Investigation of Neutron Based Techniques for the detection of Illicit Materials and explosives


Laser and Neutron Physics Section
Bhabha Atomic Research Centre
Trombay, Bombay, INDIA
image@barc.gov.in
FAX:0091-22-25515050

Abstract
The paper summarizes the work done during the Nov 2007 - November 2009 under the research contract No.: (F1.10.12) on the “Neutron based techniques for the detection of illicit materials and explosives". Most of the work planned during this period have been completed. The overall impact of CRP on our ongoing work has been quite encouraging and the interaction with other participant has resulted in several new developments.

INTRODUCTION:
During second RCM the work plan for the period during Nov 2007-Nov 2009 under this CRP has been as follows:

(a) Extension of simulation studies of tagged neutron and PTFNA methods to vehicle borne explosive detection
(b) Feasibility study of photoneutron source based explosive detection: a Simulation study
(c) Use of improved detection logic and data analysis technique for explosive detection with neutrons

Most of the goal setout for this period of 2007-2009 under this CRP have been achieved with some additional work on initiating experiments to verify these simulation results using an inhouse D-D and D-T neutron generator. We highlight here some of the major work carried out during 2007-2009 under this CRP.

1. Simulation of neutron based explosive detection in a small vehicle: Neutron based technique for explosive detection inside small vehicle have been explored using various techniques including TNA, Tagged neutron or , FNA etc. We explore
the relative merits and limitations of such a detection system using (a) PFTNA (Pulsed Fast Thermal Neutron Analysis) technique and (b) Tagged neutron or associated particle Imaging (API) technique. In PFTNA system Neutron pulses on the order of 1-10 microseconds are produced by neutron generators for analysis of gamma spectrum produced by fast and slow neutron signals. Detectors are gated to measure the inelastic gamma signal due to fast neutrons during the neutron pulse and also measure those due to capture of neutrons between pulses. In between pulses, the detector is gated. The tagged neutron or API on the other hand is based upon the physics of the D-T reaction, wherein the deuterium and tritium collide and produce a neutron at 14.1 MeV and an alpha particle at 3.5 MeV. In order to conserve momentum, both products are emitted 180° from each other, and therefore a multipixel alpha detector on the generator can be used to tag the neutron’s emission time and direction of travel. This information is used to gate the detectors to enhance the signal to background ratio. A time of flight analysis is used to determine the location in the target. This spatial localization of signal results in much improved signal to noise ratio resulting in better sensitivity of detection. Simulation studies for these two methods i.e. PFTNA and API (tagged neutron) have been carried to study the potential and limitations of these techniques.

1.1 Use of PFTNA technique for detection of explosive hidden in a vehicle: Simulation Geometry

A simple geometry as shown in Fig 1 was simulated to mimic the actual vehicle borne explosive detection system. The overall dimensions of the vehicle are 250cm (L) x 150 cm (W) X 150 cm (Ht). The explosive is assumed to be kept in the back compartment (Dickey) of this car just above the fuel tank. The neutron generator (14 Mev) was kept below the dickey while the two gamma detectors were placed symmetrically on either of the Dickey as shown in Fig 2

![Figure 1 Schematic of vehicle used in simulation studies](image)

The simulations were tested in two different configuration of explosive packing inside the car dickey. In one configuration the fuel tank and concealed explosive were configured as shown in Fig 3. The two were separated in direction perpendicular to the length of car. The explosive dimensions were 25 cm (L) x 50
cm X40 cm and length was varied to account for different quantity of explosive material. In another geometry the explosive was kept above the simulated fuel tank having dimension 140 cm (l) x 50 cm (w) x 5cm(ht). The height of the explosive volume was kept variable to increase the explosive quantity (Fig 4).

**Figure 2** Top-view of the vehicle along with the detectors

**Figure 3** Cross-section of the rear part of the car where explosive & fuel tank are side by side
1.1.1 Results of Simulation Using PFTNA Technique

As described earlier the PFTNA technique involves the use of a pulsed neutron generator and fast neutron reactions i.e. \((n, n'\gamma)\) are counted during pulse ON conditions while thermal neutrons reactions i.e. \((n, \gamma)\) reactions are counted during pulse OFF condition. For simulation purpose the pulse width of neutron generator was selected to be 10\(\mu\)s and it was assumed to be operated at 200 Hz.

(a) Fast Neutron induced gamma Spectrum:

First we have simulated this technique for the geometry of explosive as shown in Fig.3. The simulations were carried out for variable quantity of explosive and the explosive quantity varied from 50 Kg to 200Kg. A plot of relative counts in the detector volume during pulse ON conditions is shown in the following Figure 5. The figure shows presence of signature C (4.43 MeV), N (5.11MeV) and O (6.13MeV) very clearly. To distinguish the effect of variation of mass in this configuration more clearly the gamma spectrum for each mass of explosive is plotted separately and compared with the background (Fig.6). The presence of nitrogen can be used to distinguish the explosives with other materials. The detector count shows an initial increase as the quantity of explosive increases reaching a peak value and then decreases. This effect can be attributed partly to thermalization of neutron with increasing thickness of explosive and partly due to attenuation affect of both gamma and interacting neutron. The decrease is more
prominent at low photon energies and decrease markedly at high photon energies.

Figure 5 Plot of detector relative counts as a function of gamma energy in one of the detectors during generator ON state (50Kg-200kg RDX)

Figure 6 Plot of detector counts as a function of gamma energy in one of the detectors during generator ON state (50Kg, 100 Kg and 200 Kg RDX)

Similarly simulations for fast spectrum were repeated with the other geometry as described in fig 4. Fig 7 shows the relative gamma counts in the detector for different amount (50 kg, 100 kg, 150 kg, 200 kg) of explosive configured in flat geometry. We have also plotted the effect of background i.e. detector count without any explosive. To get a clearer picture of the effect of explosive quantity in its detection the plots for each of the quantity of explosive (50 kg, 100 kg, 200 kg) is plotted separately and compared with the background for the respective cases. (Fig 8).
It can be seen that there is presence of carbon peak in the background which can be attributed to the presence of fuel tank and polythene used to cover the explosive material from top.

![Graph](image1.png)

**Figure 7** Plot of detector relative counts as a function of gamma energy in one of the detectors during generator ON state (50-200kg)

![Graph](image2.png)

**Figure 8** Plot of detector relative counts as a function of gamma energy in one of the detectors during generator ON state (50kg, 100 Kg, 200Kg)

(b) Thermal Neutron induced Gamma Spectrum:

To get the thermal spectrum, the counts were collected in the detector in generator off condition. Following **Figure-9** shows the detector relative counts during the neutron generator pulse OFF state. The presence of 2.2Mev and 7.6Mev due to capture in the Hydrogen and Iron matrix can be easily seen. The weak signal of 10.83 MeV photon due to capture in nitrogen present in RDX can also be detected.
© Study of the effect of surrounding material:

We have studied the effect of background due to surrounding material on a fixed quantity (100Kg) of explosive. For simulation purpose, three different kinds of background with identical bulk density were considered (ρ=0.2gm/cc) i.e. metallic scrap, polythene matrix, spruce wood scrap. Following figure shows the result of simulation studies for all the three different cases. We have considered only the fast spectrum for the current our analysis. The fast neutron spectrum (Fig 10)shows that for nitrogenous explosive the presence of nitrogen in the fast spectrum establishes its presence. The metal and polythene background do not affect the nitrogen signal however the presence of spruce wood as background materials does affect the signature of nitrogen in fast spectrum.

Figure 9 Plot of detector relative counts as a function of gamma energy in one of the detectors during generator OFF state
The effect of surrounding material was also studied for the thermal spectrum. Following figure (Fig-11) shows the relative counts within the back dickey volume during the neutron generator pulse OFF state. The presence of 2.2Mev and 7.6Mev due to capture in the Hydrogen and Iron matrix can be easily seen. The weak presence of 10.83 MeV photon due to capture in nitrogen present in RDX can also be detected.

1.1.2 Results of simulation with Tagged Neutron technique

Simulations have been carried out for Vehicle borne explosive detection system using tagged neutron technique as well. As stated in introduction, this technique works by detection of \((n, n'\gamma)\) signal using time of flight methods in coincidence with emitted alpha particle. The presence or absence of explosive can be detected by calculating the ratio such as C/O, C/N etc. For simulation purpose the spectrum has been calculated in a predefined time window which decided by speed of 14MeV neutron and thickness of voxel. In the first attempt the geometry as shown in fig 4 was attempted. As the thickness was only 5cm (for 60kg), the tagged time interval of 1 ns was selected. The presence of important signature due to Oxygen and Nitrogen could not be detected in this configuration. We conjecture that for these geometrical arrangement detection of explosives using the tagged neutron
technique is not possible due to low time interval of 1ns. However as shown in our previous results the PFTNA method could successfully detect the presence of nitrogen.

For rest of the results alternate arrangement of rear part of car as shown in fig 3 was used. In this case the thickness of the explosive was about 25cm and the width was varied to change the quantity of the explosive material.

![Figure 12 Plot of detector count for variable quantity of explosive material](image)

Figure 12 shows the result of plot of detector flux for different quantity of explosive materials. One of the advantages of tagged neutron method is that presence of small quantity (25 kg) of explosives can also be detected quite comfortably.

(a) **The effect of attenuation and thermalization can be seen in the case of tagged neutron also.** As seen from the figure 13, the detector counts first increases as the quantity of explosive increases and there is saturation effect and if the quantity is increased further the counts start decreasing due to self attenuation within the matrix itself.
We have studied the effect of background on a fixed quantity (100 kg) of explosive. For simulation purpose there different kinds of background with identical bulk density were considered ($\rho=0.2\text{ gm/cc}$) i.e. metallic scrap, polythene matrix, spruce wood scrap. Following figure (Fig 14) shows the result of simulation studies for all the three different cases. As seen from these plots the tagged neutron technique is able to extract the signals even in presence of different background material. This shows that for the geometry under consideration the Tagged neutron technique delivers better results as compared to the PFTNA.

**Figure 13 plot of detector counts for different masses of explosive material**

**Figure 14 Plot of detector count in presence of metallic scrap ($\rho=0.2\text{ gm/cc}$) polythene ($\rho=0.2\text{ gm/cc}$) and spruce wood ($\rho=0.2\text{ gm/cc}$) background**

**2. Simulation results using photoneutron Source**

Neutron induced gamma activation has been used to identify the explosive based on their nitrogen content. The portable neutron sources such as Am-Be or Cf have been routinely used for this purpose. However handing of radioactive sources always poses a security or health hazard even if used in small quantity. With the advancement in accelerator based technologies, one can effectively used these accelerators to produce and tailor energy of neutrons as per the requirement. We have already designed such a source using microtron based accelerator and using
Be\textsuperscript{9} as a photoneutron source. These sources offer ease, hazard-free operation and can be used for both gamma scanning as well as neutron based studies. A simulation study was done to explore the possibility of using such an source for detecting the presence of nitrogen based explosives using 10.83 Mev gamma signature due to capture of thermal neutrons in nitrogen. The following Fig-15 shows the geometry used for simulation of a accelerator based neutron source. The dimension of Cargo for simulation was chosen to be 1.0 m (W) X 2.5m(L) X 2.5m(Ht). We have assumed gamma detectors (25cm(L) and Dia=12.5cm) for detecting the capture reactions (22(reflection)+22(transmission)). Lead collimators were used to localize the region of gamma emission to improve the detection and minimize the background.

![Figure 15 Schematic of cargo based explosive detection system](image)

The simulation results with two different background material i.e. material scrap and spruce wood is shown in following figures(Fig 16). The results show that the 10.83 Mev capture line is easily detected and can be used to ascertain the presence of explosive material.
3. Experiments with D-D neutron generator bulk material and contraband analysis using neutron capture prompt gamma ray detection: We have initiated an experimental program for developing neutron based explosive detection technique. As an initial step, an existing neutron generator at Purnima laboratory at BARC is being modified to work both as (a) D-D neutron generator (b) D-T neutron generator by changing the target. Presently the generator is working in continuous mode. However it is planned to modify it to produce repetitive pulses of micro-second neutron. The generator has been designed to produce $10^8$ n/s in D-D mode and about $10^{10}$ n/s in D-T mode. Using this generator in D-D mode, we have carried out a series of experiment on a variety of samples by collecting the data for prompt gamma capture. These experiments are designed to test the sensitivity and utility of different types of detectors suited for explosive detection application. This work has been carried out to prove the feasibility of using DD based neutron source for bulk material and contraband analysis using neutron capture prompt gamma ray detection. Initial experimentations have been performed using this DD neutron generator with proper thermalizer for the feasibility studies of detection of hydrogen and nitrogen capture lines (at 2.224MeV and 10.83MeV respectively) in Urea (CO(NH$_2$)$_2$) and chlorine capture lines (6.11 MeV) in salt (NaCl). These elemental compositions were specifically chosen as these elements (N, Cl, H) are found in most of the explosives and narcotics used for destruction purposes. They are only representative to demonstrate the feasibility.

3.1 Neutron Generator: A neutron generator has been made operational at BARC using Cockcroft-Walton type accelerator in which D$^+$ ions are accelerated. The main specification of the generator are given in table 1 and the photograph of neutron generator is given in fig.17. The neutron generator was operated in D-D mode with a neutron flux of $3 \times 10^7$ neutrons/sec. We have used graphite as thermalizer instead of polythene to avoid contamination from hydrogen line of polythene. We have stacked layers of 50mm graphite blocks as thermalizer in
between the source and the sample. A 75mm X 75mm BGO (Bi₄Ge₃O₁₂) detector was placed 100 mm below the sample. The experimental arrangement is shown in figure 18. The BGO was shielded all around except the sample side using 50m lead (Pb) blocks. The output of the BGO after amplification was collected using PC based MCA. Experimentations were carried out separately for both background (without sample but with neutron ON) and with sample.

Fig. 17 Neutron Generator at Purnima Lab, BARC

<table>
<thead>
<tr>
<th>Type of Machine</th>
<th>DC Accelerator</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Voltage</td>
<td>50-400 KV; Cockroft-Walton multiplier</td>
</tr>
<tr>
<td>Ion Source</td>
<td>Radio Frequency Ion Source</td>
</tr>
<tr>
<td>Type of Beam</td>
<td>D+ Ion</td>
</tr>
<tr>
<td>Extraction Voltage</td>
<td>0-5 KV</td>
</tr>
<tr>
<td>Focusing Voltage</td>
<td>0-16 KV</td>
</tr>
<tr>
<td>Pressure</td>
<td>1 x 10⁻⁶ mbar</td>
</tr>
<tr>
<td>Beam Current</td>
<td>150 µA measured at Faraday cup</td>
</tr>
<tr>
<td>Target</td>
<td>Deuterium/Tritium absorbed in Titanium on a 1 mm thick and 30 mm dia. Copper disk</td>
</tr>
</tbody>
</table>
| Neutron Yield       | 3 x 10⁷n/s for (D-D) reaction  
                     | 3 x 10⁹n/s for (D-T) reaction (Expected) |
3.2 Experiments on PGNAA: A number of samples such as urea, salt, cement, coal were investigated for the detection of elemental fingerprints. Some of the results are discussed below.

(a). Sample: Urea (CO(NH\(_2\))\(_2\)): We have used 4Kgs of urea for irradiation. Figure 2 shows the background as well as the nitrogen capture photopeak (10.829MeV) and its single escape peak (10.318MeV) and the hydrogen capture line. The inset graph depicts the nitrogen photopeak as a clean signal with no background contamination. The apparent slight drift in the peak position can be attributed to the drift in BGO electronics for the said acquisition time. Nitrogen single escape peak does not posses the same quality as it’s photopeak because of the presence of the neutron induced 10.2MeV line of germanium (\(\gamma_{73}\)Ge) present in BGO [6].
(b). **Sample: Salt (NaCl)** : Molecular weight: 58.44 gm, Density: 2.165gm/cc
: Composition: Na – 39.34%, Cl – 60.66%.

The main aim to carry out the detection chlorine (Cl) capture lines in salt is due to fact that chlorine based compounds form part of narcotics. Since Cl has more neutron capture cross-section (43b) than Na the capture gammas of Cl are much more detectable than Na. In a data collection time of 1200 seconds we could detect 4 Chlorine photo-peaks and one of their escape peaks. Figure 20 clearly shows the lines with respect to the background.

![Image showing Chlorine peaks](image)

Figure 20. Left graph shows the Chlorine peaks (labeled in MeV energy): Cl–6.619MeV and Cl – 6.11 MeV along with its single escape peak Cl’ – 5.599MeV and double escape peak Cl” – 5.08MeV. The right hand side graph shows the other Cl lines, 1.16MeV and 1.95MeV.

These are however only a feasibility study which is a part of series of such experiments being planned using DD neutron generator for contraband and benign material detection in bulk. The above results prove the utility of such source for the generation of capture lines in the elements discussed.

4. **Detection logic and data analysis technique**: The main signatures of carbon, oxygen, nitrogen, hydrogen which are present in explosives also present in many benign substances. Any such neutron based detection system generates huge amount of data due to presence of surrounding materials which are difficult to interpret without some sort of decision making procedure. One of the main aims of such decision making procedure is to minimize false positive and false negative. We have studied the feasibility of a trained neural network to determine the presence of explosives and/or contraband materials based on the elemental ratio signatures from FNA. The elemental signatures like C/N, N/O, C/O for different explosives were obtained from the data available in literature and they were used in a neural network program to predict the presence of explosives and drugs. At present only a theoretical simulation model has been developed. We are planning to test these models using Montecarlo and experimental result.

4.1 **ANN Model:**
A feed forward multilayer ANN comprising of one input layer, one hidden layer and one output layer forms the architecture for our problem. The input nodes are connected through the hidden nodes to the output nodes. The input layer consists of a set of variables \((x_1, x_2, x_3, \ldots, x_n)\), and the output layer consists of set of activation values \((o_1, o_2, o_3, \ldots, o_l)\). If the target output is to predict only one variable as a function of the variables \(x_i\)'s, then the output is a single variable \(o\). The relationship between these associations can be represented as follows:

\[
    o = C_o + \sum_{i=1}^{N} C_i \phi_i(x_1, x_2, x_3, \cdots, x_n),
\]

where, \(\phi\) are nonlinear polynomial functions. Instead of modeling an explicit functional form, ANN relates \(o_i\) with \(x_i\) using a network of connection weights between pairs of nodes of adjacent layers. The node sums the product of the inputs and the connection weights from the nodes of the previous layer and then limits it by a nonlinear threshold function. The weighed sum of inputs for the \(j^{th}\) node in layer \(k\) is given by

\[
    \text{net}_j = \sum_i w_{ij}^{(k)} x_i^{(k-1)} + b_j^{(k)}
\]

where \(w_{ij}^{(k)}\) is the connection weight between the \(i^{th}\) node in the \(k-1\) layer and \(j^{th}\) node in the \(k\) layer, \(x_i^{(k-1)}\) is the output from the \(i^{th}\) node in the \(k-1\) layer, and \(b_j^{(k)}\) is the bias associated with the \(j^{th}\) node of layer \(k\) and it produces an effect similar to adjusting the threshold of the processing node. For calculating the output of a node, the weighed sum of inputs available from eqn (2) is processed using a nonlinear activation threshold function. The tan-sigmoid function was used for this problem.

We have used backpropagation algorithm for the training of feed-forward neural network. This algorithm for neural networks seeks to find weights, such that given an input pattern from the training set of pairs of input/output patterns, the network will produce the corresponding output of the training set. When supplied with a previously ‘unseen’ input, the

![Feed-forward network used](image-url)
ANN tries to generalize the characteristics and produces the output close to the nearest match. The network’s response is based on its ability to learn through the learning algorithm. The fundamental relationship between input and output pairs forms the training set. The backpropagation algorithm attempts to minimize the overall root mean square error between the desired and actual output values for all the output nodes over all input patterns by iteratively adjusting the weights.

4.2 Results and discussion:

A schematic of the feed–forward network used for this problem is shown in Fig.21. We have used 10 input parameters (namely, C, H, N, O, Cl, C/N, N/O, C/O, Cl/C, Cl/H). A simple test case with elemental weight ratios was carried out to test the feasibility of neural network analysis for this problem. 29 patterns corresponding to different explosives and drugs were used for training. The input pattern is shown in Table 2 and their chemical composition is tabulated in Table 3.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>H</th>
<th>N</th>
<th>O</th>
<th>Cl</th>
<th>C/N</th>
<th>N/O</th>
<th>C/O</th>
<th>Cl/C</th>
<th>Cl/H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>5.04</td>
<td>35.01</td>
<td>59.97</td>
<td>0</td>
<td>0</td>
<td>0.58379</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>29.28</td>
<td>2.46</td>
<td>22.76</td>
<td>45.5</td>
<td>0</td>
<td>1.28647</td>
<td>0.50022</td>
<td>0.64352</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>16.22</td>
<td>2.72</td>
<td>37.84</td>
<td>43.22</td>
<td>0</td>
<td>0.42865</td>
<td>0.87552</td>
<td>0.37529</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>12.91</td>
<td>5.42</td>
<td>30.1</td>
<td>51.58</td>
<td>0</td>
<td>0.4289</td>
<td>0.58356</td>
<td>0.25029</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>9.84</td>
<td>4.95</td>
<td>45.89</td>
<td>39.32</td>
<td>0</td>
<td>0.21443</td>
<td>1.16709</td>
<td>0.25025</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>34.62</td>
<td>5.81</td>
<td>13.46</td>
<td>46.11</td>
<td>0</td>
<td>2.57207</td>
<td>0.29191</td>
<td>0.75081</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>16.45</td>
<td>1.38</td>
<td>38.36</td>
<td>43.82</td>
<td>0</td>
<td>0.42883</td>
<td>0.8754</td>
<td>0.3754</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>5.3</td>
<td>44.2</td>
<td>50.09</td>
<td>0</td>
<td>0</td>
<td>0.88241</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>15.94</td>
<td>1.78</td>
<td>18.59</td>
<td>63.69</td>
<td>0</td>
<td>0.85745</td>
<td>0.29188</td>
<td>0.25027</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2. Input pattern for ANN training##
In the hidden layer 35 neurons were used and tan-sigmoid activation function defined in [-1, 1] was used. In the output layer, 29 neurons were used, each representing one material given in Table 2 and tan-sigmoid activation function used was.

Table 3. Chemical compositions of the materials used for the simulation

<table>
<thead>
<tr>
<th>Explosives/drugs</th>
<th>Elementary Composition</th>
<th>Explosives/drugs</th>
<th>Elementary Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ammonium nitrate</td>
<td>H₄N₂O₃</td>
<td>15. Picric acid</td>
<td>C₆H₈N₃O₇</td>
</tr>
<tr>
<td>2. Ammonium picrate</td>
<td>C₆H₈N₃O₇</td>
<td>16. Tetryl</td>
<td>C₆H₆N₈O₄</td>
</tr>
<tr>
<td>3. RDX</td>
<td>C₃H₆N₆O₆</td>
<td>17. Tetryl</td>
<td>C₆H₆N₈O₄</td>
</tr>
<tr>
<td>4. Ethylenediamine dinitrate</td>
<td>C₂H₄N₈O₆</td>
<td>18. Trinitrobenzene</td>
<td>C₆H₃N₃O₆</td>
</tr>
<tr>
<td>5. Guanidine nitrate</td>
<td>CH₇N₃O₃</td>
<td>19. TNT</td>
<td>C₂H₃N₂O₄</td>
</tr>
<tr>
<td>6. HMTD</td>
<td>C₆H₁₂N₂O₆</td>
<td>20. TAGN</td>
<td>CH₃N₃O₃</td>
</tr>
<tr>
<td>7. CL20</td>
<td>C₃H₅N₃O₁₂</td>
<td>21. TATB</td>
<td>C₆H₆N₁₂O₆</td>
</tr>
<tr>
<td>8. Hydrazine nitrate</td>
<td>H₂N₂O₃</td>
<td>22. Dynamite</td>
<td>-</td>
</tr>
<tr>
<td>9. Mannitol hexanitrate</td>
<td>C₆H₁₂N₂O₁₈</td>
<td>23. C4</td>
<td>C₂H₈N₄O₄</td>
</tr>
<tr>
<td>10. Monomethylamine nitrate</td>
<td>CH₄N₂O₃</td>
<td>24. Heroin</td>
<td>C₂₁H₂₂NO₅Cl</td>
</tr>
<tr>
<td>11. Nitrocellulose</td>
<td>C₃H₅N₃O₁₁</td>
<td>25. Cocaine</td>
<td>C₁₇H₂₁NO₄Cl</td>
</tr>
<tr>
<td>13. Nitrotiazolone</td>
<td>C₂H₇N₃O₃</td>
<td>27. Cocaine</td>
<td>C₁₇H₂₁NO₄</td>
</tr>
<tr>
<td>14. PETN</td>
<td>C₃H₅N₆O₁₂</td>
<td>28. Mustard Gas</td>
<td>-</td>
</tr>
<tr>
<td>15. Picric acid</td>
<td>C₂H₅N₃O₇</td>
<td>29. Sarin</td>
<td>-</td>
</tr>
</tbody>
</table>

The ANN model was trained with adjusting weights for about 100 epochs to better the performance value as near to zero. The performance curve is shown in figure 22. Now after training the data vector for RDX and cocaine was tested and the output is shown in Figure 23. The same was repeated with the introduction of 5% and 10% random error. These are shown in figure 24 and figure 25.
Figure 22. Plot of MSE vs number of epochs to obtain a performance ~ e-8.

Fig. 23. ANN output for simulated input corresponding to RDX and cocaine

Fig. 24. ANN output for simulated input with 5% random error corresponding to RDX and cocaine
Our initial efforts were aimed at utilizing an ANN and train it to help us make a decision on the threat perception possibility with the input data as per the percentage elemental weight of different illicit materials. With the introduction of errors the fuzziness enhances and we will be putting our effort to model the ANN to perform better. Also we plan to generate simulated spectrums using probabilistic methods and test the ANN to better the output. Finally monte carlo based data nad actual experimental models would be tested.

**Conclusion:** The CRP has resulted in a very large amount of work covering all the aspects of CRP. Most of the objectives have been fulfilled. Some of the work is still remaining particularly in the area of Neural network and experiments and fissile material detection. There will hopefully be more result towards the end of CRP, The CRP has given impetus to explore many aspects of explosive detection using neutrons.