregation. Results indicated that the addition of silica fume (2.5% replacement), limestone powder (15% replacement) and fly ash (10% replacement) increased the flocculation rate significantly.


**Viacava, I.R., et al. (2012)**, carried out a study in which cement kiln dust (CKD) was used as filler in SCC. Properties at fresh and hardened states were studied, and it was concluded that the use of high percentages of CKD and different combinations of water/fines ratio allows economizing on the use of the admixture and the amount of cement required, resulting in SCC of medium strength and lower production costs.

**Sfikas, I. P., and Trezos, K. G. (2013)**, carried out studies to assess the effect of water-to-binder ratio and different silica fume levels of cement replacement on SCC bond using pull out tests. It was found that SCC developed an improved bond capacity compared to normal vibrated concrete of the same strength and composition.

**Siddique R. (2013)**, studied the properties of SCC made with coal bottom ash. The mixes were prepared with three percentages (10, 20 and 30) of coal bottom ash as partial replacement of fine aggregates. Test results revealed that SCC mixes developed 28-day compressive strength between 25.8 and 35.2 MPa. Abrasion resistance, water absorption and sorptivity of SCC mixes increased with the increase in bottom ash content at a particular age, and the same were found to decrease with increasing age.
Sideris, K. K., and Anagnostopoulos, N. S. (2013), carried out the evaluation of the durability properties of medium strength SCC mixes, and their comparison with the reference mixes of normal vibrated concretes. The durability properties assessed were the water absorption, the carbonation resistance and the chloride induced corrosion resistance. The coefficients calculated were used to estimate the service life of reinforced concrete structures. The results revealed that SCC mixes have a significant impact on the extension of the service life of concrete structures, especially when carbonation is considered as the main aggressive factor.

Soleymani Ashtiani M., et al. (2013), carried out experiments using the locally available materials in Christchurch, New Zealand, to develop a commercially viable high-strength self-compacting concrete (HSSCC) mixes of 100 MPa compressive strength. Reference mixes of conventionally vibrated high-strength concrete (CVHSC) were also prepared. It was found that for the same water/binder (w/b) ratio, HSSCC developed considerably higher compressive strength as compared to CVHSC. Therefore, a lower w/b ratio was chosen to reproduce CVHSC mix with strength comparable to the HSSCC mix. Fresh and hardened properties of all concrete types were evaluated at 3, 7, 28, and 90 days, and found to be satisfactory.

Sua-iam, G., and Makul, N. (2013), tested the viability of using limestone powder (LS) in SCC in which fine aggregate was partially replaced by rice husk ash (RHA). The fine aggregate was replaced with up to 100% RHA and LS by volume. The fresh properties of the RHA-containing mixtures were found to be improved in mixes having less than 60% of RHA. SCCs containing LS showed better hardened properties, and the fresh and hardened properties of SCCs made using RHA were considerably higher when combined with LS. It was concluded that LS powder has the potential to improve the properties of SCC mixes in which RHA is used to replace fine aggregate partially.
The European Project Group (2005), a consortium of companies dedicated to the promotion of advanced materials and systems for the supply and use of concrete, published a new document covering various aspects of SCC. This document titled, “The European Guidelines for Self Compacting Concrete – Specification, Production and Use”, serves to particularly address those issues related to the absence of European specifications, standards and agreed test methods.

Uysal M. (2012), performed an experimental investigation to assess the effectiveness of various types of coarse aggregates on fresh and hardened properties of SCC. Five different coarse aggregate types (basalt, marble, dolomite, limestone and sandstone) were used to produce SCC containing fly ash. The water to binder ratio was maintained at 0.33 for all mixtures. The results showed that it is possible to successfully utilize various types of coarse aggregates in producing SCC. The highest compressive strength values were seen in the SCC mix prepared with basalt aggregate, while the lowest compressive strength values were observed in the mix prepared with limestone aggregate at ages of 28, 56, and 90 days. The study also revealed that the ultrasonic pulse velocity increased with the increase of compressive strength for all SCC mixes.

Uysal, M., and Yilmaz, K. (2011), studied the effects of limestone powder (LP), basalt powder (BP) and marble powder (MP) as partial replacement of Portland cement in SCC. The water to binder ratio was maintained at 0.33 for all the mixes. The experiments showed that it was possible to successfully utilize LP, BP and MP as mineral admixtures in producing SCC. It was therefore concluded that using waste mineral admixtures like LP, BP and MP would result in economy of SCC production.

Yung W. H., et al. (2013), used waste tire rubber powder to partially replace fine aggregate self-compacting rubber concrete (SCRC). The tests revealed that when 5%
waste tire rubber powder that had passed through a No. 50 sieve was added, the 91 day compressive strength was higher than the control mix by 10%. Also, the shrinkage was higher with an increase in the amount of waste rubber, and reached its maximum at 20%. The ultrasonic pulse velocity decreased when more powder was added. The addition of 5% waste tire rubber powder brought about a significant increase in anti-sulphate corrosion property. The study concluded that using waste tire rubber powder can enhance the durability of self-compacting rubber concrete.

Zhu, W., and Gibbs, J. C. (2005), studied the use of limestone and chalk powders as fillers in SCC, and their effects on superplasticizer demand and the strength properties of the mixes. It was found that all the different limestone and chalk powders selected could be used successfully for producing SCC mixes. It was found that higher superplasticizer dosages were required for SCC using chalk powder than for that using limestone powder. The fineness of the powders had no effect on the superplasticizer demand. It was also found that the compressive strength of the SCC mixes (at early ages) containing limestone and chalk powders was significantly greater than that of the conventional vibrated reference concrete at the same water/cement ratio.

Zhu, W., and Bartos, P. J. (2003), carried out an experimental study on permeation properties of a range of different SCC mixes and compared them with selected normal vibrated reference (REF) concretes of the same grade. The SCC mixes with characteristic cube strength of 40 and 60 MPa were designed containing either additional powder as filler or containing no filler but using a viscosity agent. The tests showed that the SCC mixes had significantly lower oxygen permeability and sorptivity than the REF concretes of the same grades. The SCC mixes having no additional powder but using a viscosity agent were found to have considerably higher diffusivity than the reference mixes and the other SCC mixes.
2.3 Neutron Activation and Gamma Spectroscopic Analysis

General

Neutron activation analysis (NAA) is the standard method of determining the trace elemental composition (concentrations < 0.01%) of a sample. This technique involves the using of neutrons that are produced in a nuclear reactor for irradiating a sample, and then the characteristic gamma-rays produced by the irradiated sample are analysed using the gamma spectroscopic method to determine the elements present. It is possible to quantitatively detect about sixty different elements using this technique, with the lower limit of detection being of the order of parts per million or even parts per billion. While liquid samples can be analysed by the NAA, solids are the matrix of choice for this technique.

In the present work NAA was carried out on coarse aggregates (CAs) that were collected from twelve different geological formations in the state of Karnataka, as listed in Table 3.1. The procedure was carried out at the Dhruva research reactor at the Bhabha Atomic Research Centre (BARC), Mumbai.

In the ensuing paragraphs a brief description of the literature available on elemental analysis using the above technique is discussed.

Acharya, R. N., et al. (2000), carried out multi-element analysis on natural emeralds, and other rocks procured from Rajasthan, India. The concentrations of 21 elements were found by the NAA and high-resolution gamma ray spectrometry. The study found the segregation of some elements from associated (trapped and host) rocks to the mineral beryl forming the gemstones. A reference rock standard of the US Geological Survey (USGS BCR-1) was also analysed as a control of the method.
Alden, J. R., et al. (2006), carried out work to determine the elemental compositions of 157 samples of archaeological ceramics and geological clays from the sites of Catarpe and Turi in Chile using the NAA. They identified two major and three minor composition groups in the ceramics. The geographical distribution of the ceramics analysed indicated that bowls were exchanged between Catarpe and Turi in a pattern more similar to tribute/extraction than to market exchange, with Catarpe being the dominant site.

Al-Sulaiti, et al. (2009), in their study have attempted to analyse for the radioactivity concentration in soil in the country of Qatar. Their work was to establish concentrations of the $^{235}$U, $^{238}$U and $^{232}$Th, and also the long-lived naturally occurring radionuclide $^{40}$K. The work was successfully completed using a high-resolution gamma-ray spectrometry using a high purity germanium (HP Ge) detector placed in a low-background environment.

Ambulkar, M. N., et al. (1994), analysed the ambient air dust particulate samples collected from six different locations in the areas surrounding a cement factory in central India for 30 elements by the NAA. Samples were irradiated at the APSARA/CIRUS reactor at BARC, Mumbai, followed by counting on an HPGe detector. Several standards such as coal fly ash (SRM 1633a), urban particulate matter (SRM 1648) (from NIST, USA); vehicle exhaust and pond sediment (from NIES, Japan) and a USGS standard rock BCR-1 were also co-irradiated for quality assurance. Wide differences were observed in elemental concentrations of As, Br, Co, Cr, Fe, Se and Zn in dust particulates collected from different locations depending on its distance from the factory.

Contis, E. T. (1995), used the technique of NAA to analyse several drinking water samples for trace elements, including those of nutritional and toxic value, like selenium, vanadium, arsenic, mercury, and cadmium. Analysis of the samples showed typical elements found in natural water, like sodium, bromine, and potassium. Also, some of the
samples indicated ultra traces of uranium. Test results revealed that there were no significant traces of the elements of interest in the water samples.

**Dinescu, L. C., and Duliu, O. G. (2001),** used the NAA to determine the distribution of six possible pollutant elements (Zn, Cr, Co, As, Sb and Br), two trace elements of natural origin (Sc and Hf) and radioactive $^{137}\text{Cs}$ in three lakes, Furtuna, Lung and Mesteru, located in an active sedimentary zone of the Danube Delta. The study revealed that Zn, As, Sb and Br were the possible pollutants.

**Dmitriev, S. N., et al. (1991),** carried out experiments for the isolation of gold from geological samples by the NAA and gamma spectrometry. The study of the degree of chemical sublimation of gold was carried out with samples that had been irradiated with neutrons. The accuracy of the test was checked using reference materials and the results agreed to within 10%.

**El-Arabi, et al. (2001),** used the gamma spectroscopic method for the determination of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ contents in powdered granite samples from areas in Egypt. HPGe detector setup and 8192 channels MCA were applied for the measurements. The data showed that the concentration values of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ in these samples ranged between 102-640, 56-161 and 774-1234 Bq/kg respectively.

**El-Shershaby, A. (2002),** analysed fifty samples of rocks from the area of Gable Gattar II in the north eastern desert of Egypt using the NAA. The dose obtained for $^{238}\text{U}$ and $^{232}\text{Th}$ ranged from 165±5 to 27851±836 and 71±2 to 274±8 Bq/kg, respectively. It was concluded that the Gable Gattar granite, from uranium mineralization, has high economic potential.
El-Taher, A., and Alharbi, A. (2013), carried out the NAA to find twenty five elements in quartz collected from the eastern desert along the Egyptian Red Sea coast. The accuracy of the procedure was evaluated by the analysis of two geo-standard reference materials (Dolerite WSE and Microgabro PMS). It is claimed that the data obtained contribute to understanding the elemental composition of the quartz rock, and because there are no existing databases for the elemental analysis of quartz, these results are regarded to be a start to establishing a database for the Egyptian quartz.

El-Taher, A. (2012), used the NAA on the granite samples collected from four locations in the Aswan area in Egypt. The samples and their standards were simultaneously irradiated in a neutron flux of $7 \times 10^{11}$ n/cm$^2$/s at the TRIGA Mainz research reactor. The study provided the basic data of elemental concentrations of granite rocks. The X-ray fluorescence (XRF) test was used for comparison. The data presented are regarded as contribution to understanding the elemental composition of granite rocks. Because there are no existing databases for the elemental analysis of granite, these results are considered to be a start to establishing a database for the Egyptian granite.

El-Taher, A. (2010), obtained the uranium concentrations in some Egyptian environmental samples like Toshki soil, Aswan iron-ore, and phosphate samples from El-Sibayia in the Nile Valley and El-Quseir in the Red Sea coast were determined using the NAA in the Mainz TRIGA research reactor in Egypt. The experimental results revealed that the phosphate rocks are rich natural sources of uranium among the other minerals forming the earth crust.

El-Taher, A. (2010), used NAA and $\gamma$-ray spectrometry to determine the natural radioactivity levels of 55 samples of building materials in Egypt. The activities were found to be in the ranges of 11.7-35.6, 12.4-55.2 and 60-350 Bq/kg for $^{226}$Ra, $^{232}$Th and $^{40}$K,
respectively. These values were compared with the data from other countries and with the
world average value for soils. It was concluded that all the materials examined were
acceptable for use as building materials as specified by the Organization for Economic
Cooperation and Development (OECD) criteria.

El-Taher, A. (2010), used the NAA and HPGe detector γ-spectroscopy to determine
chromium and fifteen trace elements in chromite rock samples collected in Egypt. The
samples were prepared together with their standards and simultaneously irradiated by
thermal neutrons at the TRIGA Mainz research reactor. Short-time irradiation (1–5 min)
was used to determine Mg, Ti and Mn. Long-time irradiation (6 h) was used to determine
Na, Ga, As, La, Sc, Cr, Fe, Co, Zn, Zr, Ce, Yb, Lu, Hf and Ta.

El-Taher, A. (2007), applied the NAA for the determination of rare earth elements
(REEs) in some Egyptian granites collected from four locations in Aswan area in south
Egypt. The samples were prepared together with standards and simultaneously irradiated
in a neutron flux of $7 \times 10^{11}$ n/cm$^2$/s in the TRIGA Mainz research reactor facilities. The
following elements were determined: La, Ce, Nd, Sm, Eu, Yb and Lu. The gamma spectra
were collected by HPGe detector and the analysis was done by means of computerized
multichannel analyser.

El-Taher, A., et al. (2003), applied the thermal NAA for the determination of gold and
other elements in two Egyptian gold ores. Ten samples collected from El Sukari and Atud
in the Eastern Desert-Egypt were analysed. Short-term (1 and 5 min) irradiation was also
used for detection of the elements with shorter half-lives. The results showed that the
concentration of gold is 42.4% in El-Sukari, and 25.7% in Atud.

Flaum, C. (1984), analysed the earth formations surrounding a well borehole by obtaining
a series of capture gamma ray spectra representative of the interaction of thermal neutrons
with various chemical elements in the formation surrounding the borehole, using the gamma spectrometric technique. The volume fractions of the formation components surrounding the well borehole were then determined from the spectral elemental yields.

**Gijbels, R. (1987)**, carried out a study to review the analytical techniques which are adopted to determine the lanthanides and U and Th in geological samples. It was found that the NAA followed by high-resolution gamma-ray spectrometry using conventional coaxial and planar germanium detectors was applicable to most practical problems.

**Hall, G. E. M., et al. (1990)**, compared the results obtained for twelve elements in approximately 1600 rocks by the NAA with those obtained by the ICP emission spectrometry (ICP-ES), XRF, and atomic-absorption spectrometry (AAS). Sample duplicates and two controls were used to evaluate the accuracy of the methods compared. It was concluded that the elements Na, Fe, Ba, Co, Cr, La, Ni and Rb could be determined in rocks by NAA with sufficient accuracy, whereas the determination of Ag, Yb, Zn and Zr suffered from inadequate sensitivity. Good agreement was seen in the results for Na (by INAA, ICP-ES and XRF) and Ag (NAA and AAS).

**Huckell, B. B., et al. (2011)**, carried out experiments using the NAA to characterize the chemical composition of chert (a type of sedimentary rock) from a primary source in western North Dakota in the US. The NAA results showed that it is chemically distinct from other known chert-bearing samples.

**Karangelos, D. J., et al. (2004)**, in their study have quantified the presence of depleted uranium (DU) contamination in soil samples in Yugoslavia, using the gamma spectrometric technique, and determined the quantities of $^{238}\text{U}$ and $^{235}\text{U}$. The analysis results are discussed in relation to the natural radioactivity content of the soil at the sampling sites.
Koeberl, C. (1993), developed a fast and reliable procedure to measure the abundances of about 35 elements even in small (<1 mg) samples. Depending on the type of samples, they were either irradiated for about 8 hours at a flux of about $2 \times 10^{12} \text{n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$, or up to 100 hours at a flux of about $6 \times 10^{13} \text{n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$. Synthetic multi-element standards and geological reference materials were used as standards. HPGe detectors with high efficiencies were used for the gamma spectrometry that followed. The study yielded reliable results for a wide variety of samples, e.g., cosmic spherules in the 30-200 microgram weight range.

Medhat, M. E., and Fayez-Hassan, M. (2011), researched to obtain the concentration of trace elements responsible for the high radioactivity of a nuclear reactor shielding following decommissioning of a nuclear power station. These elements were activated by $(n,\gamma)$ reaction during the reactor service life. The elements are Ce, Co, Cs, Eu, Fe, Hf, Sb, Sc, Ta and Tb that are normally present in concrete shielding, especially in cement. Different Egyptian cement samples were irradiated by neutrons, and analysed with gamma spectrometry. It was concluded that the radioactivity from these trace elements play an important role after a long cooling time or reactor decommissioning.

Michelsen, O. B., and Steinnes, E. (1968), determined the copper content in some geological samples using the thermal neutron activation followed by gamma-spectrometry. It was found that the method was precise to about ± 5 %. It was concluded that the method would be appropriate for application to samples with a copper content of 100-1000 ppm.

Nazarov, V. M., et al. (1994), carried out NAA studies of concrete ingredients for shielding structures of nuclear installations following their decommissioning. It was found that for the long-lived induced radioactivity in materials irradiated for 30 years and cooled for more than one year such radionuclides as calcium, iron, cobalt, caesium and europium
are responsible. The results also showed that the type of the binding agent influences to a great extent the concrete shielding activity. It is opined that the concentration of the above mentioned elements should be taken into account even at the stage of designing nuclear power plants. It is envisaged that this would allow one to assess the volume and activity of radwastes and also the radioactivity effect felt by the staff engaged in the decommissioning.

Olise, F. S., et al. (2014), analysed the sediment and process-waste rich in industrially-valued cassiterite, monazite and zircon for $^{232}$Th, $^{235}$U and $^{238}$U. The work was also extended to further assess the level of radionuclides in sediments and tailings from tin mining and processing sites of Jos Plateau, Nigeria. The results showed high level of activity from the radionuclides with the tailings having higher values than the samples from the mines. It was concluded that a relatively high radiological risk and the major radiation hazard can be caused by abandoned radioactive waste or tailing material that is used for manufacturing bricks.

Peppas, T. K., et al. (2010), observed that the concentration of trace elements and radionuclides in fly ash particles of different size can exhibit significant variation, due to the various processes taking place during combustion inside a coal-based power plant. The fly ash samples were analysed by NAA followed by gamma-ray spectrometry for the determination of Al, As, Ga, K, La, Na, Mn, Mg, Sr, Sc, and V. Correlations among the radionuclides examined were observed, while individual nuclide behaviour that varied between the two types of fly ash was also examined.

Ravisankar, R., et al. (2007), carried out experiments to determine the element profiles of some beach rock samples using the NAA. Around nineteen elements were determined from fifteen samples by high-resolution gamma spectrometry. The accuracy and precision
were evaluated by using the irradiated Standard Reference Material (SRM 1646a Estuarine sediment) and were found to be in good agreement with the certified values.

**Ravisankar, R., et al. (2006)**, carried out experiments on beach rocks for finding rare earth element (REE) concentrations in samples collected from the South East Coast of Tamilnadu, India, using the NAA method. The irradiation was done at the Kalpakkam mini reactor (KAMINI), IGCAR, Kalpakkam, Tamilnadu. Accuracy and precision were evaluated by irradiating standard reference material (SRM 1646a estuarine sediment). The concentrations of REEs were determined from fifteen samples using high-resolution gamma spectrometry.

**Schwedt, A., et al. (2006)**, analysed a set of 122 ceramic vessels found mostly in Hellenistic tombs in Boeotia, Greece, using the NAA. The experiments showed a clear separation between the Copaic and eastern samples. A few of the samples also showed compositions already found among Bronze Age samples from the same region indicating a local origin. The test results of samples from the Theban tombs pointed to an import from different origins, in some cases as distant as Asia Minor.

**Srivastava, A., et al. (2011)**, analysed soil samples from the seleniferous region of Punjab State in India by the NAA using reactor neutrons and high resolution gamma spectrometry. Samples were collected from three different depths namely surface, root and geological bed zones. Concentrations of fifteen elements including selenium and arsenic were found. For the sake of comparison, soil samples collected from a non-seleniferous region were also analyzed.

**Sroor, A., et al. (2000)**, analysed three different types of glass and four different kinds of aluminium sheets using the NAA. The irradiation facilities of the first Egyptian research reactor (ET-RR-1) and a high purity germanium (HPGe) detection system were used for
the analysis. Of the thirty four identified elements, the isotopes $^{60}$Co, $^{65}$Zn, $^{110m}$Ag, $^{123m}$Te, $^{134}$Cs, $^{152}$Eu and $^{182}$Ta were considered to be of special significance because of their long half-lives. A comparison between the different types of containers was also made to select the most suitable one for sample irradiation.

Steinhauser, G., et al. (2006), applied the NAA technique to determine the concentrations of twenty five elements in pumice samples collected from the Mediterranean region: Milos, Santorini, Kos, Giali and Nisyros (Greece), Lipari (Italy) and Cappadokia (Turkey). It was found that pumice or volcanic ash can be correlated in many cases to their volcanic sources by comparison of the typical main and trace elemental concentration patterns, commonly called “chemical fingerprint”. Only a small sample of size 5 mg was found to be sufficient for the test.

Uosif, M. A. M. (2007), analysed the natural radioactivity in selected sedimentary samples from different locations on the east and west banks of the Nile River in Upper Egypt to detect the presence of radioactive elements using gamma spectroscopy. From the analysis of radiations from $^{226}$Ra, $^{232}$Th and $^{40}$K isotopes, the samples were found to contain Ra, Th and K in concentrations up to $52 \pm 7.3$, $76.2 \pm 6.2$ and $351.9 \pm 17.6$ Bq/kg respectively.

Uwah, E. J., et al. (1993), adopted the NAA in the quantitative evaluation of the three major radioelements (U, Th and K) concentrations in a few rock samples collected at Ugep area in Nigeria. A preferential enrichment of Th to U and K was observed in most samples analysed, with U/Th ratios ranging from 0.11 to 0.25. K contents were fairly normal in some samples analysed, with Th /K ratios ranging from 2 to 5. Anomalous Th/K ratios were obtained for samples from those areas identified in the airborne survey maps as the “Th-anomaly zones”.

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**Wasserman, J. C., et al. (2001),** studied the geochemistry of four sediment cores using the NAA. The purpose of the study was to determine whether less common elements like the rare earths or the actinides are associated with contaminant metals like zinc. The results showed very strong zinc contamination in the top layers (more than 1000 $\mu$g $g^{-1}$) and background concentrations at the bottom (15 $\mu$g $g^{-1}$). It was also found that elements like chromium which are usually released by the heavy industries did not show a contamination profile.

**Watterson, J. I. W., et al. (1983),** used the NAA method for the study of samples ranging from granites, diamonds, coals, and some sedimentary units collected across South Africa. The results showed that the NAA technique can be used fruitfully to identify and map the mineralised phase of the granite. Trace element signatures were found for diamonds which were the characteristics of the sources. As for coal, and particularly in the case of the sediments, the method proved to be a highly effective tool for the identification of sedimentary units.

**Zhu, J., et al. (2012),** carried out work on the limestone samples collected from the Longmen Grottoes, also known as the Longmen Caves or Dragon's Gate Grottoes in China. NAA technique was used to determine the concentrations of major, trace and rare-earth elements (REEs). The results revealed that rocks in the northern area were made of the mineral dolomite, while rocks in the middle and southern areas were comprised of limestone. These results provided useful information for identifying and relocating fragments that had lost their identity.
2.4 Studies on Neutron Transmission through Concrete

General

The material used for radiation shielding depends on the type of radiation that needs to be contained. While alpha particles can be stopped easily by a thin sheet of paper, beta and gamma radiations can be arrested effectively with the use of plastic and lead shields respectively. Neutrons being uncharged particles do not get contained easily. It has been found that concretes of normal and high densities can effectively attenuate neutrons and arrest their propagation.

In the following paragraphs a brief review of the literature available on studies carried out on neutron transmission through concrete is presented.

Abdo, et al. (2002), studied the attenuation properties of baryte concrete as a biological shield for nuclear power plants, particle accelerators, research reactors, laboratory hot cells and different radiation sources. Investigations were carried out by measuring the transmitted fast neutron and gamma ray spectra through cylindrical samples of baryte concrete (density: 3490 kg/m$^3$). A reactor-collimated beam and neutron-gamma spectrometer were employed during the measurements. Measured and calculated results were compared and a reasonable agreement was found.

Kase, K. R., et al. (2003), observed that the most common material for shielding radiation is concrete, which can be prepared with various materials having different densities, and these different concrete mixes can have very different attenuation characteristics. To understand the radiation attenuation in concrete of different constituents, experiments were carried out on the transmission of leakage neutrons from a medical linear accelerator
(LINAC). The study revealed that neutron transmission through the high-density concretes can be estimated most reasonably and conservatively by using the linear tenth-value layer of normal concrete. It was also observed that the neutron transmission depends on the hydrogen content of the concrete mix.

**Korkut, T., et al. (2012)**, used $^{241}$Am-Be source and three samples including different amounts of boron atoms per unit volume, namely colemanite, ulexite and tincal in total macroscopic cross section experiments. The half value layers of samples were calculated and compared to those of paraffin. It was concluded that increased concentration of boron atoms can enhance the neutron shielding property of the samples.

**Korkut, T., et al. (2010)**, made use of MgB$_2$, NaBH$_4$ and KBH$_4$ samples containing different percentages of boron. Neutron macroscopic cross-section measurements of these were done by using a source of mono-energetic neutrons ($E_{\text{eff}} = 4.5$ MeV). The half value layers of the mixes were compared to those of paraffin which is one of the most commonly used neutron moderators. It was concluded that increase in boron concentration can improve the neutron shielding property of materials.

**Korkut, T., et al. (2010)**, prepared four baryte and four concrete samples with 0%, 5%, 10% and 15% colemanite concentrations, and carried out neutron dose transmission measurements by using a source of mono-energetic neutrons ($E_{\text{eff}} = 4.5$ MeV). The study revealed that when colemanite percentages of the samples increase, neutron dose transmission values for the samples decreased. It was concluded that it is possible to enhance the neutron shielding property of baryte and ordinary concrete by adding higher quantities of colemanite.

**Maiti, M., et al. (2004)**, carried out studies and presented simple empirical expressions for transmission of flux and dose through concrete for neutrons from proton induced reactions. The calculated effective dose outside a concrete shield showed overall good
agreement with the effective dose estimated from the measured neutron flux. It was also found that the calculated effective attenuation length showed a rising trend with incident proton energy and shield thickness.

Nakao, N., et al. (2004), arranged a high energy neutron irradiation room for carrying out studies on shielding, activation, and radiation damage of materials. A high energy neutron source produced in the forward direction from a thick tungsten target bombarded by 500 MeV protons was used for the purpose. An ordinary concrete shield of 4 m thickness was erected in the room in contact with the beam exit located at a distance of 2.5 m downstream from the target center. Activation detectors of bismuth, aluminium, indium, and gold foils were inserted into eight slots in the shield and the attenuation of the neutron reaction rates were obtained by measurements of gamma rays from the activation detectors. A simulation study was also performed, and it was found that there was a fair degree of agreement with the measured values.

Shin, K., et al. (1991), in their paper describe the spectral measurements of intermediate-energy neutrons ($E_n \leq 65$ MeV) transmitted through iron, lead, graphite, and concrete shields. The transmitted spectra of associated gamma rays were also obtained. A collimated beam of neutrons induced by 65-MeV protons in a thick copper target was used in the measurements. Measurements of both neutrons and gamma rays penetrating the shields were carried out. It was concluded that the gamma-ray spectra obtained behind the graphite and concrete shields may possibly be due the transmission of source gamma rays from the copper target through the shields.

Shin, K., et al. (1991), in their work describe the transmission measurements of medium energy neutrons through concrete shields. In their work, neutrons produced by the bombardment of 75 MeV protons on a thick Cu target, were collimated to a 7.5 cm diameter beam, and injected onto concrete shields of 20, 50 and 100 cm thickness. The
neutrons transmitted through the shields were measured, and it was found from a comparison between the calculated and measured fluences that the attenuation profile of the integrated fluence above 20 MeV, as well as the penetrated neutron spectra, were well reproduced.

Uwamino, Y., et al. (1982), studied the attenuation of neutrons and photons transmitted through graphite, iron, water, and ordinary concrete assemblies. Source neutrons and photons were produced by 52-MeV proton bombardment of a 21.4 mm thick graphite target placed in front of the assembly. These experimental results are considered to be benchmark data on neutron and photon penetration by neutrons of energy above 15 MeV. The agreement of calculations was well within the accuracy of 7% in the measured attenuation coefficients for graphite, iron, and water, and <10% for concrete.