INTRODUCTION
CHAPTER-I

INTRODUCTION

1.1. STATEMENT OF THE PROBLEM:

Energy is the most fundamental requirement of every society or nation for its development. It is considered a necessary prerequisite for development. It is vital to the sustenance of a modern economy. Future economic growth depends on the long-term availability of energy. Per capita energy consumption is indicator of the development stage of any country. This is clearly indicated in the average energy consumption per capita across the nations viz. developed countries like USA, France, Japan, Russia consumes more energy than an average Indian (Fig.1.1a). It is clear from Fig.1 that per capita energy consumption in India in 2008 was only 743 KWh against the world average of 2782 KWh (PIB, 2012). The per capita consumption of electricity in the country also increased from 15 KWh in 1950 to 778.71 KWh in 2010 to 814 KWh in 2011. The installed capacity of power plants has also increased to about 1,86,655 MW by December, 2011 from a meagre 1713 MW in 1950(CEA,2012).

As India is passing through a phase of rapid growth in economic empowerment, for economic growth, it will require large amount of energy. It is predicted that the total electricity demand will grow over 950,000 MW by the year 2030 which will still be less than one-fourth of the current U.S. per capita energy need (Kalam, 2011). According to Kalam (2011), India has potential for solar and wind energy due to abundant sunshine and places of high wind velocity, but solar and wind power are not stable and they are dependent mainly on weather and sunshine conditions.

Requirement of large amounts of energy in the form of electricity cannot be fulfilled simply by using solar, wind and other sources of energy. If we really want to fulfill our energy need, we have to develop nuclear energy in a big way. As per WNA (2012), till November, 2012, 436 nuclear reactors are under operation in 30 countries worldwide producing about 2518 billion KWh electricity with installed capacity of 374,135 MWe which is 13.5 % of total electricity generated by different sources (Fig.1.1c). Further, 62 new nuclear reactors are under construction with installed capacity of 62,789 MWe (WNA, 2012). Meanwhile in India, we are generating only
4780MW of nuclear power which is only 3% of the total power generation in the country, most of the energy in India is coming from coal based thermal power (Table.1.1a & Fig.1.1b) (CEA, 2012).

Fig.1.1a: Per capita electricity consumption in developed countries of world and India in 2008 (PIB, 2012).

Fig.1.1b: Pie chart showing all India share of various Energy resources (as on 31stDecember, 2011) (CEA, 2012).

Fig.1.1c: Pie chart showing share of various energy sources in world electricity production in 2008 (WNA, April 2012 from CEA, 2010).
Table 1.1a: All India Installed Capacity of energy resources (CEA, 2012)

<table>
<thead>
<tr>
<th>SL.NO.</th>
<th>Energy Resources</th>
<th>Total generation (in MW)</th>
<th>Contribution (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Nuclear Power</td>
<td>4780</td>
<td>3.0</td>
</tr>
<tr>
<td>2.</td>
<td>Hydro Power</td>
<td>38748</td>
<td>20</td>
</tr>
<tr>
<td>3.</td>
<td>Gas</td>
<td>17742.85</td>
<td>10</td>
</tr>
<tr>
<td>4.</td>
<td>Diesel</td>
<td>1199.75</td>
<td>1.0</td>
</tr>
<tr>
<td>5.</td>
<td>Coal</td>
<td>104021.40</td>
<td>55</td>
</tr>
</tbody>
</table>

In order to fulfill the increasing demand of power given the large population base, nuclear energy appears to be the only option. Further nuclear industry is having more than 14,000 reactor-years of experience. The main fuels for production of nuclear energy are uranium and thorium. Thorium based technology for productions of commercial nuclear power have not yet fully developed. Most of our nuclear energy programme is based on uranium. Hence discovery of new uranium deposits are in demand to increase our nuclear energy share in the overall requirement of our energy need for the future.

Many significant deposits of uranium have been located world over in which the grade of uranium varies from 0.025% U₃O₈ in Late Archean Quartz Pebble Conglomerates type in Witwatersrand Basin of South Africa (Frimmel and Minter, 2002; Hazen et al., 2009) and upto 15% U₃O₈ in Proterozoic unconformity related at McArthur River deposits in Athabasca basin of Canada (Cuney, 2005) respectively. The single giant deposit of uranium has been located at Olympic Dam in Australia containing about 2,50,000 tonnes of uranium with grade 0.05 % U₃O₈ together with Au, Cu and REE (Hitzman et al., 1992). The highest grade uranium deposits are mainly confined to Canada (Roy et al., 2006) and Australia (Lambert et al., 2006). As far as Indian continent is concerned only low to medium grade uranium deposits have been so far unearthed (Chaki et al., 2010).

The nuclear power programme of India is mainly based on uranium resources which are presently being mined from Jaduguda, NarwaPahar, Bhatin, Turamdih, Bandhuhurang and Bagjata mines, all located along 160 km long arcuate shaped E-W
running Singhbhum Shear Zone in the state of Jharkhand whose grade varies from 0.029 to 0.067 % U$_3$O$_8$ (Gupta, 2006).

In the context of India’s energy security, development of nuclear power is essential. According to Srivastava (2011), the present share of nuclear power in India is only 3.7 % of total installed capacity. The vision - 2020 of the Department of Atomic Energy, Government of India envisages a cumulative installed capacity of 20,000 MWe. Present and future plan of nuclear power in India is given in table.1.1b (IAEA, 2009). India plan is to reach a nuclear capacity of 63,000 MWe by 2032 by setting up 16 new indigenous pressurized heavy water reactors (Economic times, 2010). India aims to supply 25% of electricity from nuclear power by 2050 (WNA, 2012). Out of total target of 63,000MW, 40,000MW will be produced from light water reactors (LWR) with international cooperation. Presently 20 reactors are under operation in India with installed capacity of 4780MWe (NPCIL, 2012).

In order to enhance the share of nuclear power generation in the country’s total power scenario, more nuclear power reactors construction (Figs.1.1c and 1.1d) and more uranium deposits are to be discovered in the near future so that the gap between demand and supply of the uranium can be minimized. In order to achieve self-sufficiency in uranium resources to support the present vision of uranium based nuclear power programme as well as future requirement for the country, uranium exploration and exploitation in a big way is the demand of the time. It is therefore necessary to locate suitable geological domain favorable for discovering new uranium resources in the country in general and eastern India in particular.

In eastern India, Singhbhum-Orissa Craton is a well known uranium province where structurally controlled hydrothermal vein type uranium mineralization have already been discovered in schistose rocks all along Singhbhum shear zone (SSZ) at several locations. Work is still in progress in this zone to locate another sizeable uranium deposits. Work has also been taken up in the same craton mainly in Iron Ore Group (IOG) basins situated along the periphery of Singhbhum granite to search for Late Archean-Early Proterozoic quartz-pebble conglomerate (QPC) type deposits. In this context, the area along western margin of Bonai granite in parts of Sundergarh...
district in Orissa state was selected to locate and characterized QPC type uranium mineralization.

<table>
<thead>
<tr>
<th>Type of Reactors</th>
<th>Capacity (MWe)</th>
<th>Cumulative Capacity (MWe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20- PHWR reactors operational</td>
<td>--</td>
<td>4780</td>
</tr>
<tr>
<td>2-LWR under construction at Kudankulam, TamilNadu</td>
<td>2x 1000</td>
<td>6780</td>
</tr>
<tr>
<td>PFBR under construction at Kalapakkam</td>
<td>500</td>
<td>7280</td>
</tr>
<tr>
<td>Planned Projects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8PHWR (8 x 700)</td>
<td>8 x 700}</td>
<td>21,180</td>
</tr>
<tr>
<td>FBR (4x500)</td>
<td>4x500}</td>
<td></td>
</tr>
<tr>
<td>LWR (6 x 1000)</td>
<td>6 x 1000}</td>
<td>13,900</td>
</tr>
<tr>
<td>AHWR(1 x 300)</td>
<td>1 x 300}</td>
<td></td>
</tr>
</tbody>
</table>

The investigations helped in the discovery of radioactive QPC all along the western margin of Archaean Bonai granite right from Baratangra in the west to the north of Balisura village in PhulJhori Pahar in the east over a strike length of about 8-10 km intermittently. Detailed study revealed the presence of number of QPC lenses of varying dimension with U-Th mixed anomaly and also indicated the presence of detrital uraninite and monazite grain in them. The area has potential for further detail work including sub-surface exploration to establish QPC type uranium mineralization in the area.

1.2. INTRODUCTION OF STUDY AREA:

The area of study forms a part of Singhbhum-Orissa craton of Eastern India which falls in the part of survey of India Toposheet No. 73 C/13, in parts of Sundergarh district of Orissa state. The location of Orissa state and Sundergarh district are shown in Figs.1.2a and 1.2b. The area is easily approachable by metalled road from Rourkela to Bonaigarh via National Highway (NH)-23 and is about 40km. SE of Rourkela steel city. Rourkela, Panposh and Jharsuguda are the rail head which is situated on Howrah-Mumbai rail-line of South-Eastern railway of Indian Railway network. Jharsuguda is the nearest rail head to district headquarter of Sundargarh district (about 35km) located at Sundargarh town.
South-Eastern railway also passes through steel city of Rourkela and a small place named Panposh located in Sundergarh district only. Additional branch lines from Rourkela to Birmitrapur (28km) and from Bondamunda to Barsuan (68.6km) are also available for the transportation of minerals in the district. In addition to this, the district HQ is also connected to different parts of the district and other district HQ of Orissa through road network by public transport system.
Sundergarh district was formed on 1st January, 1948 by merging two ex-states of Gangpur and Bonai, with district headquarter at Sundargarh town. It lies in the northern part of Orissa state. It is bounded to north by Ranchi district of Jharkhand state, to south by towns of Jharsuguda, Sambalpur and Deogarh district of Orissa, on the east and north-east by Keonjhar district of Orissa and West Singhbhum district of Jharkhand, on the west and north-west by Raigarh district of Chhattisgarh (Fig.1.2b).

1.3. GEOGRAPHY, DEMOGRAPHY AND OTHER RESOURCES OF THE AREA:
The district lies between $21^0 35'\ N$ and $22^0 32'\ N$ latitudes and between $83^0 32'\ E$ and $85^0 22'\ E$ longitudes. The district headquarters is located at Sundargarh. The total area of the district is about 9712 Sq.km. out of which 4232.57 Sq.km. area are covered under forest. The geographical area of the district ranks second position in the state and also ranks 77th position among the districts of India.

Total population of Sundergarh is 2,080,664 as per latest provisional figures released by Directorate of Census Operations in Orissa. The data show increase of 13.66 percent in 2011 compared to 2001 census. As per census 2011, density of Sundergarh District per square km is 214 compared to 188 per sq.km of 2001. Sex ratio of girls in Sundergarh district per 1000 boys was recorded 971 i.e. an increase of 14 points from the figure of 2001 census which was around 957. As regards the population, the district occupies sixth position in the state of Orissa. Sundergarh population constitutes 4.96 percent of total Orissa population. The average literacy rate of Sundergarh district is 74.13 percent. In all, there were total 1,357,840 literates in 2011 compared to 1,015,485 literates in 2001 census.

The annual mean rainfall in the district is 1657.1mm. The district is an undulating tableland broken up by rugged hills ranges and torrential hilly streams and rivers Ib (Tributary of Mahanadi) and Brahmini river. The general slope in the district is from north to south. Alluvial and lateritic soils are the main soil found in the district. The average height of the undulating tableland in the district is 700 feet which rises upto 2000 feet. The Bonai subdivision in the south-east is occupied by rugged forest cover and hills intersected by gorges and passes and having a narrow valley of Brahmini River and its tributary. The east and west of Brahmini valley is occupied by high hill
ranges. Brahmni is the main river whose tributaries are Sankh and Koel river. Another river in the district is IB river which is tributary of Mahanadi.

About 43% of the total district area is covered with forest, the forest type mainly belongs to northern tropical dry deciduous forest having Sal, Assan and Kurum. The area occupied by forest is around 3534.92 sq.km, out of which 2664.64 sq.km. area is under reserve forest and 612.07 sq.km. area falls under protected forest. The forest product includes bamboo, timber and Kendu leaves which are exports oriented. The district is also rich in mineral resources which include mainly iron, manganese, limestone and lead.

1.4. REVIEW OF LITERATURE:

Krishnan (1937) for the first time studied the area south of Raghunathpali conglomerate as Iron-ore series and considered them younger to Gangpur series. Later Sarkar and Saha (1962) equated these rocks with the Dhalbhum Formation of Singhbhum Group. Prasada Rao, et al. (1964) mapped the area and grouped them into six groups. Kanungo and Mahalik (1967) shows that Gangpur Group in fact overlies the rocks south of Raghunathpali conglomerate. Palaeocurrent data analyzed by Kanungo and Mahalik (1970) revealed sedimentary transport for Gangpur basin from the south. Ramachandran and Raju (1982) have designated rocks of southern Gangpur- Bonaigarh region into six Groups. Sarkar and Saha (1992) carried out aerial photo-interpretation of the area between Bonai and north of it. Mahalik (1987) grouped the rocks lying between Bonai granite and Gangpur rocks into a new group designated as Darjing Group. Naik (2001) revised the stratigraphy of the area and mapped the rocks between Base of Birtola and Kumakela-Rourkela as “Chandiposh Group”. Chaki et al. (2005) has also given a review on the area along with age data on Tamparkola granite and other granites occurring further west of it.

As far as uranium exploration is concerned, no agency other than Atomic Minerals Directorate for Exploration and Research (AMD), a unit of the Department of Atomic Energy, Government of India is responsible for comprehensive exploration of radioactive resources. The first uranium deposits in the country was located at Jadugura along Singhbhum shear zone of East Singhbhum district of Jharkhand.
(erstwhile Bihar state) as early as 1956 (Gupta, 2006). Since then number of uranium deposits were discovered along this shear zone namely at Bhatin, NarwaPahar, Turamdih etc.

The first uraniferous quartz-pebble conglomerate in India was reported from Chikmagalur, Dharwar craton of Karnataka, South India (Rama Rao, 1974). Since then, several occurrences were discovered at the base of Bababudan and Chitradurga Groups in Karnataka (Pandit, 2002). Based on similarity in geology and time and space control, geological cum radiometric survey were also taken up in different parts of Orissa to locate QPC type uranium mineralization.

1.5. AIM OF THE STUDY:

Quartz-pebble conglomerates (QPC) of Neoarchaean to Paleoproterozoic are well known to host uranium mineralization either associated with gold or without gold. These deposits make up approximately 13% of the world's uranium resource (Dahlkamp, 1993; IAEA, 1996). They are also known to contain economic grade concentration of REE mainly Y and also platinum group of elements. The two most famous examples of such deposits are Witwatersrand Au-U (gold is main while U is by-product) in South Africa and U (+Y) deposits of Blind River, Elliot Lake, Canada (Hazen et al., 2009). Similar type of uraniferous QPCs are also known to occur in India mainly from Walkunji in Dharwar Craton of South India (Rama Rao, 1974; Viswanath et al., 1988; Pandit, 2002) and Koirar (Saxena et al., 1974; Mishra et al., 1997), Gorumahisani-Badampahar, Malaygiri-Bankhol Iron-Ore Group (IOG) basins (Das et al., 1988), Daitari basins (Mishra et al., 2008; Kumar et al., 2011) and in Dhanjori basin (Vasudeva Rao et al., 1988) of Singhbhum-Orissa Craton in eastern India.

Such type of QPCs occurrences have also been located along western and eastern margin of Archean Bonai granite which are radioactive and shows mixed U-Th character. The work by Kumar et al., (2009) helped in delineating many new radioactive QPCs lenses along western margin of Archean Bonai granite in parts of Sundergarh district of Orissa.
The aim of the work is to characterize these QPC occurrences located along western margin of Bonai granite based on their geological, petro-mineralogical and geochemical studies and to evolve a model for the genesis of QPC and associated radioactive minerals mainly uranium.

1.6. RATIONALE BEHIND SELECTION OF AREA FOR RESEARCH:

Singhbhum-Orissa Craton is a well known uranium province. QPC shares 13% of global resources of uranium and 0.33% of known uranium resources in India. QPC are generally Uraniferous with Gold, Platinum or REE (eg. Witwatersrand QPC, South Africa is gold bearing and U is by-product; and Blind River deposit, Elliot Lake, Canada is uranium bearing with REE, mainly Y. Earlier work have indicated presence of uranium and gold in SOC mainly in QPC at the base of Iron Ore Group (IOG) basins situated along the periphery of Singhbhum granite along eastern margin of Bonai granite in main Koira iron ore basin and also in Tomka-Daiteri IOG basin. Hence work has been taken up in SOC in Iron Ore Group (IOG) equivalent QPC-quartzite sequence situated along the western margin of Bonai granite to characterize QPC based upon their geological, petrological and geochemical criteria along western margin of Bonai granite in parts of Sundergarh district in Orissa state which will help in search for Late Archean-Paleoproterozoic Quartz-Pebble Conglomerate (QPC) type uranium deposits.

1.7. OBJECTIVES : The objectives of the research work include:

1.7.1. Identification and delineation of radioactive (uraniferous) quartz-pebble conglomerates (QPC) at the base of Iron Ore Group (IOG) along western margin of Bonai Granite Pluton (BGP) in Singhbhum-Orissa craton of Sundergarh district of Orissa (Now Odisha) of Eastern India.

1.7.2. Characterization of radioactive quartz-pebble conglomerates (QPC) and associated IOG quartzites by understanding the geological set up, detailed petro-mineralogical and textural features.

1.7.3. Identification of radioactive phase/s in QPC to find the presence of radioactive phases responsible for radioactivity in them.

1.7.4. Geochemical characterization of QPC and quartzites to understand their paleoweathering condition, provenance and tectonic setting.
1.7.5. Radioelement distribution to know the concentration level of U, Th and % K, hence their uraniferous, thoriferous or mixed U-Th nature.

1.7.6. Radioactive QPC and associated quartzites for REE, PGE, Au and Ag concentration to decipher their economics which can be taken out as by-product during the mining of radioactive mineral mainly uranium.

1.7.7. Control/s of uranium mineralization in QPC.

1.7.8. Constraints on the genesis of uranium with the help of geological, petrological and geochemical data to understand the origin of QPC-quartzite sequence along with genesis of uranium and associated Au-REE-PGE mineralization in this part of Singhbhum-Orissa Craton of eastern India.

With a view to achieve the above objectives, the following methodology was adopted:

1.8. METHODOLOGIES ADPOTED FOR RESEARCH WORK:

The methodologies adopted for research work includes:

1.8.1. Field Work (Geological Mapping and Radiometric Survey):

1.8.1.1. Geological Mapping on 1: 50,000 scale and later on 1: 1000 scale to delineate QPC lenses.

1.8.1.2. Sampling: High resolution sampling of QPCs and quartzites for their detailed elemental analysis.

1.8.1.3. Scintillometer Counter(SM) survey: SM counter was used for recording radioactivity associated with QPCs and quartzites all along the strike and dip of the rocks for delineation of radioactive lhouunits.

1.8.2. Laboratory Work:

1.8.2.1. Gamma-Ray Spectrometry(GRS) : for analysis of eU, U, Th and % K in QPC, IOG quartzites and basal Bonai granite.

1.8.2.2. Petromineralogical studies: For identification of rock types and their framework mineralogy, textural features and alterations.

1.8.2.3. Cellulose Nitrate film Autoradiographic study (CN-film study): For identification of radioactive phases (Alpha-track detection).
1.8.2.4. Image Analyses: Photo-micrography of important mineralogical and textural features.

1.8.3. Geochemical Study of Host Lithounits and Associated IOG Quartzites:

1.8.3.1. X-Ray Fluorescence (XRF): For major and trace element analysis,

1.8.3.2. Scanning Electron Microscopy-Energy Dispersive Spectrometer (SEM-EDS): For identification of mineral phases,

1.8.3.3. Inductively Coupled Plasma-Mass Spectrometer (ICP-MS): For U, Th, Hf, Sc, Ag and REE,

1.8.3.4. Graphite furnace-Atomic Absorption Spectrometer (GF-AAS): For Au analysis Mineral chemistry,

1.8.3.5. Electron Probe Micro-Analyzer (EPMA): For mineral chemistry of detrital grains,

1.8.3.6. Ni-S Fire assay: For PGE (Like Pt, Pd, Rh, Os, Ru and Ir),

1.8.3.7. Compilation of petrological, geochemical like major oxides, trace elements, REE data, Au, Ag, PGE data, their interpretation and genetic model preparation.

1.9. INSTRUMENTS USED FOR VARIOUS STUDY

1.9.1. Microscopic Study: Carried out with the help of polarizing microscope, E-600, Nikon Make, Japan having image analysis system with Biovis, version 1.50 for microphotography. The study included, Identification of rock forming and ore minerals, important texture and geological features, Alteration, deformation if any, Microphotography of important features using image analysis system. In addition to this, CN-film autoradiography, also known as solid state nuclear track detection (SSNTD) study was carried out on polished thin sections of radioactive QPC for: (i) study of alpha tracks density, their shape their (ii) locating and identification of radioactive phases in polished thin sections by alpha tracks matching technique (ii) photo-micrography of radioactive phases and corresponding alpha density tracks. The alpha tracks were studied by using polarizing microscope, E-600, Nikon Make, Japan having image analysis system with Biovis, version 1.50 for photo-micrography.
1.9.2. **Scintillometer Survey (SM):** SM counter was used to detect radioactivity for various lithounits exposed in the area of research. For the purpose, scintillometer model, SM 141 D of ECIL Make was used. Scintillometer consists of a NaI(Tl) crystal coupled to PMT as detector. The power requirement is 4.5V. The voltage needed to drive the PMT is 1000V. Pulses are required to be amplified before they are shaped by the univibrator and then fed to the integrating circuit. The current reading in micro ammeter connected to this integrating circuit gives the idea of the radiation exposure level of the surveyed area.

**Salient features (ECIL Make scintillometer)**

(i) Two ranges are provided:
   (a) High Sensitivity 0.1 mR/hr FSD.
   (b) Low Sensitivity 1.0 mR/hr FSD.

   \[(\text{mR} = \text{milliroentgen})\].

(ii) Time constant = 7.5 sec.; (iii) Power requirement = \(3 \times 1050\)D Eveready cell (1.5V); (iv) Cell life = 25 hrs continuous use; (v) Weight = 3.5 Kg (with cells).

Scintillometer is calibrated to read exposure rate. First of all 10 to 15 readings are taken for background and their mean as well as standard deviations are determined. Then the reading is taken over the outcrop or any area of interest and then again 10 readings are taken. If the mean value of these reading is more or less than the mean value of background plus/minus 3 times the standard deviations, the value is considered as the anomalous (Bhaumik et al., 2004) The samples are then collected for accurate analysis of the radioactive content in the laboratory where samples area analyzed for \(\text{eU}_3\text{O}_8\), Ra (\(\text{eU}_3\text{O}_8\)), ThO\(_2\) and K by Four Channel Gamma Ray Spectrometry and by beta-gamma method to know the U\(_3\)O\(_8\) content, if \(\text{eU}_3\text{O}_8\) value more than 100.

1.9.3. **Four Channel Gamma Ray Spectrometry (4-Channel-GRS) of rocks:**

Rock samples contain radioactive elements U, Th and K\(^{40}\). U and Th have a long list of daughter products emitting so many gamma photons of different energies. K\(^{40}\) is mono energetic element emitting gamma photons of energy 1.46 MeV. U and Th have complex spectra. We select the energy where the interference from other elements is low as well as the relative abundance is good; 1.76 MeV for U (emitted by Bi\(^{214}\)) and 2.62 MeV for Th (emitted by Tl\(^{208}\)) are selected for purposes of spectrometry, which are universally accepted. The intensities of these characteristic
gamma radiations are proportional to the concentrations of the respective radioisotopes in the sample. Any detector has a finite resolution resulting in Gaussian shaped peaks. Hence, to get better counting statistics, 99% the photo peak is required to be covered; a window covering $3\sigma$ on both sides of the peak is fixed. Resolution is inversely proportional to the square root of the energy. The windows fixed are:

- $1.36 \text{ MeV} - 1.56 \text{ MeV}$ for K,
- $1.66 \text{ MeV} - 1.86 \text{ MeV}$ for U ($\text{Bi}^{214}$) and
- $2.42 \text{ MeV} - 2.82 \text{ MeV}$ for Th ($\text{TI}^{208}$).

Four channel gamma ray spectrometer instruments include a $5''\times4''$ NaI(Tl) crystal and PMT coupled assembly, pre-amplifier (Pre-Amp.), high voltage unit (HV Unit), spectroscopy amplifier (Spect. Amp.), four single channel analysers (SCAs), four counter timers and two nim (nuclear instrument module) bins for fixing SCAs and counter timer modules. The detector assembly is enclosed in a lead chamber of $4''$ thickness. Three SCAs are used for the three channels e.g., K, U and Th. The fourth channel ($400 \text{ keV} - 3 \text{ MeV}$) is used for counting of all the emitted gamma photons. This is for estimation of $\text{eU}_3\text{O}_8$, uranium oxide equivalent content of a sample determined irrespective of its individual content of Th, K$^{40}$ and U.

- **$\text{eU}_3\text{O}_8$ Estimation:**

The $\text{eU}_3\text{O}_8$ content of a sample is determined by the method of equivalence of gamma count between equilibrium uranium standard and that of the sample. The $\text{eU}_3\text{O}_8$ content of sample is related to the $\text{U}_3\text{O}_8$ content of the standard ($\text{G}_{\text{Std}}$) by the relation:

$$\text{G}_{\text{Sample}} = \frac{(\text{M}_{\text{Std}} \times \text{G}_{\text{Std}})}{\text{N}_{\text{Std}}} \times \frac{(\text{N}_{\text{Sample}}/\text{M}_{\text{Sample}})}{};$$

$\text{M}_{\text{Std}}$ and $\text{N}_{\text{Std}}$ are the mass and net rate of gamma count due to standard. $\text{N}_{\text{Sample}}$ and $\text{M}_{\text{Sample}}$ are the corresponding quantities for sample.

- **Estimation of U, Th and K:**

In the laboratory, the windows are setup using $^{137}\text{Cs}$ and $^{60}\text{Co}$ standards. Known $\text{U}_3\text{O}_8$, ThO$_2$ and K$_2$O standards are used for calculating stripping factors and sensitivity factors. Then the samples are counted for a fixed time [3000 sec for low grade samples (e.g., less than 100 ppm of $\text{eU}_3\text{O}_8$) and 600 sec for high grade samples] and using the above formulae for U, Th and K; their concentrations are calculated.
• **Precision of Estimates:**

Measurement of the rate of gamma count will have some fluctuation associated with it, which is called natural fluctuation. Radioactivity is a truly random process that follows Poisson statistics. Hence the counts we observe will have some fluctuation in them around the mean value. The quantity $\sigma/\sqrt{n}$ is known as standard error. Considering all these factors and the background observed in each channel, the minimum reportable grades are calculated. They are found to be 2 ppm of eU$_3$O$_8$, 10 ppm of ThO$_2$, 5 ppm of Ra (eU$_3$O$_8$) and 0.5\% of K at 1\% error level of 10\%.

• **Beta-Gamma Method:**

Gamma ray spectrometric method for assaying samples by using characteristic gamma emissions of $^{208}$Tl$_{81}$ (2.62 MeV), $^{214}$Bi$_{83}$ (1.76 MeV) and $^{40}$K$_{19}$ (1.46 MeV) provides thorium and potassium concentrations without any ambiguity as thorium for all practical purposes remains in equilibrium (only 50 years required for Th to attain equilibrium with its daughters). But for uranium it is not the case as the uranium decay series is shown to be subdivided into five separate groups named as (i) uranium group ($^{238}$U$_{92}$ $\rightarrow$ $^{234}$U$_{92}$); (ii) thorium isotope ($^{230}$Th$_{90}$); (iii) radium isotope ($^{226}$Ra$_{88}$); (iv) radon group ($^{222}$Rn$_{86}$ $\rightarrow$ $^{210}$Pb$_{82}$) and (v) lead group ($^{210}$Bi$_{83}$ $\rightarrow$ $^{206}$Pb$_{82}$).

The elements within each group tend to remain in equilibrium with the parent of the group, although the parent of the group may not itself be in equilibrium with the parent of the decay series, $^{238}$U$_{92}$. The length of time required for secular equilibrium to become established is dependent on the half-life of the longest-lived daughter in the decay chain below the parent. When the U–Series is in disequilibrium gamma ray spectrometric measurement based on 1.76 MeV may give only concentration of Ra (eU$_3$O$_8$) but it cannot provide the actual concentration of U$_3$O$_8$. Hence measurement of beta emission is required. In the following we see how both total beta and total gamma measurements may lead to estimation of actual concentration of uranium.

By simultaneous beta and gamma counting it is possible to estimate the quantity of uranium irrespective of its state of equilibrium using the equation

$$U = U'_{\beta} (1 + a) - a U'_{\gamma}$$

$U'_{\beta}$ and $U'_{\gamma}$ are estimated based on the total beta and total gamma counting respectively uranium. The other constant ‘a’ is determined experimentally using a
disequilibrium standard of value e.g., 0.84% of actual U$_3$O$_8$ and 0.38% of Ra(eU$_3$O$_8$) of mass 55.75617 gm. The formula for calculating ‘a’ is given by;

$$\text{a} = (\text{U} - \text{U}_\beta') / (\text{U}_\beta' - \text{U}_\gamma')$$

U$_\beta'$ is % eU$_3$O$_8$ determined by total $\beta$ counting and U$_\gamma'$ is the same determined by total $\gamma$ counting. When thorium is present in the ore its effect is similar to that of an excess of radium. It is seen that if Th/U ratio is greater than 10, a fairly close result is even possible to obtain.

1.9.4. X-Ray Fluorescence Analysis (XRF)

Analysis were carried out with XRF, Philips model PW 1410 at XRF Lab of AMD, DAE at Hyderabad. Major oxides and trace elements were analyzed in QPC and quartzites powdered samples. Major oxides like Si, Ti, Al, Fe (Ferric, Total), Mg, Mn, Ca, Na, K and P were determined by XRF while trace elements includes V, Cr, Co, Ni, Zn, Ga, Rb, Ba, Sr, Y, Zr, Nb, Ce, Pb, Th and U. However, due to low content of Na in QPC, 21 samples of QPC and 15 samples of IOG quartzite were subjected to determination of Na by flame photometry and Hf, Zr, Th and Ce by ICP-MS. U content were also determined by ICP-MS due to lack of matching standard in XRF Lab. Loss on ignition (LOI) were determined at Chemistry Lab, AMD, Jamshedpur.

1.9.5. Inductively Coupled Plasma - Mass Spectrometry (ICP-MS):

Rare earth elements, U and Th in 21 samples of QPC and 15 samples of IOG quartzites have been determined by ICP-MS, model Platform XS at AMD Chemistry Lab., Hyderabad. The standards used are SY-2, SY-4, and MRG-1(Canadian certified reference material project). The method determination limit for La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu and Y are 0.11, 0.24, 0.04, 0.37, 0.16, 0.17, 0.06, 0.03, 0.05, 0.01, 0.02, 0.01, 0.04, 0.01 and 0.14 ppm while for Th and U are 0.21 and 0.22ppm respectively. However instrumental detection limit in ppt are 2.2, 4.8, 0.8, 7.3, 3.1, 3.4, 1.1, 0.54, 0.93, 0.12, 0.49, 0.18, 0.82, 0.19 and 2.8 ppm respectively for La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu and Y and 4.1 & 4.3 ppm for Th and U. The % error in determination are 2 for La, Ce, Pr, Dy,
and Y; 1 for Nd, 3 for Sm, 4 for Eu, Gd and Tb; 5 for Er, Tm and Yb; 7 for Ho, 10 for Lu. But for both Th and U error in determination are 2%.

In addition to above elements, Ag, Zr and Hf were also determined by ICP-MS. The instrumental determination limit and method determination limit for Ag, Zr and Hf are 1ppb, 3ppb, 1ppb and 1ppm, 3ppm and 1ppm respectively while error in their determination are 20%.

1.9.6. Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP-AES)
Scandium (Sc) was determined by ICP-AES model- Jobin Yvon (France) Ultima-2 at AMD Chemistry Lab; Hyderabad. Standard used for Sc is aqueous Sc₂O₃ (1ppm, 10ppm). Sc was measured at 361.384nm. Instrument detection limit for Sc is 0.9ppb, method detection limit is 1ppm and error in determination is 5%.

1.9.7. Graphite Furnace – Atomic Absorption Spectrometry (GF-AAS)
(GF-AAS) analysis have been carried out on few selected samples of QPC using AAS-graphite furnace at chemical Lab., AMD, DAE, Jamshedpur and Hyderabad. Au was determined by Analytik Jena ZEEnit 650 model of GF-AAS at AMD, Chemistry Lab., Hyderabad and Analytik Jena ZEEnit 700 model of GF-AAS. At Chemistry Lab, AMD, Jamshedpur. Their instrumental determination limit, method determination limit and error in determination are 4 ppb, 20 ppb and 10% respectively. Bur for Analytik Jena ZEEnit 700 model, method detection limit is 10ppb and error is 10%.

1.9.8. Flame Photometer
Na₂O in QPC and quartzites were determined by flame photometer at Chemistry Lab, AMD, DAE, Hyderabad. Na₂O was determined by Systronic Flame Photometer 128 model having 0.1ppm instrument determination limit, 100 ppm (0.01%) method determination and error in determination is 5%.

1.9.9. Electron Probe Micro-Analyzer (EPMA)

EPMA analysis on uraninite, pyrite, monazite, zircon and galena were carried out using Electron Probe Micro Analyzer (EPMA) Model SX-50, manufactured by M/s. CAMECA, France at EPMA Lab of AMD, Hyderabad. Elements like U, Th, Pb, Si,
Ca, Ti, Y and other RE₂O₃ were analyzed in uraninite and monazite grains. It has three vertical and one inclined linear focusing wavelength dispersive spectrometers fitted with LIF, PET, TAP and pseudo crystals (PC1 & PC2) diffracting crystals. The system is controlled on and off line by Sun Micro System under Unix environment. The laboratory undertakes non-destructive microdomain (1 micron diameter) near surface, qualitative and quantitative analyses of elements with atomic number 5 (Boron) and above with detectable limits generally of 0.01%.

1.9.10. Scanning Electron Microscopy - Energy Dispersive Spectrometry (SEM-EDS):

This facility was utilized at the Department of Geology, Presidency University, Kolkata. The polished thin section prepared from epoxy at AMD, Petrology Lab, Jamshedpur were later on coated with carbon and then studied by SEM-EDS at Presidency University, Kolkata. The model used is SEM TESCAN VEGA model which was attached with OXFORD EDS. Accuracy of calculations for EDS data is at semi-quantitative.

1.9.11. Analysis of Platinum Group of Elements (PGE):

A total of ten samples including five QPC and five IOG quartzites were analyzed for PGE at Chemistry Laboratory, AMD, DAE, Hyderabad by Ni-S fire-assay method. All PGE including Pt, Rh, Ir, Re etc. have been analyzed.