Chapter 3: MATERIALS AND METHODS

3.1 Composition of Self-Compacting Concrete (SCC)

3.1.1 General

Concrete, in general, is a mixture of paste, and aggregates (sand and stone chips). The paste, which is composed of cement and water, coats the surface of the aggregates. The addition of water causes a reaction called ‘hydration’ to take place, when the paste solidifies and hardens to form a strong rock-like mass known as ‘concrete’. Concrete, therefore is a material that is plastic and mouldable when freshly mixed, strong and durable when hardened. It is these qualities of the material that make it amenable for the construction of structures like bridges and dams, highways and high-rise buildings.

3.1.2 SCC: Ingredients Used

Self-Compacting Concrete (SCC) is prepared using the same constituents as the normal vibrated concrete (NVC), except for one or two additional materials like (ACI 237R-07, 2007 & EFNARC Guidelines, 2002):

i. Mineral Admixture, and

ii. Chemical Admixture.

As per IS 9103: 1999 (Reaffirmed 2004), Admixture is “a material other than water, aggregates, and hydraulic cement and additives like pozzolana or slag and fibre reinforcement, used as an ingredient of concrete or mortar and added to the batch immediately before or during its mixing to modify one or more of the properties of concrete in the plastic or hardened state”. Admixtures are used in concrete to serve various purposes like:

i. improve workability without increase in water content,
ii. reduce bleeding and segregation,

iii. accelerate or retard setting time,

iv. control strength development, and

v. enhance durability to frost action, thermal cracking, alkali-aggregate expansion, sulphate attack, and corrosion of steel, etc.

Today, worldwide, most of the concrete produced contains one or more admixtures; it is estimated that in the developing countries some 80 to 90 per cent of concrete produced contains chemical admixtures (Mehta, P. K., and Monterio, P. J. M., 2006).

The mineral admixture used in SCC preparation could be one or more of the following:

i. Fly ash

ii. Ground Granulated Blast Furnace Slag (GGBS)

iii. Silica Fumes (Micro-silica)

iv. Rice Husk Ash

v. Metakaolin, etc.

The chemical admixture employed in SCC preparation could be one or both of the following:

i. High Range Water Reducing Admixture (HRWRA), and

ii. Viscosity Modifying Admixture (VMA).

There are three basic mixture-proportioning approaches for developing SCC mixtures, which are as follows (ACI 237R-07, 2007):

i. High powder content and HRWRA;

ii. Low powder content, HRWRA, and VMA; and

iii. Moderate powder content, HRWRA, and moderate VMA dose.
The mixture proportioning adopted in this work does not make use of any VMA, and therefore the mixes may be classified under the category ‘High powder content and HRWRA’.

In this work the proportioning and preparation of SCC mixes of grades M25 and M30 were carried out using the materials listed as under:

1. Coarse Aggregate (CA): Twelve different types of CA procured from various geological rock formations across the state of Karnataka, as listed in Table 3.1
2. Fine Aggregate: Locally available river sand
3. Cement: Ordinary Portland Cement (OPC)
4. Mineral Admixture (powder): Fly ash, and GGBS procured locally
5. Water: Conforming to drinking water standards, and

The important relevant features and the tests carried out on the constituent materials of SCC are described in the following paragraphs.

**3.1.2.1. Coarse Aggregate (CA)**

Coarse Aggregate (CA) or rock chips make up the major portion of any concrete. They give body to the concrete, reduce shrinkage, and effect economy. Their impact on various characteristics and properties of concrete is enormous. To know more about any concrete it is very essential that one should know more about the CA. The depth and range of studies that are required to be made in respect of aggregate to understand their widely varying effects and influence on the properties of concrete cannot be underrated (Shetty, M.S., 2013).
As per **IS 383-1970** (Reaffirmed 2002), stones or rock chips that are retained on IS sieve size of 4.75 mm are considered as CA. The CAs may be described as any of the following types:

i. Uncrushed gravel or stone which results from natural disintegration of rock

ii. Crushed gravel or stone when it results from crushing of gravel or hard stone, and

iii. Partially crushed gravel or stone when it is a product of the blending of (i) and (ii).

The CA samples used in the present work are of the second type in the above list.

The present work involves the preparation of SCC using twelve different types of CA samples of 20 mm down size procured from the geological formations across the state of Karnataka. The CA sample procurement was made on the basis of the Geological Report (**No. DMG: SGU: G.R:2009-10:621, 2009**), obtained from the Department of Mines & Geology, Government of Karnataka, Udupi Region. The details of the quarry location and the geological identification of the rock type are listed in Table 3.1.

It may be noted that the CA samples have been given Code Numbers KA-1, KA-2, KA-3, …, KA-12 for ease of identification.

These twelve CA samples were used separately in attempts to prepare SCC of grades M25 and M30. The details of the mix proportioning method adopted, fresh and hardened properties of the trial mixes are included in Section 3.5 of this Chapter.
Table 3.1: Rock samples procured from geological formations in Karnataka

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>CA Sample Code</th>
<th>Quarry Location</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>KA-1</td>
<td>Karkala</td>
<td>Gneiss</td>
</tr>
<tr>
<td>2</td>
<td>KA-2</td>
<td>Hebri</td>
<td>Granite</td>
</tr>
<tr>
<td>3</td>
<td>KA-3</td>
<td>Tumkur</td>
<td>Trap</td>
</tr>
<tr>
<td>4</td>
<td>KA-4</td>
<td>Tumkur</td>
<td>Basalt</td>
</tr>
<tr>
<td>5</td>
<td>KA-5</td>
<td>Mysore</td>
<td>Peninsular Gneiss</td>
</tr>
<tr>
<td>6</td>
<td>KA-6</td>
<td>Bagalkot</td>
<td>Dolomite rock</td>
</tr>
<tr>
<td>7</td>
<td>KA-7</td>
<td>Kolar</td>
<td>Deccan Trap</td>
</tr>
<tr>
<td>8</td>
<td>KA-8</td>
<td>Bagalkot</td>
<td>Sandstone</td>
</tr>
<tr>
<td>9</td>
<td>KA-9</td>
<td>Ramadurga</td>
<td>Quartzite</td>
</tr>
<tr>
<td>10</td>
<td>KA-10</td>
<td>Chitradurga</td>
<td>Chitradurga Group Granite</td>
</tr>
<tr>
<td>11</td>
<td>KA-11</td>
<td>Lokapur</td>
<td>Limestone</td>
</tr>
<tr>
<td>12</td>
<td>KA-12</td>
<td>Udupi</td>
<td>Laterite</td>
</tr>
</tbody>
</table>

All the twelve CA samples procured were tested for the following properties:

i. Free Moisture Content

ii. Fineness Modulus after carrying out the Sieve Analysis as per **IS 2386-1963: Part I** (Reaffirmed 2002)

iii. Water Absorption, Specific Gravity, and Bulk Density as per **IS 2386-1963: Part III** (Reaffirmed 2002), and

The properties obtained after conducting the tests on Coarse Aggregates are listed in Table 4.1 of Chapter 4.

### 3.1.2.2. Fine Aggregate

As per **IS 383-1970** (Reaffirmed 2002), aggregate most of which passes IS sieve size of 4.75 mm is considered as Fine Aggregate. They fill up the gaps between the CA in concrete and make it denser. The Fine Aggregate may be described as any of the following types:

i. Fine Aggregate resulting from the natural disintegration of rock and which has been deposited by streams or glacial agencies

ii. Fine Aggregate produced by crushing hard stone, and

iii. Fine Aggregate produced by crushing natural gravel.

In the present work naturally occurring river sand was used as Fine Aggregate. The following tests were carried out to determine the relevant properties of Fine Aggregate:

i. Grain Size Distribution using Sieve Analysis as per **IS 2386-1963: Part I** (Reaffirmed 2002), and

ii. Specific Gravity, and Bulk Density as per **IS 2386-1963: Part III** (Reaffirmed 2002).

The properties obtained after conducting the tests on Fine Aggregate are listed in Table 3.2.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Property of Fine Aggregate</th>
<th>Result/Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific Gravity</td>
<td>2.55</td>
</tr>
<tr>
<td>2</td>
<td>Bulk Density</td>
<td>1350 kg/m³</td>
</tr>
<tr>
<td>3</td>
<td>Particle Size Distribution</td>
<td>Zone III</td>
</tr>
</tbody>
</table>

### 3.1.2.3 Cement

Cement, in the general sense of the word, can be described as a material with adhesive and cohesive properties which make it capable of bonding mineral fragments into a compact
whole. For constructional purposes, the meaning of the term ‘cement’ is restricted to the bonding of materials like stones, sand, bricks, building blocks, concrete, etc. The cements used in the making of concrete have the property of setting and hardening when mixed with water by virtue of a chemical reaction and are, therefore called ‘hydraulic cements’ (Neville, A.M., 2003).

The cement used in this work is the Ordinary Portland Cement (OPC) of grade 43 conforming to **IS 8112-1989** (Reaffirmed 2005). The following properties of OPC were determined by conducting laboratory tests as per the relevant Indian Standard Codes cited as under:

i. Fineness as per **IS 4031-1999: Part II** (Reaffirmed 2004)

ii. Standard Consistency as per **IS 4031-1988: Part IV** (Reaffirmed 2005)

iii. Initial and Final setting times as per **IS 4031-1988: Part V** (Reaffirmed 2005)

iv. Compressive Strength as per **IS 4031-1988: Part VI** (Reaffirmed 2005), and


The properties obtained after conducting the tests on cement are listed in Table 3.3.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Property</th>
<th>Result/Value Obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific Gravity</td>
<td>3.15</td>
</tr>
<tr>
<td>2</td>
<td>Fineness (m²/kg)</td>
<td>255</td>
</tr>
<tr>
<td>3</td>
<td>Standard Consistency (%)</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>Setting Time (minutes)</td>
<td>Initial 36, Final 585</td>
</tr>
<tr>
<td>5</td>
<td>Compressive Strength (N/mm²)</td>
<td>3 days 25.6, 7 days 36.8, 28 days 45.2</td>
</tr>
</tbody>
</table>
3.1.2.4. Fly Ash (FA)

Also known as “pulverized-fuel ash”, it is a residue resulting from the combustion of ground or powdered or crushed bituminous coal (anthracite) or sub-bituminous coal (lignite). About 80 per cent of the total ash is finely divided and gets out of the boiler along with flue gases and is collected by suitable techniques. It is sometimes referred as chimney ash and hopper ash. The balance about 20 per cent of ash gets collected at the bottom of the boiler and is taken out by suitable methods and is referred as “bottom ash”. Fly ash is collected and stored in dry condition. When fly ash alone or along with bottom ash is carried to storage or deposition lagoon or pond in the form of water slurry and deposited, it is termed as “pond ash”. Whereas if fly ash, alone or along with bottom ash is carried to a storage or deposition site in dry form and deposited, it is termed as “mound ash” (IS 3812-2003: Part I).

FA is the most common artificial pozzolana (a material which while in finely divided state develops binding property in the presence of Ca (OH)$_2$ and water). The FA particles are spherical (which is advantageous from the flowability and water requirement point of view of SCC), and have a very high fineness, and specific surface. The high specific surface of FA means that the material is readily available for the chemical reaction that takes place during hydration. (Neville, A.M., 2003).

FA can be incorporated into concrete in varying percentages of cement content. The main influence of incorporation of FA is that on water demand and workability of the concrete mix. The fresh mix is considerably more cohesive and the bleeding is substantially reduced. This makes the mix suitable for pumping. The reduction in water demand of fly ash based concrete is usually ascribed to the spherical shape of the fly ash particles, this being called the “ball-bearing effect” (Neville, A.M., 2003).
In our country the generation of FA by coal/lignite based power stations during 2012-13 stood at 163.56 million tonnes, of which 100.37 million tonnes (61.37%) was utilized. (CEA Report, 2014). The disposal of FA into the atmosphere can cause serious environmental pollution issues, and therefore it is very essential that the material is consumed usefully in the making of cements and concretes of various types.

The American Society for Testing and Materials (ASTM) broadly classifies FA into two classes (Shetty, M.S., 2013), as under:

i. Class F Fly Ash: This is produced by burning anthracite or bituminous coal. It has less than 5% CaO.

ii. Class C Fly Ash: This is produced by burning lignite or sub-bituminous coal. Some Class C FA may contain CaO content in excess of 10%.

The Class F FA used in this work was procured from the sites of the Udupi Power Corporation Limited, a nearby thermal power generation station. The specific gravity of the FA used was found, and is presented in Table 3.4.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Property</th>
<th>Result/Value Obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific Gravity</td>
<td>2.2</td>
</tr>
</tbody>
</table>

3.1.2.5 Ground Granulated Blast Furnace Slag (GGBS)

Slag is a waste product in the manufacture of pig iron, with about 300 kg of slag being produced for each tonne of pig iron. It is a mixture of lime, silica, and alumina that is the same oxides that make up OPC but not in the same proportions. For use in the manufacture of
blended cement (called Portland slag cement), the slag has to be quenched so that it solidifies as glass, crystallization being largely prevented (Neville, A.M., 2003).

Portland slag cement is obtained by mixing Portland cement clinker, gypsum and granulated slag in suitable proportions and grinding the mixture to get a thorough and intimate mix between the constituents. It may also be manufactured by separately grinding Portland cement clinker, gypsum and granulated slag and then mixing them intimately. The resultant product is cement which has physical properties similar to those of ordinary Portland cement. In addition, it has low heat of hydration and is relatively better resistant to soils and water containing excessive amounts of sulphates of alkali metals, alumina and iron, as well as to acidic waters, and can, therefore, be used for marine works with advantage. The manufacture of Portland slag cement has been developed primarily to utilize blast furnace slag, a waste product from blast furnaces. The development of manufacture of this type of cement will considerably increase the total output of cement production in the country and will, in addition, provide a profitable use for an otherwise waste product (IS 455-1989) (Reaffirmed 2005).

The GGBS can be ground to a fineness ranging between 350 and 500 m²/kg, which is finer than OPC. Increased fineness leads to increased activity at early ages. The GGBS can be incorporated into fresh concrete mixes in varying percentages of cement, and the possible beneficial effects of this addition are as follows (Neville, A.M., 2003):

i. The fresh concrete mix has improved workability, better mobility and cohesiveness

ii. The heat development is slower so that the peak temperature is lower, and

iii. A denser microstructure of hydrated cement paste is achieved which improves long-term strength, durability, and the risk of alkali-silica reaction can be eliminated.
As per IS 12089-1987 (Reaffirmed 2004) the physical state of aggregation of granulated slag shall be in the form of granules. The proportion of lumps exceeding 50 mm size shall not constitute more than 5 per cent of the mass of slag. The composition of granulated slag shall comply with the chemical requirements listed in Table 3.5.

Table 3.5: Chemical requirements of GGBS for use in manufacture of Slag Cement

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Constituent</th>
<th>Per cent (Maximum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Manganese oxide</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>Magnesium oxide</td>
<td>17.0</td>
</tr>
<tr>
<td>3</td>
<td>Sulphide sulphur</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The specific gravity of the GGBS sample used was determined, and is presented in Table 3.6.

Table 3.6: Specific Gravity of GGBS

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Property</th>
<th>Result/Value Obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific Gravity</td>
<td>2.95</td>
</tr>
</tbody>
</table>

3.1.2.6 Water

IS 456-2000 (Reaffirmed 2005) recommends that water used for mixing and curing concrete shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel. Potable water is generally considered satisfactory for mixing and curing concrete. Mixing or curing of concrete with sea water is not recommended because of the presence of harmful salts in sea water.

In the present work drinking water available in the vicinity of the laboratory was used for preparing and curing the SCC mixes and specimens.

3.1.2.7 High Range Water Reducing Admixture (HRWRA):

The chemical admixture used in the present work is the HRWRA (also called superplasticizer), to enhance and maintain the fluidity (plasticity) of the SCC mix at a
considerably low value of water-to-cementitious material ratio (w/cm). The commercially available product called “Structuro 100” is the chemical admixture used in this work. As suggested by IS 9103-1999 (Reaffirmed 2004), manufacturer’s recommended dosage of the chemical was used. The manufacturer’s flyer on the product may be found in Appendix- A.

3.2 SCC: Guidelines, Specifications, and Acceptance Criteria

3.2.1 General
Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as normal vibrated concrete (NVC). SCC offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. SCC is often produced with low water-cement ratio providing the potential for high early strength, earlier demoulding and faster use of elements and structures. The elimination of vibrating equipment improves the environment on and near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise and vibration. The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and civil engineering construction (The European Project Group, 2005).

Concrete that requires little vibration or compaction has been used in Europe since the early 1970s but self-compacting concrete was not developed until the late 1980’s in Japan. In Europe it was probably first used in civil works for transportation networks in Sweden in the
In the mid-1990s, The European Federation of Specialist Construction Chemicals and Concrete Systems (EFNARC) published their “Specification & Guidelines for Self-Compacting concrete” (EFNARC Guidelines, 2002) which, at that time, provided state-of-the-art information for producers and users. Since then, much additional technical information on SCC has been published.

The Self-Compacting Concrete European Project Group was founded in January 2004 with representatives from:

- The European Precast Concrete Organisation (BIBM)
- The European Cement Association (CEMBUREAU)
- The European Ready-mix Concrete Organisation (ERMCO)
- The European Federation of Concrete Admixture Associations (EFCA), and
- The European Federation of Specialist Construction Chemicals and Concrete Systems (EFNARC).

The document titled, “The European Guidelines for Self Compacting Concrete - Specification, Production and Use,” prepared and published during May 2005 by the European Project Group is today used in proportioning and preparing SCC in most parts of Europe and other developed countries in the world.

### 3.2.2 SCC: Guidelines and Acceptance Criteria

SCC may be used in pre-cast applications or for concrete placed on site. It can be manufactured in a site batching plant or in a ready mix concrete plant and delivered to site by truck. It can then be placed either by pumping or pouring into horizontal or vertical structures. The workability of SCC can be characterised by the following properties:
- Filling ability
- Passing ability
- Segregation resistance

A concrete mix can only be classified as Self-compacting Concrete (SCC) if the requirements for all three characteristics are fulfilled. Many different test methods have been developed in attempts to characterise the properties of SCC. So far no single method or combination of methods has achieved universal approval and most of them have their adherents. For site quality control, two test methods are generally sufficient to monitor production quality. Typical combinations are Slump-flow and V-funnel, or Slump-flow and J-ring. With consistent raw material quality, a single test method operated by a trained and experienced technician may be sufficient (EFNARC Guidelines, 2002). A comprehensive list of test methods for assessing the workability properties of SCC is shown in Table 3.7.

**Table 3.7: Test methods for assessing the workability properties of SCC**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Test Method</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slump-flow by Abrams cone</td>
<td>Filling ability</td>
</tr>
<tr>
<td>2</td>
<td>T50 cm slump flow</td>
<td>Filling ability</td>
</tr>
<tr>
<td>3</td>
<td>J-ring</td>
<td>Passing ability</td>
</tr>
<tr>
<td>4</td>
<td>V-funnel</td>
<td>Filling ability</td>
</tr>
<tr>
<td>5</td>
<td>V-funnel at T5 minutes</td>
<td>Segregation resistance</td>
</tr>
<tr>
<td>6</td>
<td>L-box</td>
<td>Passing ability</td>
</tr>
<tr>
<td>7</td>
<td>U-box</td>
<td>Passing ability</td>
</tr>
<tr>
<td>8</td>
<td>Fill-box</td>
<td>Passing ability</td>
</tr>
<tr>
<td>9</td>
<td>GTM screen stability test</td>
<td>Segregation resistance</td>
</tr>
<tr>
<td>10</td>
<td>Orimet</td>
<td>Filling ability</td>
</tr>
</tbody>
</table>

In the present work for the purpose of assessing the workability of the SCC mixes in the laboratory, a set of selected tests from Table 3.7 were carried out on the fresh mixes. The tests carried out, and the typical range of their values (Acceptance Criteria) as per EFNARC Guidelines, 2002 are listed in Table 3.8.
Fig. 3.1(a) through Fig. 3.4(a) show the schematic (specifications and dimensions) of the four equipment, juxtaposed with the Fig. 3.1(b) through Fig. 3.4(b) of photographs of the corresponding equipment fabricated for using in the present work.

Fig. 3.1(a): Slump Cone & Base Plate (Specifications)

Fig. 3.1(b): Slump Cone & Base Plate (Fabricated)

Fig. 3.2(a): V – Funnel (Specifications)

Fig. 3.2(b): V – Funnel (Fabricated)
Fig. 3.3(a): L – Box (Specifications)

Fig. 3.3(b): L – Box (Fabricated)

Fig. 3.4(a): U – Box (Specifications)

Fig. 3.4(b): U – Box (Fabricated)
Table 3.8: Acceptance criteria for Self-compacting Concrete

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Test Method</th>
<th>Unit</th>
<th>Typical Range of Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>1</td>
<td>Slump-flow by Abrams cone</td>
<td>millimeters</td>
<td>650</td>
</tr>
<tr>
<td>2</td>
<td>T50 slump flow</td>
<td>seconds</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>V-funnel</td>
<td>seconds</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>L-box</td>
<td>(ratio)</td>
<td>0.8</td>
</tr>
<tr>
<td>5</td>
<td>U-box</td>
<td>millimeters</td>
<td>0</td>
</tr>
</tbody>
</table>

The details of the above tests with regard to the procedures and methodology of carrying them out may be found in Appendix - B.

3.3 Neutron Activation and Gamma Spectroscopic Analysis of CA samples

3.3.1 General

Compact, efficient and cost-effective radiation shield design for nuclear reactors and accelerators has been an important subject of study for the last few decades. Self-compacting concrete (SCC) is one of the preferred choices for cost-effective shield in these facilities. In reactors and in positive ion accelerators prompt radiation field is dominated by neutrons. For the entire life-time of the facility, the shield wall will be subjected to long term irradiation by neutrons. We should have an estimate of induced radioactivity per unit mass of the shield wall in order to plan decommissioning of the facility.

Estimation of radio-activation of concrete shields in reactor and accelerator facilities is very important during decommissioning (Masumoto, K., et al., 2003). At the end of the year 2011, about 124 nuclear power reactors were shut down throughout the world (Deju, R., et al., 2013). The structural decommissioning of these facilities would produce radioactive waste, mostly concrete. Depending on the type of the reactor (e.g., water cooled/gas
cooled/research/power reactor) operating at hundreds of MWe, a few hundred to thousands of tons of radioactive concrete waste is produced (Thierfeldt, S., 2010; O’Sullivan, O., et al., 2010; and Choi, W. K., 2009). These wastes often contain long-lived radioactivity. Masumoto, K., et al., (2003), showed that in an accelerator environment $^{152}$Eu, $^{60}$Co, $^{134}$Cs, $^{22}$Na, $^{54}$Mn are some of the important isotopes produced in concrete through neutron activation. For the accelerator facility studied in their work an activity of 0.02 Bq/g of $^{60}$Co resulted in a dose rate of 0.1 μSv/hr.

Presently, in Europe the amount of recycled radioactive concrete waste is between 1200-2000 tons/year (Deju, R., et al., 2013), and this is expected to rise to about 7,000 tons/year by the year 2030. The disposal of these materials would pose a major problem because the facilities and the final disposal technologies are not only limited but also expensive. Thus, the amount of waste that arises from operating and decommissioning activities is a serious impediment for the proliferation of nuclear technology. Waste recycling, volume and activity reduction are very essential in decreasing the costs of decommissioning nuclear facilities. Radiological as well as physical and chemical characterisation of these waste materials are important, in order to segregate, process, and dispose them off. Aggregates, being the major constituent of concrete (approx. 60-80% volume of the material), can cause considerable influence on the strength, dimensional stability, and durability of concrete (Mehta, P. K., 2006).

The primary objective of this work is to identify the appropriate coarse aggregates (CA) (stone chips used in preparation of concrete) that may be employed in the preparation of low radio-activation concrete for radiation shielding, by carrying out the quantification of trace elements present in the aggregates that are capable of generating long lived activation products. The CA samples used in this work were procured from twelve different regions.
(geological formations) of Karnataka state, India, as listed in Table 3.1. The data of geological formations in Karnataka was obtained from the Department of Mines & Geology, Government of Karnataka (Report No. DMG: SGU: GR: 2009-10:621, 2009). In the present work it is intended to estimate the radio-activation of these twelve CA samples due to neutron irradiation and determine the relative concentration of six different elements which give rise to long-lived radioactivity. Relative concentration of an element in different CA samples will help to identify the CA samples which will generate low amount of induced radioactivity. Though these data will be useful for selecting appropriate CA for neutron shielding in India, the geological composition of the rock samples will make these data interesting globally.

Neutron activation analysis (NAA) is the technique employed to serve the present purpose. NAA has widely been used by many workers in order to determine elemental or chemical composition of different types of samples. Freitas M.C., et al., (2004), applied NAA to analyse the composition of aerosols and estimate the amount of ambient Pb and PM10 (particulate matter below 10 mm). Fathivand, A.A., et al., (2011), also used NAA for analysis of air samples. Sujari, A.N.A., et al., (1987), used NAA for determination of Ag in foodstuff. Prompt gamma NAA (PGNAA) has been used by Naqvi, et al., (2006), for the measurement of chlorine in concrete.

In the following paragraphs a detailed description of the experimental procedure for sample preparation, neutron activation, and gamma spectrometry of the irradiated samples is included.

The results of gamma spectrometric analysis, and induced activity calculation are included in Section 4.4 of Chapter 4 on Results and Discussions.
3.3.2 The NAA Method

![Diagram of neutron capture by a target nucleus followed by emission of gamma rays](image)

**Fig.: 3.5** Neutron capture by a target nucleus followed by emission of gamma rays

The sequence of events occurring during the most common type of nuclear reaction used for NAA, namely the neutron capture or (n, gamma) reaction, is illustrated in Fig. 3.5. When a neutron interacts with the target nucleus via a non-elastic collision, a compound nucleus forms in an excited state. The excitation energy of the compound nucleus is due to the binding energy of the neutron with the nucleus. The compound nucleus will almost instantaneously de-excite into a more stable configuration through emission of one or more characteristic prompt gamma rays. In many cases, this new configuration yields a radioactive nucleus which also de-excites (or decays) by emission of one or more characteristic delayed gamma rays, but at a much slower rate according to the unique half-life of the radioactive nucleus. Depending upon the particular radioactive species, half-lives can range from fractions of a second to several years.

In principle, therefore, with respect to the time of measurement, NAA falls into two categories: (1) prompt gamma-ray neutron activation analysis (PGNAA), where measurements take place during irradiation, or (2) delayed gamma-ray neutron activation...
analysis (DGNAA), where the measurements follow radioactive decay. The latter operational mode is more common, as about 70% of the elements have properties suitable for measurement by DGNAA.

### 3.3.3 NAA of CA Samples

NAA was carried out on the twelve CA samples collected from different geological formations across the state of Karnataka, India. A list of the CA samples procured is given in Table 3.1. A brief description of the procedure followed may be found in the following paragraphs.

Nearly 50 mg of each of the twelve rock samples was wrapped separately in aluminium foils. Two standard reference materials, IAEA-433 and IAEA-158, (Appendices C & D), procured from the International Atomic Energy Agency (IAEA), Vienna, Austria, were also wrapped in separate aluminium foils. These two packets of samples and reference materials were irradiated simultaneously (co-irradiated) for three days at the same position in the Dhruva research reactor at the Bhabha Atomic Research Center, Trombay, India.

The neutron fluence used in the irradiation is given in Table 3.9. Since it was intended to estimate the trace elements that give rise to long lived radionuclides, the samples were allowed to cool for three months so that all the short lived activities decayed down to insignificant levels. After three months, presence of $^{60}$Co was detected from the aluminium foil used for wrapping the rock samples. So the aluminium foils were removed and the samples were re-wrapped in paper. These samples were then counted for 5000 seconds each on a low background gamma counting set-up using a p-type high purity germanium (HP Ge) gamma spectrometer. The gamma spectrometric system had a 30% relative efficiency and a
resolution of 1.95 keV at 1332.5 keV. Energy calibration of the detector was carried out using the reference standards $^{60}$Co, $^{137}$Cs, $^{152+154}$Eu radioactive sources. The room background spectrum where the counting setup was installed was also measured for the same counting time. The net spectrum for each of the samples was obtained by subtracting the background spectrum from the recorded sample spectrum.

Table 3.9: Neutron fluence values at the position of irradiation of the samples

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Neutron Energy Range</th>
<th>Fluence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>$&lt; 0.625$ eV</td>
<td>$1.03 \times 10^{18} \text{ n/cm}^2$</td>
</tr>
<tr>
<td>2.</td>
<td>$0.625 \text{ eV} - 0.821 \text{ MeV}$</td>
<td>$2.26 \times 10^{17} \text{ n/cm}^2$</td>
</tr>
<tr>
<td>3.</td>
<td>$0.821 \text{ MeV} - 10\text{MeV}$</td>
<td>$1.64 \times 10^{16} \text{ n/cm}^2$</td>
</tr>
</tbody>
</table>

Some of the important long lived gamma emitting radionuclides generally produced in the concrete shields of nuclear reactors and accelerators along with the thermal neutron cross section for the relevant reactions are listed in Table 3.10 (Mughabghab, S.F., 2006). It may be noted that total cross section for the reaction $^{151}$Eu(n,g)$^{152}$Eu is the sum of the cross sections ($\sigma_g = 5900$ barns) populating the ground state of $^{152}$Eu$^g$ and that ($\sigma_{m2} = 3300$ barns) for the second metastable state $^{152}$Eu$^{m2}$ which decays by isomeric transition with a half-life of 9.2 minutes. From Table 3.10 we find that, in concrete, long-lived activity (half-lives in years) due to $^{60}$Co, $^{134}$Cs, $^{152,154}$Eu are formed due to (n, $\gamma$) reactions on $^{59}$Co, $^{133}$Cs, $^{151,153}$Eu respectively. Relatively short lived activity (half lives in days) $^{46}$Sc, $^{59}$Fe, and $^{182}$Ta are formed due to (n, $\gamma$) reactions on $^{45}$Sc, $^{58}$Fe, and $^{181}$Ta respectively. The long-lived radionuclides are important from the point of view of decommissioning after the end of life.
time of the facility, whereas the short-lived radionuclides are responsible for collective dose to personnel during maintenance and other activities during the operational life of the facility. So, in order to identify the CA samples suitable for low radioactivation it is necessary to determine the amount of the respective parent nuclide in different samples.

The twelve CA samples collected from Karnataka state were analysed for the production of the seven radioisotopes mentioned in Table 3.10 due to neutron activation. Quantitative analysis of the respective parent elements were carried out by comparing the gamma spectroscopic data of the samples with those for two reference materials IAEA-158 and IAEA-433 as detailed in Section 3.3.3.1 of this Chapter.

### Table 3.10 Long lived radionuclides produced in the concrete shields of nuclear reactors and accelerators through (n, γ) reaction

<table>
<thead>
<tr>
<th>Parent Nuclide</th>
<th>γ energy (keV)</th>
<th>Nuclear Reaction</th>
<th>Radio-isotope</th>
<th>Half-life</th>
<th>Abundance</th>
<th>Thermal neutron cross-section (barns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{45}$Sc</td>
<td>889.3</td>
<td>$^{45}$Sc (n,γ) $^{46}$Sc</td>
<td>$^{46}$Sc</td>
<td>83.8 d</td>
<td>100%</td>
<td>27.2</td>
</tr>
<tr>
<td>$^{58}$Fe</td>
<td>1099.2</td>
<td>$^{58}$Fe (n,γ) $^{59}$Fe</td>
<td>$^{59}$Fe</td>
<td>45 d</td>
<td>0.282%</td>
<td>1.32</td>
</tr>
<tr>
<td>$^{59}$Co</td>
<td>1332.5</td>
<td>$^{59}$Co (n,γ) $^{60}$Co</td>
<td>$^{60}$Co</td>
<td>5.26 y</td>
<td>100%</td>
<td>37.2</td>
</tr>
<tr>
<td>$^{133}$Cs</td>
<td>795.8</td>
<td>$^{133}$Cs (n,γ) $^{134}$Cs</td>
<td>$^{134}$Cs</td>
<td>2.05 y</td>
<td>100%</td>
<td>30.3</td>
</tr>
<tr>
<td>$^{151}$Eu</td>
<td>1408.0</td>
<td>$^{151}$Eu (n,γ) $^{152}$Eu</td>
<td>$^{152}$Eu</td>
<td>13.5 y</td>
<td>47.8%</td>
<td>9200</td>
</tr>
<tr>
<td>$^{154}$Eu</td>
<td>1274.4</td>
<td>$^{154}$Eu (n,γ) $^{154}$Eu</td>
<td>$^{154}$Eu</td>
<td>8.5 y</td>
<td>52.2%</td>
<td>312.0</td>
</tr>
<tr>
<td>$^{181}$Ta</td>
<td>1121.3</td>
<td>$^{181}$Ta (n,γ) $^{182}$Ta</td>
<td>$^{182}$Ta</td>
<td>115 d</td>
<td>100%</td>
<td>20.5</td>
</tr>
</tbody>
</table>

#### 3.3.3.1 Quality Control Analysis

Quality control analysis of the experimental set-up to test the accuracy of the measured results were realized by using two certified reference materials, treating one as a standard and
the other as a sample. Of the two standard samples, IAEA-158 (S₁) was treated as the known standard, and IAEA-433 (S₂) was treated as the unknown standard. Elemental composition of both S₁ and S₂ are provided by IAEA. We have recorded the counts under each of the gamma peaks mentioned in Table 3.10 for both the samples. Elemental composition of S₂ is determined from the measured counts, measured weight of the two samples S₁ and S₂, and the known elemental composition of S₁ as detailed below.

Since both the samples S₁ and S₂ were co-irradiated and counted in identical geometry, the concentration (N₂) of an element in the unknown standard S₂ is given by:

\[
\frac{N_1}{N_2} = \frac{C_1/W_1}{C_2/W_2} \quad (3.1)
\]

or,

\[
N'_2 = \left( \frac{C_2}{C_1} \right) \times \left( \frac{W_1}{W_2} \right) \times N_1 \quad (3.2)
\]

where:

- \(C_1\) = counts/second for sample S₁ (IAEA-158)
- \(C_2\) = counts/second for sample S₂ (IAEA-433)
- \(W_1\) = weight of the sample S₁
- \(W_2\) = weight of the sample S₂
- \(N_1\) = Elemental concentration of a particular element in sample S₁ as quoted by IAEA
- \(N'_2\) = Calculated elemental concentration of a particular element in sample S₂
- \(N_2\) = Elemental concentration of a particular element in sample S₂ as quoted by IAEA

From Equation (3.2) we see that if the weights \(W_1\) and \(W_2\) for samples S₁ and S₂, respectively, and concentration \(N_1\) of an element in sample S₁ are known, concentration of the same element in sample S₂ can be determined from the measured counts \(C_1\) and \(C_2\) under the relevant gamma peak for the two samples. We have calculated the concentration \(N_2\) of an
element in sample $S_2$ using the IAEA quoted value for $N_1$. This calculated value $N_2'$ is compared with the IAEA quoted value for $N_2$ in Table 4.18 of Chapter 4.

Concentrations of Sc, Fe, Co, Cs, Eu and Ta in the twelve different CA samples from Karnataka state have been determined following the same method described above for the quality control analysis. For this purpose the peak counts for the seven different radioisotopes produced from the samples are compared with those from the two IAEA standards. The result of this analysis is given in Table 4.19 of Chapter 4.

3.3.3.2 Calculation of induced activity

Activity of the seven radioisotopes mentioned in Table 3.10 and induced in the CA samples due to neutron irradiation have been determined from the measured concentration of the parent elements. The activity $A$ of a particular radio-nuclide in the sample after the cooling period is given by:

$$A = N \int \sigma(E)\varphi(E) dE \left(1 - e^{-\lambda t}\right) e^{-\lambda \tau} \quad (3.3)$$

where:

- $N$ = number of atoms of the target parent nuclide available in the sample for interaction
- $\sigma(E)$ = production cross-section of the radioisotope through neutron activation at energy $E$
- $\varphi(E)$ = neutron fluence at energy $E$
- $\lambda$ = decay constant of the radionuclide formed
- $t$ = irradiation time
- $\tau$ = cooling time of the irradiated sample

To estimate the potential activity build-up in the rock samples due to thermal neutrons, the number of parent atoms in a given sample was determined from the measured elemental concentration. It was then folded with the neutron flux and production cross section at neutron energy $E$. The total activity induced for a radioisotope was thus calculated using
Equation (3.3) for a given irradiation time and a decay time by integrating over the entire energy range of neutron fluence. In order to obtain the detailed neutron fluence distribution \( \varphi(E) \) we have used a normalized typical core reactor spectrum for a \(^{235}\text{U}\) based thermal reactor (Bitelli, U., et al., 2009). This normalized spectrum is folded with the total neutron fluence used in the present work to obtain the energy distribution of neutron fluence. The thermal neutron induced excitation function \( \sigma(E) \) for different radioisotopes were taken from published data (Mughabghab, S.F., 2006). The calculated activity are given in Table 4.20 of Chapter 4.

From the calculated activity of each of the seven radioisotopes the \( \gamma \) dose also has been estimated in all the twelve CA samples using the relation:

\[
D = \frac{6A E}{d^2} \quad (3.4)
\]

Where \( D \) is the dose in mR/hr, \( A \) is the activity of the \( \gamma \) emitting radioisotope in mCi, \( E \) is the total energy of emitted \( \gamma \) radiation in MeV, \( d \) is the distance in ft. of point of observation from the source.

The total dose from a CA sample is obtained from the sum of the doses due to all the seven isotopes. Time variation of the dose has been followed starting from a cooling time of 94 days to 123 months, as may be seen in Fig. 4.13 of Chapter 4.

The discussion of the above test results is included in Section 4.4 of Chapter 4.
3.4 SCC: Mix Proportioning Methods, Fresh and Hardened Properties

3.4.1 General

There is no standard method for SCC mix design and many academic institutions, admixture, ready-mixed, precast and contracting companies have developed their own mix proportioning methods (The European Project Group, 2005). Generally, it is advisable to design conservatively to ensure that the concrete is capable of maintaining its specified fresh properties despite anticipated variations in raw material quality. Some variation in aggregate moisture content should also be expected and allowed for at mix design stage (EFNARC Guidelines, 2002). Laboratory trials should be used to verify properties of the initial mix composition. If necessary, adjustments to the mix composition should be made.

The proportioning of the mixture constituents required for SCC may be done as per the following procedure:

- Set the required performance
- Select the materials to be used including aggregates, powders, and admixtures
- Design and adjust mix composition
- Verify or adjust performance in the laboratory
- If the performance is satisfactory verify performance at the site

In the event that satisfactory performance cannot be obtained, then consideration should be given to fundamental redesign of the mix. Depending on the apparent problem, the following courses of action might be appropriate:

- using additional or different types of filler
- modifying the proportions of the sand or the coarse aggregate
- using a viscosity modifying agent (VMA), if not already included in the mix
• adjusting the dosage of the superplasticizer and/or the VMA
• using alternative types of superplasticizer (and/or the VMA), more compatible with local materials
• adjusting the dosage of admixture to modify the water content, and hence the water/powder ratio.

3.4.2 Mix Proportioning/Design Procedures and Properties of the SCC mixes

In this work SCC mixes of two grades, viz. M25 and M30 were prepared by adopting four different prevailing methods of mix proportioning. The methods adopted are as follows:

i. The Okamura Method (Okamura, H., et al., 2003)
ii. The Nan Su et al. Method (Nan Su, et al., 2001)
iii. The EFNARC Method (EFNARC Guidelines, 2002)

The mixes prepared were tested for their fresh properties to verify if they clear the regulations of Acceptance Criteria listed in Table 3.8 of this Chapter.

The hardened properties of the standard specimens measured are as follows:

• Compressive strength at the end of 3, 7, and 28 days of curing (Cubes: 150 mm side).
• Flexural strength at the end of 3, 7, and 28 days of curing (Prisms: 100x100x500mm).
• Split tensile strength at the end of 3, 7, and 28 days of curing (Cylinders: 150mm diameter, 300mm length).

Guidelines from the following IS Codes were adopted in determining the hardened properties:


A comparative study of the quantities of the mix constituents, fresh and hardened properties are made to arrive at the method which is most suitable and advantageous, and hence preferred to prepare the hardened SCC specimens (slabs of size 30x30x10 cm) for Neutron Transmission Study discussed in the Section 3.6 of this Chapter.

The constituent materials used in preparing the mixes are the same as those listed in Section 3.1.2 of this Chapter, except that the CA sample used is the dolomite rock procured from Bagalkot (Code No. KA-6), as it is found to develop least induced radioactivity as may be seen from Table 4.20 of Chapter 4.

A brief discussion of the features of the above four methods, the mix proportions obtained, the fresh and hardened properties of SCC of grades M25 and M30 achieved using them, may be found in the following paragraphs.

### 3.4.2.1 The Okamura Method

This method was proposed in the year 1993 by Okamura, Maekawa, and Ozawa of Japan *(Nan Su, et al., 2001)*, who are regarded as the pioneers of SCC technology. As per this method, following are the proportions of the constituents of SCC to be adopted:

- **Coarse Aggregate**: 50% of the solid volume.
- **Fine Aggregate**: 40% of the mortar volume.
- **Water-powder ratio**: 0.9 to 1.0.
The super plasticizer dosage and the final water-powder ratio are determined so as to ensure self-compactability.

The main advantage of this method is that it avoids having to repeat the same kind of quality control test on concrete. However, the major drawback of this method is that it requires quality control of paste and mortar prior to preparing the SCC mix, while most ready-mixed concrete producers may not have the necessary facilities for conducting such tests (Nan Su, et al., 2001).

The quantity of mix constituents, fresh and hardened properties of the M25 and M30 grade SCC produced using this method are listed in Table 4.2 through Table 4.11 of Chapter 4.

3.4.2.2 The Nan Su et al. Method

This method was proposed by Nan Su, Kung-Chung Hsu, and His-Wen Chai of Taiwan in the year 2001. The authors aver that the amount of aggregates, binders and mixing water, as well as type and dosage of superplasticizer to be used are the major factors influencing the properties of SCC. In this method, first the amount of aggregates required is determined, and the paste of binders is then filled into the voids of aggregates to ensure that the concrete thus obtained has flowability, self-compacting ability and other desired SCC properties. Following is the sequence of the steps to be followed for producing SCC using this method:

- Step 1: Calculation of Coarse Aggregate and Fine Aggregate contents
- Step 2: Calculation of Cement content
- Step 3: Calculation of mixing water content required by cement
- Step 4: Calculation of Fly ash and GGBS contents
• Step 5: Calculation of total mixing water content needed in SCC
• Step 6: Calculation of superplasticizer dosage

Trial mixes are carried out using the contents of materials calculated and quality control tests for verifying the fresh property features of SCC. If results of the quality control tests fail to meet the performance required of the fresh concrete, adjustments in the material quantities should be made until all properties of SCC satisfy the requirements.

A description of the step-by-step procedure to be followed to achieve SCC using the above method may be found in Appendix - E.

The quantity of mix constituents, fresh and hardened properties of the M25 and M30 grade SCC produced using this method are listed in Table 4.2 through Table 4.11 of Chapter 4.

3.4.2.3 The EFNARC Method

EFNARC stands for ‘The European Federation of Specialist Construction Chemicals and Concrete Systems’, and was founded in March 1989. It has members drawn from most European and other developed countries who are specialists in the area of construction chemicals and concrete systems. During February 2002 EFNARC published, “Specifications and Guidelines for Self-Compacting Concrete,” which is a comprehensive document that covers the various aspects of SCC. The document recommends indicative typical ranges of proportions and quantities of constituents of SCC in order to obtain self-compactability, which are as follows:

• Water/powder ratio by volume : 0.80 to 1.10
• Total powder content: 160 to 240 litres (400-600 kg) per cubic meter
• Coarse aggregate content: 28 to 35 per cent by volume of the mix
• Water content: Not to exceed 200 litres per cubic meter
• Sand content: To balance the volume of the other constituents

Laboratory trials should be used to verify properties of the initial mix composition. If necessary, adjustments in terms of the quantity of constituent materials added to the mix composition is to be made. More frequent adjustment of mix proportions, particularly water content, may need to be made, depending on the results from monitoring aggregate moisture content.

The quantity of mix constituents, fresh and hardened properties of the M25 and M30 grade SCC produced using this method are listed in Table 4.2 through Table 4.11 of Chapter 4.

3.4.2.4 The IS Code Method

Indian Standard Code of Practice IS 456-2000 (Fourth Revision) in its Annex J (Amendment No. 3, August 2007) has given a few guidelines/features of SCC, which are as under:

• Slump flow: 600 mm (Minimum).
• Fines (< 0.125 mm): 400 kg/m³ to 600 kg/m³.
• Sand content: more than 38%.
• Mineral admixture: 25-50 % by mass of cementitious materials.
• HRWRA and VMA: appropriate dosages.
The above values/ranges of the SCC mix constituents are only indicative, and can be helpful to obtain the material quantities for the first trial. Adjustments in terms of additions or deductions have to be made in appropriate measures so as to ensure that the final SCC mix clears all the fresh property tests listed in Table 3.8.

The quantity of mix constituents, fresh and hardened properties of the M25 and M30 grade SCC produced using this method are listed in Table 4.2 through Table 4.11 of Chapter 4.

The discussion of the above test results is included in Section 4.3 of Chapter 4.

3.5 SCC: Features of Mixes containing the CA samples of Karnataka

The twelve coarse aggregate (CA) samples collected from different geological formations of the state of Karnataka were used separately in the preparation of twelve different SCC mixes. Two grades of SCC were prepared, viz., M25 and M30. Each mix had the same constituents, except for the coarse aggregate, which was different for different mixes. The mix proportioning methodology proposed by Nan Su et al., (2001) was adopted in working out the mix constituents. The quantities of ingredients, fresh and hardened properties of the SCC mixes achieved/attempted are listed in Table 4.12 through Table 4.17 of Chapter 4.

It was found that SCC could be achieved using only nine of the twelve CA samples. The Code Nos. of these samples are KA-1, KA-2, KA-3, KA-4, KA-5, KA-6, KA-7, KA-10, and KA-11. The mixes containing three CA samples, viz. KA-8, KA-9, and KA-12 failed the fresh property tests, as may be seen from Tables 4.13 and 4.16 of Chapter 4.

The hardened properties tested for the SCC mixes are as follows:
- Compressive strength at the end of 3, 7, and 28 days of curing (Cubes: 150 mm side), and
- Modulus of Elasticity at the end of 28 days of curing (Cylinders: 300 mm length, and 150 mm diameter),

both as per IS 516-1959 (Reaffirmed 2004): Indian Standard Methods of tests for strength of concrete.

The results of the hardened property tests are listed in Tables 4.14 and 4.17 of Chapter 4. SCC mixes prepared using the nine CA samples mentioned above (KA-1, KA-2, KA-3, KA-4, KA-5, KA-6, KA-7, KA-10, and KA-11), were used in casting of slabs of size 30x30x10 cm for carrying out the Neutron Transmission studies as detailed in the Section 3.6 of this Chapter.

The discussion of the above test results is included in Section 4.3.2 of Chapter 4.

3.6 Studies on Neutron Transmission through SCC slabs

As mentioned in Section 3.5 of this Chapter, the M25 and M30 grade SCC mixes prepared using the nine CA samples viz. KA-1, KA-2, KA-3, KA-4, KA-5, KA-6, KA-7, KA-10, and KA-11, were used in casting of slabs of size 30x30x10 cm. On these slab specimens the Neutron Transmission studies were carried out at the 16-Curie Americium-Beryllium Neutron Source Handling Facility at M.I.T., Manipal. A schematic diagram of the facility is shown in Fig. 3.6.
The specifications of the Neutron Detector (LUDLUM 42-30H) are as follows:

- **DETECTOR:** 2 atm $^3$He tube LND 25185 or equivalent
- **MODERATOR:** 25.4 cm (10in.) diameter polyethylene sphere
- **COMPATIBLE INSTRUMENTS:** Typically used with area monitors such as Models 375, 177-50, and 177-61
- **SENSITIVITY:** 200 cpm/mrem/hr (241AmBe fast neutrons)
- **GAMMA REJECTION:** 10 cpm or less through 10 R/hr (100mSv/hr) (137Cs)
- **DETECTION RANGE:** Thermal to approximately 12 MeV
- **ENERGY RESPONSE:** Thermal to 7 MeV follows the radiation protection guide curve for neutron dose
- **INPUT SENSITIVITY:** –2 mV
- **OPERATING VOLTAGE:** 1100 Vdc
- **CONNECTOR:** Series "C" (others available)
- **SIZE:** 38.1 x 25.4 x 26.2 cm (15 x 10 x 10.3 in.) (H x W x D), including bracket
- TEMPERATURE RANGE: -20 to 50 °C (-4 to 122 °F)
- WEIGHT: 8.8 kg (19.5 lb)
- FINISH: Drawn-and-cast aluminum fabrication, with beige powder-coating.

From the transmission studies carried out, the following two aspects of the SCC mixes (Grade M25 and M30), as regards the neutron shielding property were determined:

1) Linear Attenuation Coefficient (LAC), $\mu$

2) Half Value Thickness (HVT), $t_{1/2}$

Following is a brief description of the above two aspects of the SCC mixes prepared.

### 3.6.1 Linear Attenuation Coefficient for Neutron Transmission

It is a quantity that characterizes how easily a material or medium can be penetrated by a beam of light, sound, particles, or other energy or matter. A large attenuation coefficient means that the beam is quickly "attenuated" (weakened) as it passes through the medium, and a small attenuation coefficient means that the medium is relatively transparent to the beam.

It is expressed using units of reciprocal length, and found from the relation:

$$D_1 = D_0 e^{-\mu t}, \text{ where:}$$

- $D_1$ = Final Dose rate
- $D_0$ = Initial Dose rate
- $t$ = Thickness of the medium (SCC slab)
3.6.2 Half-Value Layer

Half-value layer (HVL) or half-value thickness (HVT), of a material is the thickness of the material at which the intensity of radiation entering it is reduced by one half.

Half Value Thickness is found from the relation:

\[ t_{1/2} = \frac{0.693}{\mu} \]

The LAC and HVL for the two different grades of SCC prepared using the CA samples, along with the densities of the mixes are listed in Tables 4.21 and 4.22 of Chapter 4.

The discussion of the above test results is included in Section 4.5 of Chapter 4.