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Ben-Gurion University of the Negev
Nuclear Engineering Unit

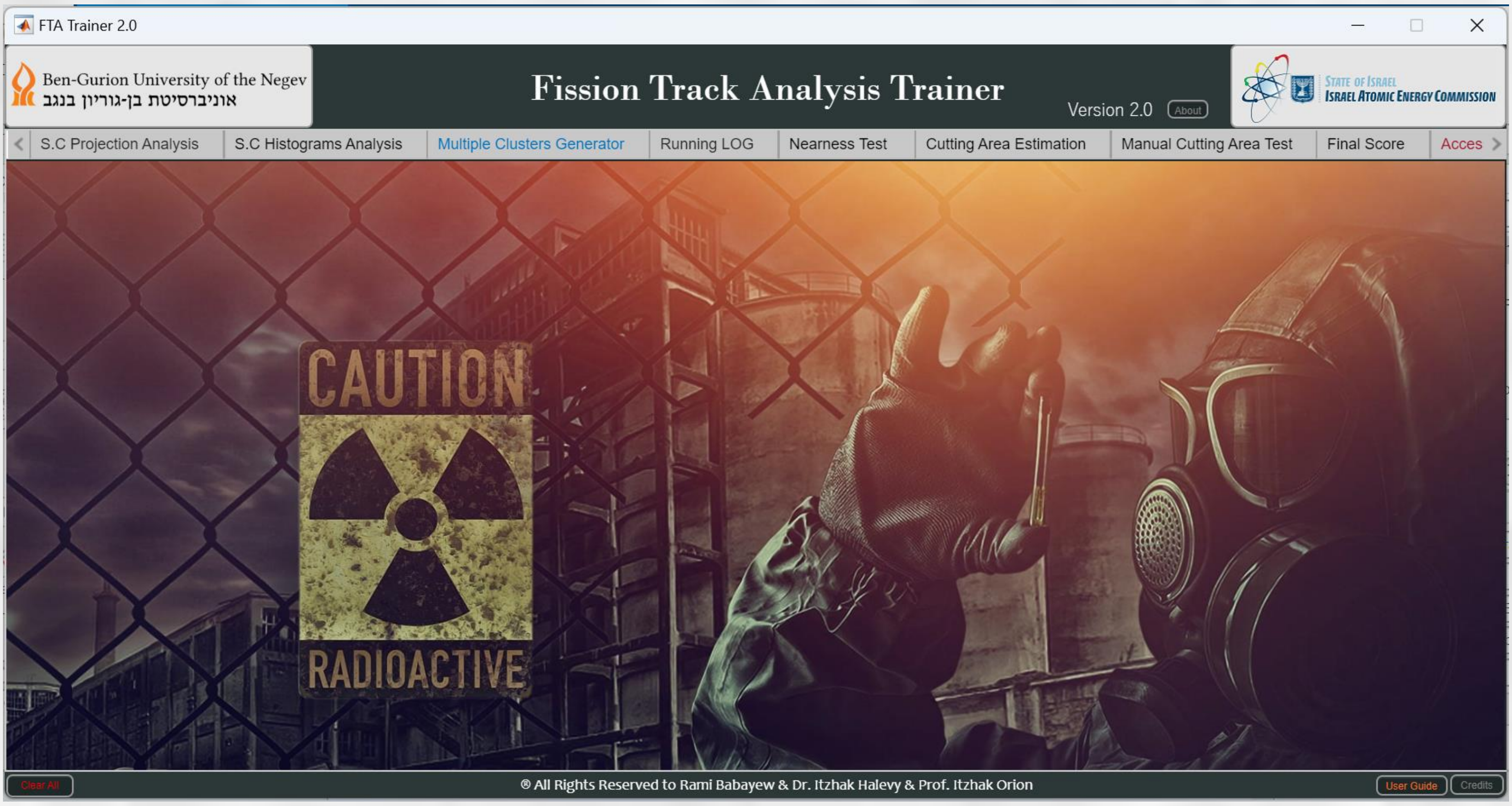
The Faculty of Engineering

Nuclear Engineering Unit

Fission Track Analysis (FTA) Trainer

Application Version 2.0

- User Guide -



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29 January 2024

Table of Contents

1. Introduction

1.1. Overview

Variants of the Fission Track Analysis (FTA) methodology have been used for decades in many fields, such as nuclear forensics, safeguards investigations, radiometry, geology, and cosmology. A fission-track (FT) is a microscopic-scale radiation-damaged site, which can be induced on a solid-state nuclear track detector – SSNTD (e.g., polycarbonate sheet, mica, etc.) by a radiant array of nuclear fissions of a single particle under thermal neutron flux. In nuclear forensics, the tracks are developed and made visible by chemical etching of the SSNTD. Since an FT cluster arises from a single particle, it exhibits a stochastically round shape, which defines both the presence and the location of a POI. When detected with transparent or translucent SSNTDs, FTs have optical characteristics that enable their visualization and identification using transmitted or reflected light microscopy.

The FTA Trainer is a cutting-edge simulation software application for nuclear forensics modeling. The software was developed using MATLAB App Designer infrastructure. The Application is exported as an executable file and can run on Windows-based computer without any specific environment or infrastructure.

The application utilizes a versatile database based on Monte Carlo simulations and can be used for research purposes and employee training in nuclear forensics as well. For example, it's possible to simulate fission tracks accurately based on physical and radiation parameters, resembling light microscope images. These serve as foundational data for AI-driven decoder software and image analysis.

Calculations can be made based on accurate real data. For example, by entering the diameter of the Fissile Material, Thermal neutron flux, Fission cross-section (Selectable between ^{235}U, ^{233}U, and ^{239}Pu), Radiation time, and Fissile material mass, it is possible to calculate the number of tracks that are produced in a simulated Cluster.

The simulation shows the spatial behavior of the fission products and the plane projection. In addition, it emphasizes the different appearance of the clusters depending on the distance between the fissile material and the SSNTD.

Using the FTA Trainer, the following options are configurable, and simulations can be made based on specific parameters which the user demands:

1. Size of a fissile particle.
2. Enrichment.
3. Mass of the fissile particle.
4. Specific fissile isotope (Selectable between ^{235}U, ^{233}U, and ^{239}Pu).
5. Neutron flux.
6. Energy of neutrons.
7. Neutron flux radiation duration.
8. Geometric Parameters.
9. Multi Cluster generator (arbitrary and systematic).
10. Different depths and slices of particle in the sample foil.
11. 3-Dimensional visualization of the fission clusters.
12. 3-Dimensional visualization of the fissions in the radiated particle.
13. Projection of upper and lower SSNTD detectors.
14. Nearness test for detecting potential overlapped clusters.
15. Etching time influence on clusters based on semi-empiric experiment.
16. ROI Cutting estimation ideal areas.
17. Employee certification test.

In addition, the following parameters can be Calculated:

1. Calculation of a number of tracks based on physical parameters.
2. Calculation of total fissile mass of a batch of clusters.
3. Mini bulk and Micro bulk.
4. Histograms of the fission products track lengths and the projected length on the SSNTD (after 3-dimensional slicing).
5. Finale score for tested employee.

By bridging theory and application, the software enhances nuclear forensics investigations, contributing to nuclear security and nonproliferation efforts. This versatile and accurate tool promises deeper insights and robust methodologies in nuclear forensics.

1.2. System Requirements

Minimum computer requirements:

1. Intel® Core ™ i7-1065G7 CPU 1.50 GHz.
2. RAM: 16 GB.
3. Windows 10 operating system.
4. Free space memory: 5 GB.

2. Getting Started

The app based on visual components lay out design, creating a user-friendly graphical user interface. By entering to the app, the main screen shows up as shown in Figure 1.

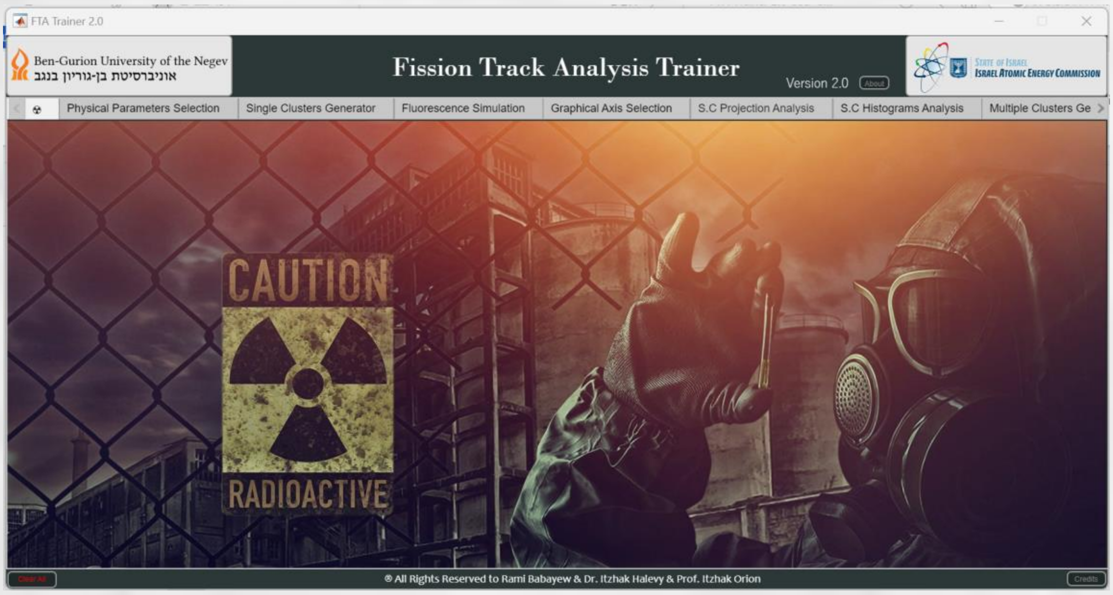


Figure 1. Main Screen of the FTA Trainer Application

The functionality in the application divided into 13 Tabs which the user can chose, depending on the functionality needed. By entering the tab on the upper side of the window, using the PC mouse, the application will open the chosen function tab. For convenience, it's possible to pick "remote" tabs faster by pressing one of the arrows, which opens a shortcut list of all the tabs, as show in Figure 2.

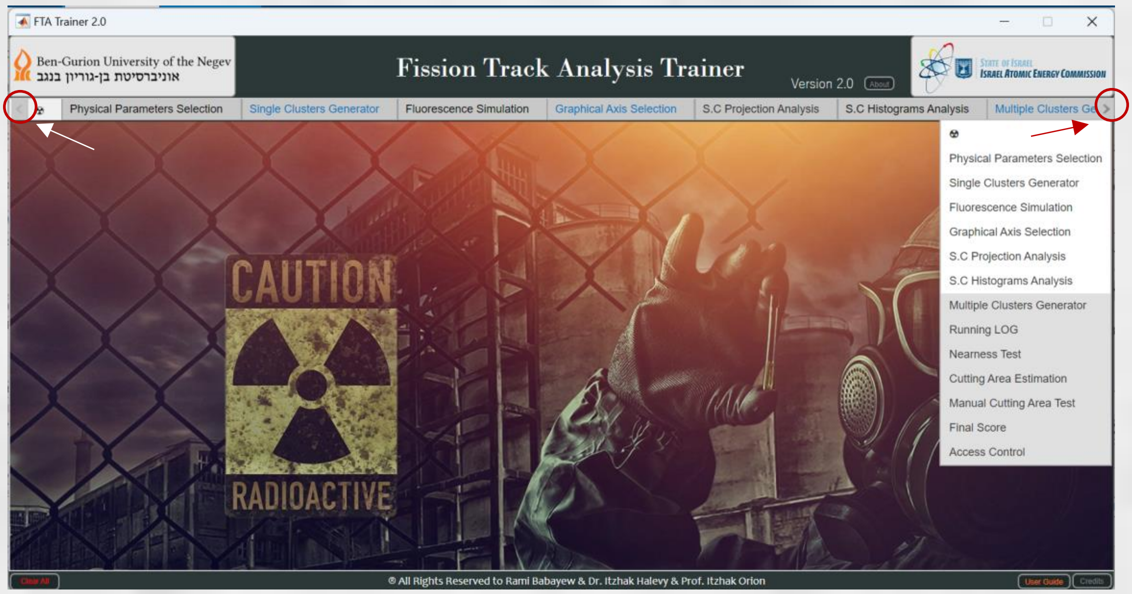


Figure 2. Main Screen of the FTA Trainer Application
displaying shortcut list of the functionality tabs

2.1. Physical Parameters Tab

In this Tab, particle properties calculations can be made based on real given data. The calculations based on nuclear and particle physics theories according to proven equations. See Figure 3.

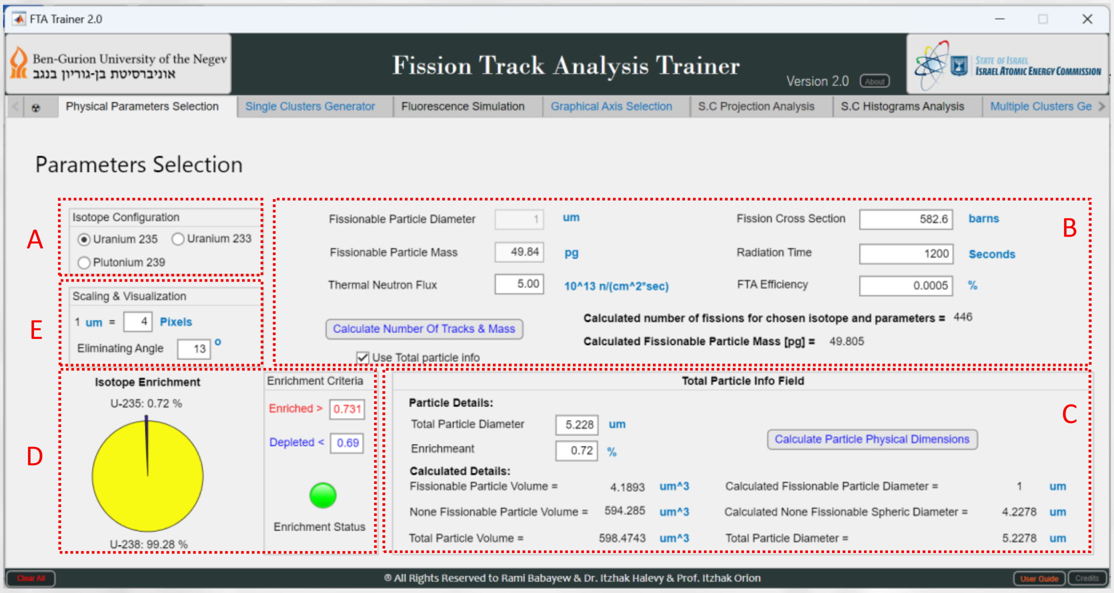


Figure 3. Physical Parameters Tab

In **Section A**, the user has the option to select from three different simulated isotopes: ^{235}U, ^{233}U, and ^{239}Pu. Each of these isotopes has unique properties and applications in the field of nuclear physics and engineering.

In **Section B** it's possible to calculate the Number of Tracks which can be produced in a simulated Cluster. When the check box 'Use Total particle info' isn't selected (☐), the user can enter any configuration desired. After choosing the parameters, by entering 'Calculate Number of Tracks & Mass' button, the app will calculate the number of tracks for the specific configuration.

In **Section C**, by choosing desired total particle diameter and enrichment and entering 'Calculate Particle Physical Dimensions' will calculate the particle physical dimensions. Calculating the diameter of fissile material involves considering it as a spherical object with the fissile substance located at its center. In this scenario, we assume the absence of any neutron-absorbing materials within the sphere. It's possible to use the parameters from Section C in Section B by Selecting the check box 'Use Total particle info' (☑).

Section D making visualization of the selected enrichment in pie percentage diagram.

The enrichment status lamp will be ***Green*** when the particle is with natural enrichment, ***Blue*** when the particle is depleted and ***Red*** when the particle enriched. The user can choose in this section the enrichment boundaries.

Section E responsible for visualization preferences for another Tabs, will be discussed later.

2.2. Single Clusters Generator Tab

The Single Clusters Generator Tab allows users to create customizable single clusters by specifying either a chosen number of tracks or utilizing the automatically calculated number of tracks from the Physical Parameters Tab. See Figure 4.

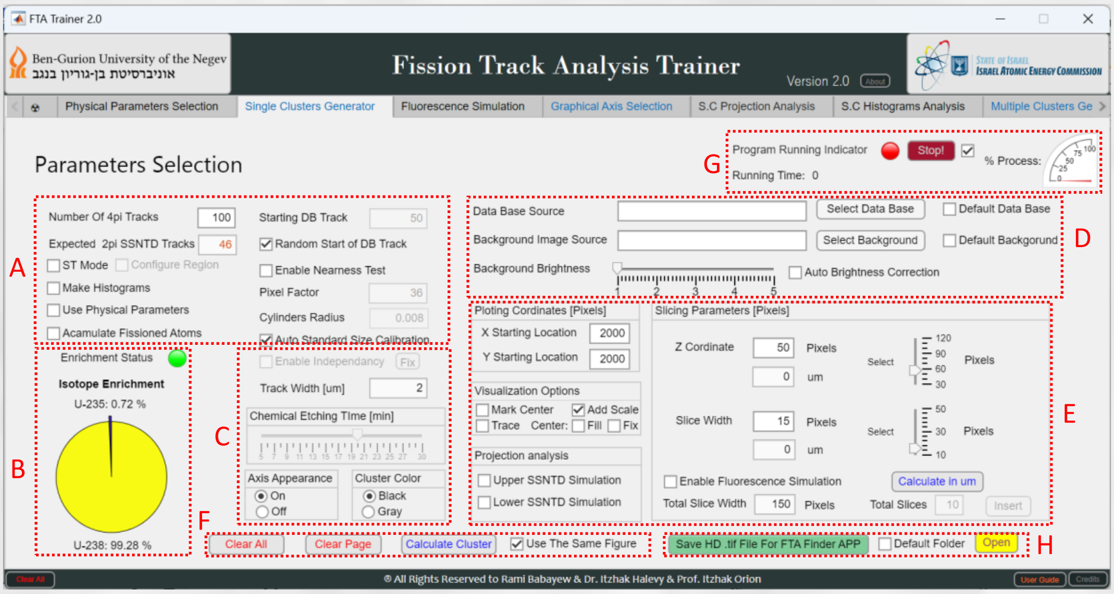


Figure 4. Single Clusters Generator Tab

Section D is dedicated to choosing data base of fission products trajectories and background image source. There's an option to use build in default data base and background image by selecting (☑) the check box placed near the fields. In addition, for extra dark images, there's an option to increase the brightness (manually or automatically by selecting the check box near the brightness slider).

Section A is dedicated to customizing the cluster by the user and extra features. If 'Use Physical Parameters' check box is selected, the software automatically taking the number of tracks for the simulation from the Physical Parameters Tab.

If the 'Use Physical Parameters' check box is not selected, the user can choose the number of tracks by entering number into the 'Number Of 4pi Tracks' Field. Under this field, there's a field called 'Expected 2pi SSNTD Tracks' which estimating the number of tracks the simulation will produce on 1 SSNTD. By selecting 'ST Mode' check box, the program will generate only single tracks, scattered in a selected region (a pop-up window will show up when the option is selected). By selecting 'Make Histograms' check box, the software will generate length analysis (see chapter 2.6). By Selecting 'Accumulate Fissioned Atoms' check box, the software will estimate fissions placement in 3 dimensions and will generate a 3D model of all the fission sites which initiated in the simulated particle (see chapter 2.5).

In **Section A** the user can choose whether the starting DB track will be random or specified (the option depends on selecting the 'Random Start of DB Track' check box). By selecting 'Enable Nearness Test' check box, the software will perform a test which is widely discussed in chapter 2.9.

In addition, **Section A** enables the user to calibrate the size of the clusters. In default, 'Auto Standard Size Calibration' check box is selected. For changing the calibration, the user can cancel the selection in the check box and enter new calibration numbers.

Section B is a real time visual indicator which is indicating the enrichment level of the simulated particle.

The FTA method utilizes a manual, time-sensitive chemical etching process to reveal FT clusters from particles of interest (POIs). In our R&D process, using LEXAN® SSNTD, we examined the impact of different etching times on the actual track width and integrated these findings into the FTA Trainer software application. This enhancement enhances the software's flexibility, making it more closely aligned with real-world conditions. **Section C** is the chemical etching generator which is based on the findings. By canceling the 'Auto Standard Size Calibration' check box in **Section A**, the option of choosing desired etching time will reveal. The user can choose the desired etching time using the 'Chemical Etching Time[min]' slider.

In the bottom of **Section C,** the user can choose color of the generated cluster and, in addition, choose if a Axis appearance is desired in the plotting graph.

Section E:

- Sub Section 'Ploting Cordinates [Pixels]' – Enables the User to choose the X-Y coordinates for placing a generated fission track cluster. (When 'ST Mode' check box is selected, only the first track will appear in the selected X-Y coordinates).
- Sub Section 'Visualization Options' – Enables the User to chose adding a Scale into to plotting graph by selecting 'Add Scale' check box. In addition, it gives the option to mark the center of generated cluster in red by selecting 'Mark Center' check box. In extreme conditions, when the user choosing not the default calibration parameters in **Section A**, there are tracks in the center of a cluster which are looking to synthetic, therefor by choosing 'Fill' or 'Fix' center check boxes, its possible to improve the plotting quality and appearance.
- Sub Section 'Projection Analysis' – Enables the User to demand a projection analysis which is widely discussed in chapter 2.5.
- Sub Section 'Slicing Parameters [Pixels]' – Enables the User to choose the depth of a simulated particle in the simulated "catcher" (See appendix A). the configurable depth can be changed either in the 'Z Coordinate' Field or in the slider placed near the field. In addition, the user can choose the depth of the trajectory inside the simulated SSNTD by choosing a number in the 'Slice Width' field or wither in the slider placed near the field. And option to convert Particle Depth ('Z Coordinate') and Trajectory depth ('Slice Width') from Pixels to µm is existing.
  In this Subsection, there's an option to enable fluorescence simulation by selecting 'Enable Fluorescence Simulation' check box, and the number of slices which the Z stack will generate ('Total Slices' field), See chapter 2.3.

Section F including the main generation button for cluster generating ('Calculate Cluster'). Near this button, there 'Use The Same Figure' check box which gives the option whether to us or not to use the same UI Figure for plotting (there's an option to plot separately or to "accumulate" clusters in the same background image). In addition, in this section there's a 'Clear Page' button and 'Clear all' button.

Section G is an indicator for the generation process in percentage, the red lamp is turning green when the program is running and turning back to red when the program is ended the run.

Section H dedicated for saving the plot of the process (the process generates cluster or clusters placed on a dedicated background image, and shown in a separated window called UI Figure). By entering the 'Save HD .tif File For FTA Finder APP' button, the software will ask for a path for saving the image in '.tiff' format (the image size is by default 4098 x 3264 pixels). there is an option to demand that the saving process will use a default folder by selecting the 'Default Folder' check box. The 'Open' Button is for opening the default folder if required.

Sections G and **B** exhibit similarities with other tabs in the application, eliminating the necessity to redundantly reiterate them in the subsequent chapters of the document.

2.3. Fluorescence Simulation Tab

Since a real SSNTD is transparent its possible with real samples to generate an image which is three dimensional by using in depth auto focusing (Z-Stack) of the microscope. Fluorescence Simulation Tab is a tool for simulating this scenario. When the check box 'Enable Fluorescence Simulation' is selected (☑) in Section E of the Single clusters Tab, the app will perform Z-Stack 3-Dimnsional visualization simulation which demonstrates the repetitiveness of the track's lengths, identified by colors. The simulation will appear in **Section A**. See Figure 5.

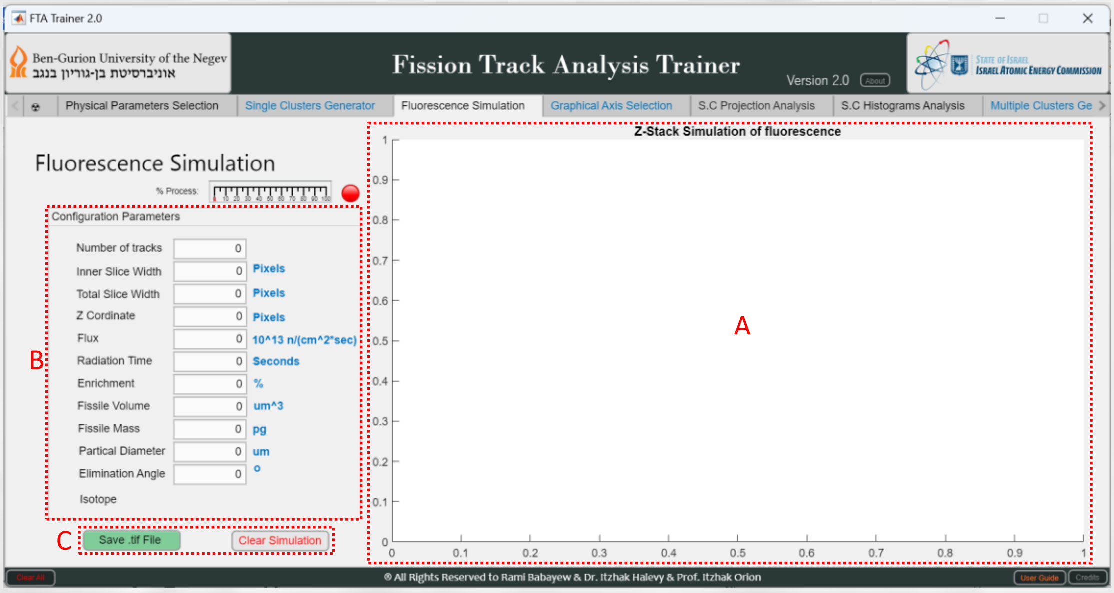


Figure 5. Physical Parameters Tab

Section B summarizes all the relevant data of the simulated particle.

Section C enables the user to clear the simulation or to save a '.tif' file of the simulation.

2.4.Graphical Axis Selection Tab

For making the generation tool more accurate when placing a desired cluster by X-Y axis, a Graphical selection of coordinates added in a new tab as shown in Figure 6.

In **Section A**, the user can choose the generation tool (single cluster or multi cluster – which explained in chapter 2.7).

This tab is automatically updated after each run which the user makes in the dedicated tabs of generating clusters. In addition, it's possible to make cluster generation from the Tab itself by following set of instructions which is placed in the left side of the screen for convenience. When Single Cluster (SC) is chosen in **Section A**, the program enables **Section B.** When Multi Cluster (MC) is chosen in **Section A**, the program enables **Section C.**

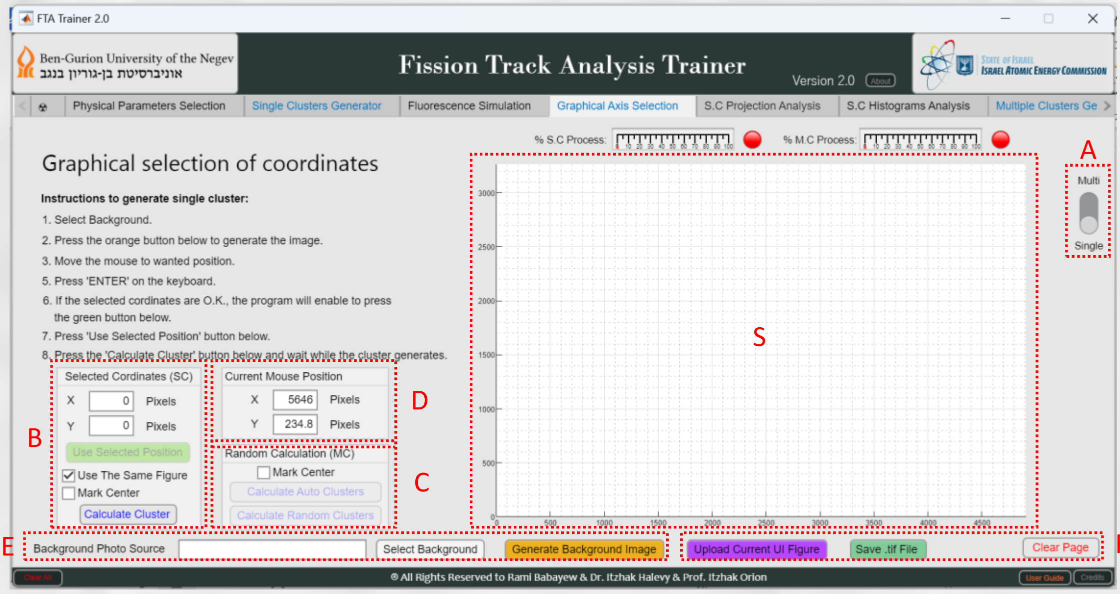


Figure 6. Graphical Axis Selection Tab

Section D shows relevant axis information - real time current mouse position.

Section E enables choose a background image before generating and has dedicated button for generating the image from selected folder.

Section F enables to save '.tif' image from the application tab screen (**Section S**) and clear the page. In addition, 'Upload Current UI Figure' button enables to upload a UI Figure which is generated in the tab screen (UI Figure is a figure which the application generates to an independent screen).

2.5.Single Clusters Projection Analysis Tab

Projection analysis of the fission product paths is added to the software for studying deeply the behavior of nuclear fission products when making an interaction with the SSNTD Detectors, which are placed in a "sandwich configuration" containing the particle (See Appendix A).

The simulation shows the spatial behavior of the fission products and the plane projection. In addition, it emphasizes the different appearance of the clusters depending on the distance between the fissile material and the projected plane in the LEXAN®. A 3D analysis is available to map the exact sites of fissions in the simulated particle. Projection tracks on upper and lower SSNTDs ('**B**' and '**C**' graphs respectively). In addition, the middle graph ('**A**') shows a 3D simulation which mapping the exact sites of fissions in the simulated particle (each fission mapped by colorful sphere, the red sphere is the entire fissile particle). When the check box 'Upper/Lower SSNTD Simulation' is selected (☑) in **Section E** of the Single clusters Tab, the app will perform Projection analysis for the selected SSNTD (Or both). In addition, by enabling 'Acamulate Fissioned Attoms' in section A of Single clusters Tab, the app will perform visualization of fission sites in the sample. See Figure 7.

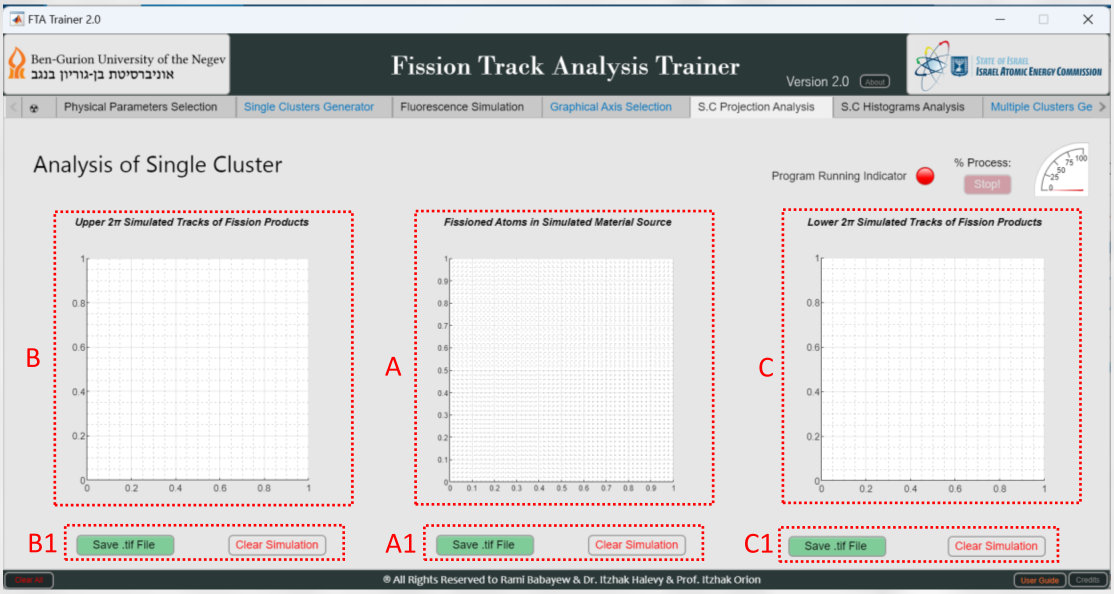


Figure 7. S.C Projection Analysis Tab

Section B1 including buttons enabling saving or clearing the simulation in graph **B**.

Section A1 including buttons enabling saving or clearing the simulation in graph **A**.

Section C1 including buttons enabling saving or clearing the simulation in graph **C**.

2.6. Single Clusters Histogram Analysis

To demonstrate the relation of the fission products energy to the track's lengths, a histogram analysis option was added to the software to count the number of tracks per length. When thermal neutrons are used in the simulations (E≅0.025eV), the fission products are generated with two typical kinetic energies. Therefore, if a histogram analysis is performed, most of the track's lengths will be contained in a bimodal Gaussian distribution. The analysis of track lengths, using the developed FTA Trainer software, enables the investigation of their potential to distinguish between different isotopes, in alignment with existing theoretical principles.

The Tab is dedicated to the Single Cluster Generator only. When the check box 'Make Histograms' is selected (☑) in **Section A** of the Single clusters Tab, the software will perform a length analysis of the generated track and will show the histograms in **Section A**, **B** and **C** which are shown in Figure 8.

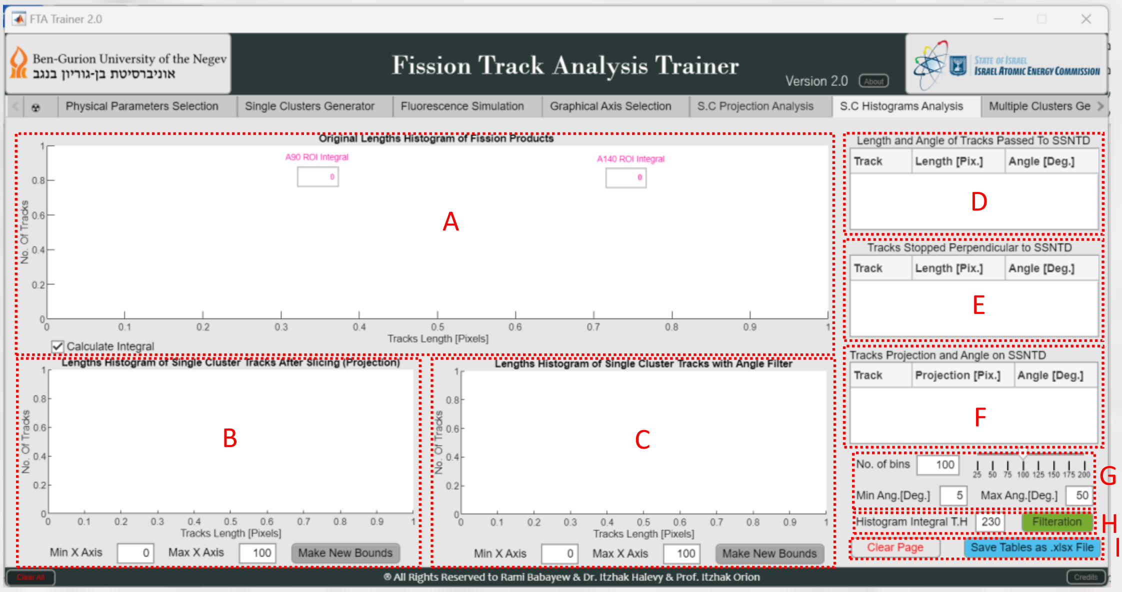


Figure 8. S.C Histograms Analysis Tab

The histogram in **Section A** is based on the original lengths of the fission products, all the incidents stored in a table shown in **Section D**. Due to geometrical considerations, tracks which are perpendicular to the SSNTD are not accumulated to the histogram, therefore they are stored in separated table shown in **Section E**. The criteria angle is chosen in **Section E** in 'Use Physical Parameters' Tab. The data stored for each incident including number of track, the track length (in Pixels) and the trajectory angle.

The histogram in **Section B** is based on the lengths of the projected trajectories of the fission products, all the incidents stored in a table shown in **Section F**.

The histogram presented in **Section C** is derived from the lengths of the fission products post-processing, which involves a selection based on an angle filter.

In **Section A** there's a check box for enabling an integral calculation for each hump in the bimodal Gaussian distribution. The integral function is dividing the X axis into 2 regions, the "cut" position of these 2 regions can be configurated in **Section H**.

In the bottom side of **Sections B** and **C** there is an option to configure the minimum and maximum values of the X axis regions of the histograms showed.

Section G dedicated for bin configuration for all the 3 histograms shown in **Sections A**, **B** and **C**. In addition, it includes the trajectory filter criteria which is used in the histogram in **Section C**.

In **Section I** there's a save button for the tables, and there a clear button for the data as well.

2.7. Multiple Clusters Generator Tab

The Multiple Cluster Generator GUI enables creating configurable multiple clusters based on selected number of tracks, or the calculated number of tracks from the Physical Parameters Tab. This tool can save time when many clusters are needed. The configurability has similar options to the Single Cluster Generator, except the additional option of choosing random parameters. See Figure 9.

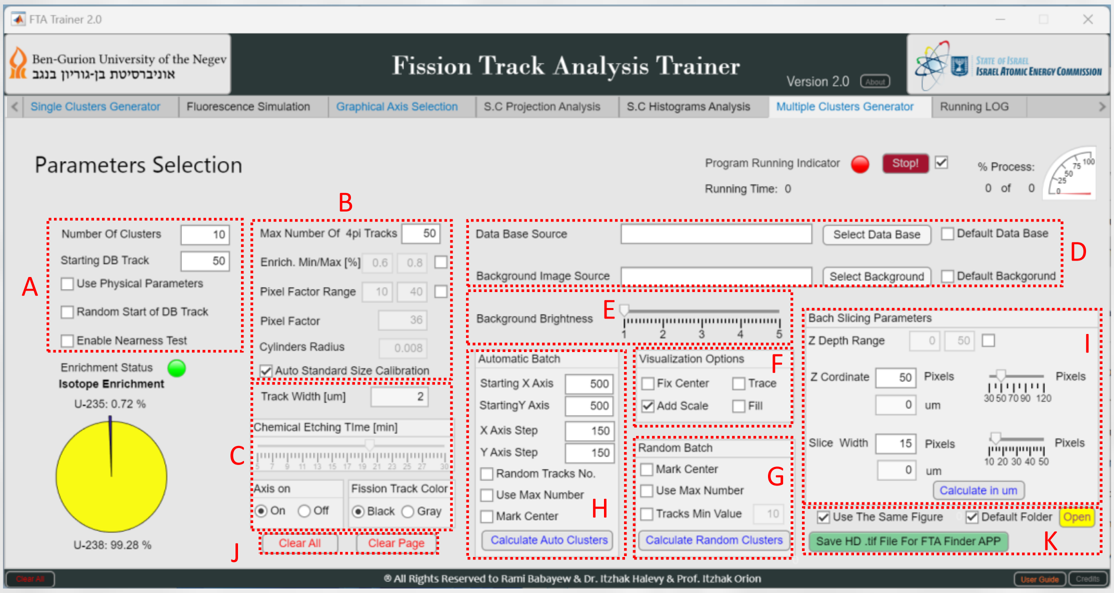


Figure 9. Multiple Clusters Generator Tab

Section D is dedicated to choosing data base of fission products trajectories and background image source. There's an option to use build in default data base and background image by selecting (☑) the check box placed near the fields. In addition, for extra dark images. **Section E** gives the option to increase the brightness of the selected background image (manually or automatically by selecting the check box near the brightness slider).

Section A is dedicated to customizing the cluster by the user and extra features. If 'Use Physical Parameters' check box is selected, the software automatically taking the number of tracks for the simulation from the Physical Parameters Tab. If the 'Use Physical Parameters' check box is not selected, the user can choose the number of tracks by entering number into the 'Number Of 4pi Tracks' Field. In **Section A** the user can choose whether the starting DB track will be random or specified (the option depends on selecting the 'Random Start of DB Track' check box). In this section the user can choose the number of clusters needed for generation ('Number Of Clusters' field).

In addition, by selecting 'Enable Nearness Test' check box, the software will perform a test which is widely discussed in chapter 2.9.

Section B enables the user to calibrate the size of the clusters. In default, 'Auto Standard Size Calibration' check box is selected. For changing the calibration, the user can cancel the selection in the check box and enter new calibration numbers. In addition, because of the random functions of the multi clusters generator, there is an option to the user to define a limit of the max tracks that can be generated for a given cluster ('Max Number Of 4pi Tracks' Field). For enrichment levels, the user can choose a region (the default region is 0.6 - 0.8% but can be changed after selecting the checkbox placed near the region fields).

Section C is the chemical etching generator which is based on the findings. By canceling the 'Auto Standard Size Calibration' check box in **Section A**, the option of choosing desired etching time will reveal. The user can choose the desired etching time using the 'Chemical Etching Time[min]' slider.

In the bottom of **Section C,** the user can choose color of the generated cluster and, in addition, choose if an Axis appearance is desired in the plotting graph.

Section F Enables the User to choose adding a Scale into to plotting graph by selecting 'Add Scale' check box. In addition, it gives the option to mark the center of generated cluster in red by selecting 'Mark Center' check box. In extreme conditions, when the user choosing not the default calibration parameters in **Section A**, there are tracks in the center of a cluster which are looking to synthetic, therefor by choosing 'Fill' or 'Fix' center check boxes, it's possible to improve the plotting quality and appearance.

Section I Enables the User to choose the depth of a simulated particle in the simulated "catcher" (See appendix A). The configurable depth can be changed either in the 'Z Coordinate' Field or in the slider placed near the field. In addition, the user can choose the depth of the trajectory inside the simulated SSNTD by choosing a number in the 'Slice Width' field or wither in the slider placed near the field. And option to convert Particle Depth ('Z Coordinate') and Trajectory depth ('Slice Width') from Pixels to µm is existing.

Because of random functions of the multi clusters generator, the user can choose a region of depth (the default region is 0 - 50 but can be changed after selecting the checkbox placed near the region fields).

Section G is dedicated for generating random batch of clusters with random characteristics (X-Y coordinates, number of track, particle depth in the "catcher", fissile enrichment, and trajectory data base). Its is possible to limit the lowest number of track by selecting the 'Tracks Min Value' check box (and enter a number in the field placed near the checkbox).

Section H is dedicated for generating an automatic batch of clusters which generated using "steps" in the X axis and Y axis. The user can choose the starting point of the batch, and the "step size" for each axis. The section gives an option to the user selecting a random tracks number for the batch (by selecting 'Random Track No,' check box).

In addition, in both **Sections G** and **H** there's an option to demand from the software to use for each cluster generated, the max number of tracks which is selected in **Section B** (in the field 'Max Number Of 4pi Tracks'). In the generated batch, its possible to demand from the software to add red circle In the center of the cluster (by selecting the 'Mark Center' check box).

Section K dedicated for saving the plot of the process (the process generates cluster or clusters placed on a dedicated background image, and shown in a separated window called UI Figure). By entering the 'Save HD .tif File For FTA Finder APP' button, the software will ask for a path for saving the image in '.tiff' format (the image size is by default 4098 x 3264 pixels). there is an option to demand that the saving process will use a default folder by selecting the 'Default Folder' check box. The 'Open' Button is for opening the default folder if required. In addition, there is a 'Use The Same Figure' check box which gives the option whether to use or not to use the same UI Figure for plotting (there an option to plot separately or to "accumulate" clusters in the same background image).

In **Section J** there's a 'Clear Page' button and 'Clear all' button.\

2.8. Running LOG Tab

The LOG Saves in real time all the Important details and parameters of each program running (Single or Multiple cluster generation). The LOG saves for each cluster the following data (See Figure 10, **Section A**):

a. Running Number
b. Time and Date
c. Thermal Neutron Flux [10^{13} n/(cm^2*sec)]
d. Number of Tracks
e. Two Dimensional Coordinates [Pixels]
f. Fissile material diameter [µm]
g. Total material diameter [µm]
h. Enrichment percentage of the material
i. Fissile material mass [pg]
j. Fissile material volume [µm^3]
k. Total material volume [µm^3]
l. Total Mass of particle.

The user can calculate a variety of collective parameters and summarize the details of long runs in the following aspects of the examined SSNTD (See Figure 10, **Section C**):

a. Total mass detected.
b. Total fissile mass detected.
c. Maximum Micro-Bulk Particle enrichment.
d. Minimum Micro-Bulk Particle enrichment.
e. Mini-Bulk enrichment.
f. Enrichment and Standard deviation of the enrichment of total simulated clusters. (Mini-Bulk in the ICPMS-MC).
g. Indication of the enrichment phase by color for each generated cluster (Red - Enriched, Green – Natural, Blue – Depleted).

The user can choose the threshold for depleted and enriched particles (See Figure 10 , **Section B**).

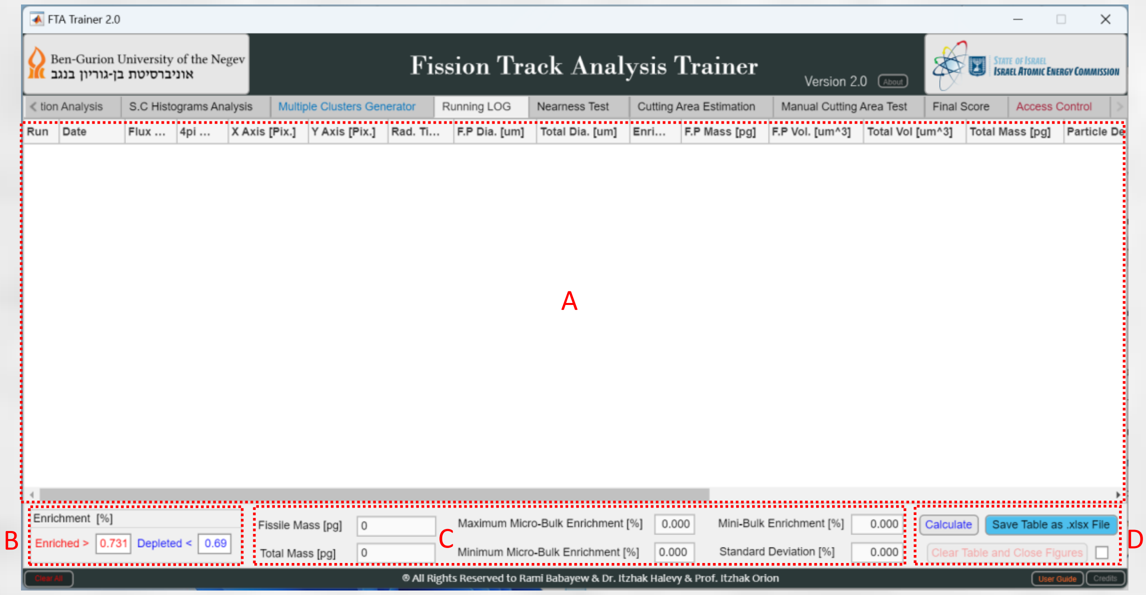


Figure 10. Running Log Tab

In **Section D**, button for saving the Log Table, Button for Calculating parameters and a button for clearing the table of the Log with an enabling Checkbox.

2.9. Nearness Test Tab

This tab is a tool for further examining generation of clusters made using the fission track clusters generators in the application. As a result of the importance of avoiding mixed clusters, Nearness Cluster Test tool is added to the application for indicating visually close cluster. By setting a Threshold (in Pixels), the user can use the nearness test tool to be aware of clusters which are too close to each other. See Figure 11.

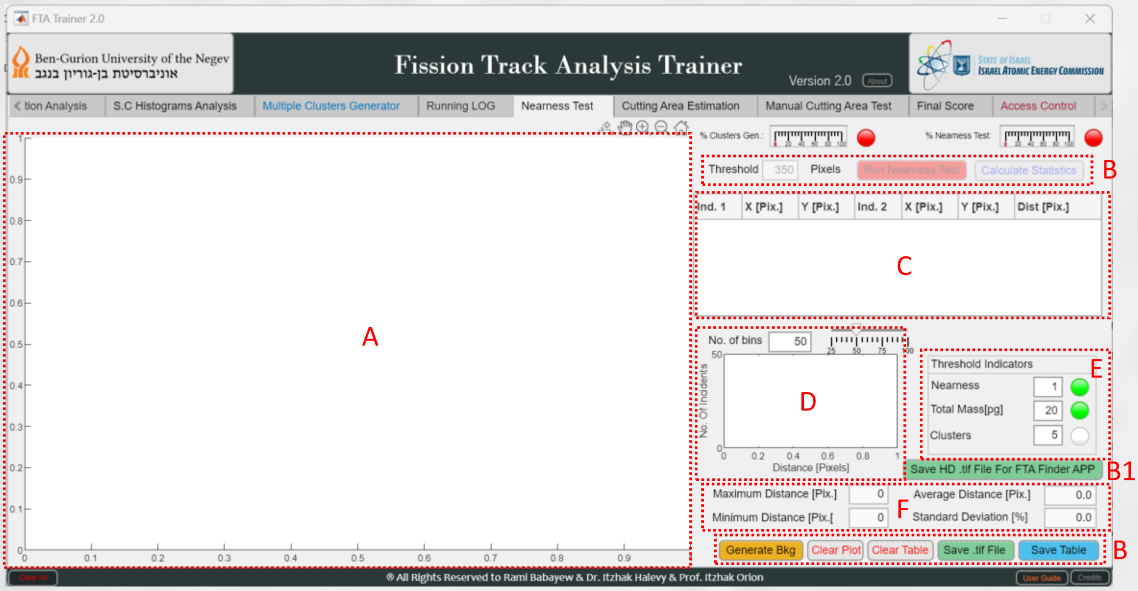


Figure 11. Nearness Test Tab

Section A is dedicated to show the image background and the simulated clusters. When the check box 'Enable Nearness Test' is selected (☑) in **Section E** of the Single clusters Tab or Multi clusters Tab, the app will enable the User to select Threshold (in pixels) and to run a nearness test after generating at least 2 clusters objects (**Section B**). In addition, in **section B** there's a calculation button for calculating all the relevant information (Shown in **Section C**) about clusters which are found to be close one to another (placing distance under the threshold). In **Section F**, the statistical results. **Section D** enables the user to examine the probability of the distances by making an histogram of all the nearness incidents found and shown in **Section C**. The number of bins of the histogram is configurable. In **Section E**, 3 indicators placed which showing the number of clusters which are placed in the image and being tested. In addition, its count the number of nearness incidents found and the total fissile mass. **Section B** enables generating background image, clearing it and saving the screen and the nearness information table. Button **B1** enables to save the screen in HD.

2.10. Cutting Area Estimation Tab

The method usually used when performing FTA particle analysis is dissolving the material containing the test particles in the LEXAN® foil, called a ״catcher״, and inserting it between two SSNTD detectors in the ״sandwich formation” (Appendix A).

To clarify the distinction between bulk and particle analysis, a ״cutting״ procedure is frequently employed on the ״catcher״. This procedure entails the isolation and dissolution of a single particle (POI), as identified by Fission Track Analysis (FTA), for subsequent analysis via mass spectrometry techniques (i.e., ICPMS).

In the field of nuclear forensics, our research group is currently developing innovative techniques designed to enhance the reliability and precision of our analyses. These novel approaches are designed to provide more accurate and robust answers to nuclear forensics questions. Currently, only trained operators can analyze microscope images of FTA data. Since this analysis depends on the operator׳s judgment and skills, it is obvious that different operators will produce slightly distinct results. A new operator׳s training period is lengthy, and it requires using numerous examples from previously measured data and some that we can only predict.

׳Cutting Area Estimation׳ Tab is an expansion tool to the nearness test tool. The tool giving a visual demonstration to the ideal estimated rectangle size which is needed for a cutting suspected area of a sample before sending it to further particle analysis (i.e., ICPMS). The software has proven invaluable for assessing the proficiency of new operators. See Figure 12.

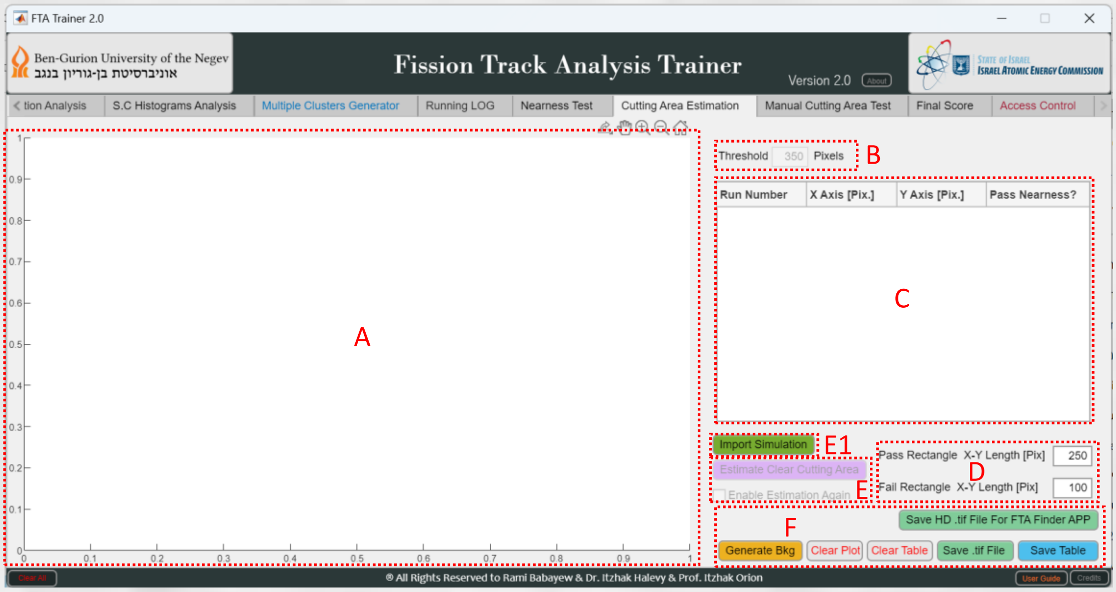


Figure 12. Cutting Area Estimation Tab

Section A is dedicated to show the image background, the simulated clusters and the estimation result (visually).

The Cutting Area Estimation function tool can suggest to the operator whether the clusters are potential to be cut separately or not. The clusters which are good for cutting differentially (which are passed the nearness test) will be surrounded by green rectangles, and the clusters which are can't be cut differentially (didn't passed the nearness test) will be surrounded by blue rectangles. When the check box 'Enable Nearness Test' is selected (☑) in **Section E** of the Single clusters Tab or Multi clusters Tab, and only after a Nearness test has been performed on generated clusters, the 'Cutting Area Estimation' Tab will be enabled Automatically.

Section B Showing the nearness threshold which is chosen by the user for the nearness test.

In **Section D** users can customize their preferences by selecting the dimensions of the rectangles used to suggest cuts within the estimated area. These selections influence the software's subsequent cutting operations.

Section E including the estimation button to start the estimation. In addition, there's a checkbox for enabling to estimate cutting area again after adding simulated clusters (after 1 estimation the estimation button is disabled until the checkbox is selected).

Button **E1** enables to upload a UI Figure as a background for performing cutting area estimation.

Section C is a detailed conclusion of the cutting area estimation which is performed. The conclusion includes the number of the cluster, its X-Y coordinates and if its passed the nearness test or not. The passed clusters are signed by Green color (in the image and in the table) and the clusters which didn't passed the nearness test signed by Blue color.

Section F enables to the user to change background image and to save the image after performing estimation as well as the conclusion table. In addition, there's an option of clearing the estimated image and the conclusion table.

2.11. Manual Cutting Area Test Tab

The Manual Cutting Area Tab is a Qualification test for operators. It's designed to be intuitive test which examining the judgment and the accuracy of operator before the working on real samples. In addition, this tool can be used for senior operators as well, for training and invigoration.

The Manual Cutting Area Test tool demands from operator to suggest which clusters can be cut separately and which clusters cannot. The clusters which are good for cutting differentially will be surrounded by yellow rectangles, and the clusters which can't be cut differentially will be surrounded by red rectangles. See in Figure 13 how the Tab looks like when starting the application.

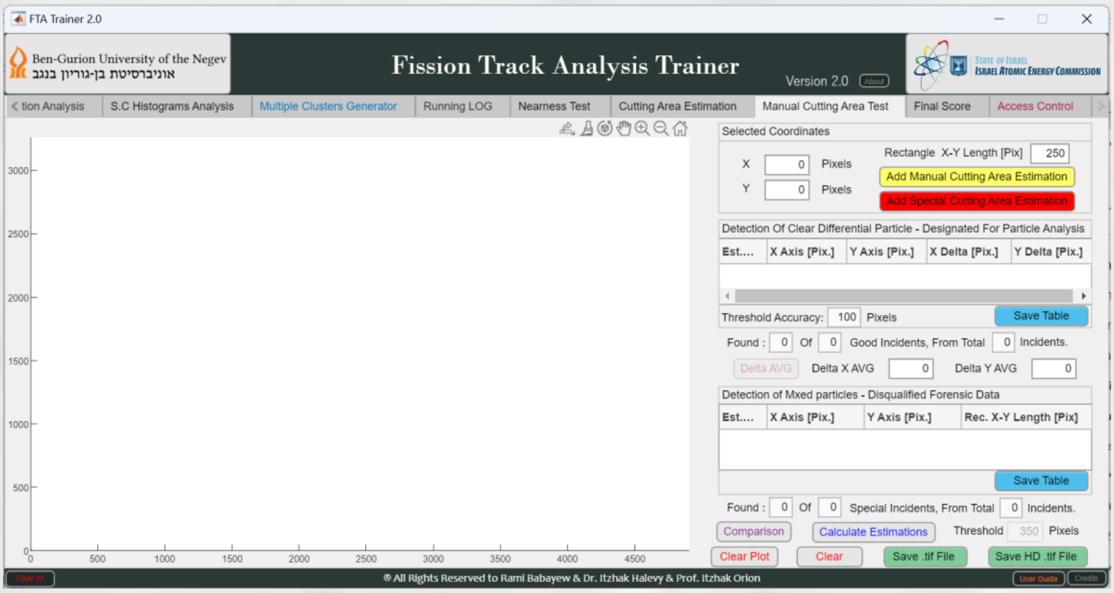


Figure 13. Manual Cutting Area Test Tab after entering to FTA Trainer application (Before performing nearness test)

When the check box 'Enable Nearness Test' is selected (☑) in **Section E** of the Single clusters Tab or Multi clusters Tab, and only <u>after a Nearness test has been performed</u> on generated clusters, the Manual Cutting Area Test ' Tab will be enabled Automatically. A new set of button will show up in the bottom of screen, See Figure 14, **Section B**. We label 'Manual Cutting Area Estimation' as the region suggested by the operator for differential cutting. Conversely, we designate 'Special Cutting Area Estimation' as a region that the operator recommends not to be cut differentially.

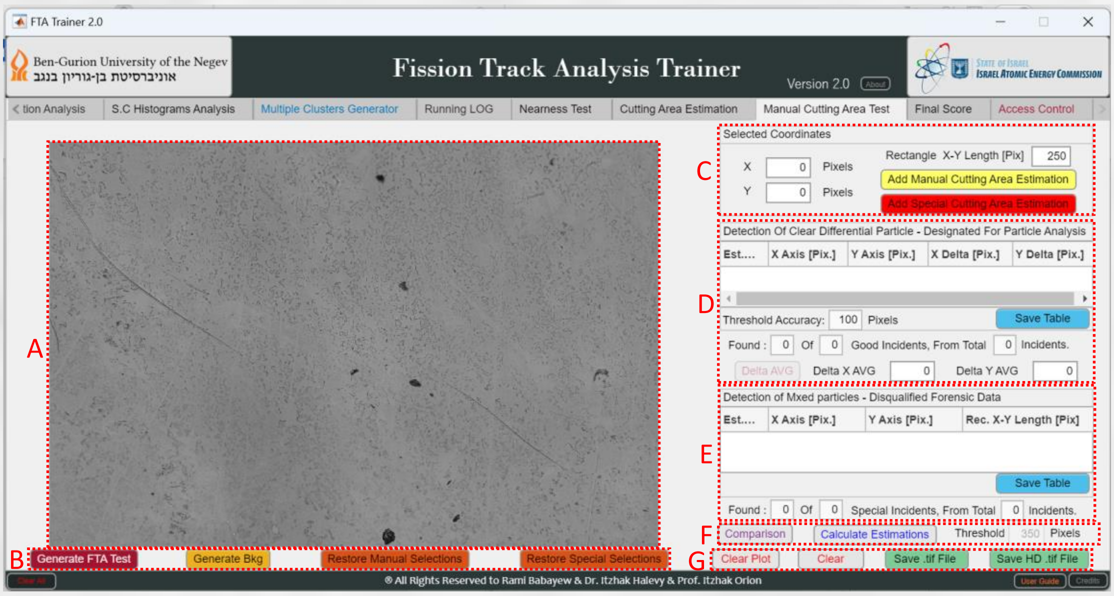


Figure 14. Manual Cutting Area Test Tab after performing nearness test

Section A is dedicated to show the image background, the simulated clusters, and the Manual Cutting Test process (visually).

Section B:

- Button 'Generate FTA Test' – Generates the clusters from the nearness test and beginning the manual cutting test.
- Button 'Generate Bkg' generate a selected background image from the single\multi cluster generators.
- Buttons 'Restore Manual Selections' & 'Restore Special Selections' enables restore the users selections after deleting them by using clear plot button which placed in **Section G**.

In **Section C** there are 2 buttons and X-Y coordinates estimator. After the user/operator generates manual cutting test by pressing 'Generate FTA Test' button, he can chose 2 types of labels for the clusters region: 1. Good region for cutting or 2. Bad region for cutting. For choosing the first option and place a yellow rectangle region on the screen, the user needs to place the mouse on the dedicated region, press 'ENTER', and then a left click with the PC mouse on the button 'Manual Cutting Area Estimation' in **Section C**. Conversely, For choosing the second option the user should do the same instructions with the button named 'Special Cutting Area Estimation'.

Section D shows a conclusion of all the "good" cutting regions which the user is suggested. In addition, in the section there is a saving button for the table.

Section E shows a conclusion of all the "bad cutting regions which the user is suggested. In addition, in the section there is a saving button for the table.

Section F showing the threshold which the operator chose in the nearness test before. In addition, it includes a button which making an estimation of the indicated regions (the good and bad regions), which is shown in the bottom of region D and E respectively.

If the operator is signed as an administrator (explained in chapter 2.13), there is an additional option in **Section F** – demanding from the software to perform a visual comparison between the results of the Cutting Area Estimation to the operator's suggestion. This option helps to learn from own mistakes faster (its acts like a very major "Hint", that's way this option is blocked and open only for admins).

Section G enables saving the screen and clearing it.

2.12. Final Score Tab

After completing a test within the 'Manual Cutting Area Test' Tab, users have the option to assess the accuracy of their suggested cuttings by clicking the 'Import Results' button (**A1**). This action allows the software to import the user's recommendations and compare them against ideal cutting solutions. The process generates seven parameters, each representing a critical criterion evaluated in **Section A**.

By selecting the 'Calculate' button (**B1**), the software computes additional intermediate parameters based on the seven criteria and presents a score percentage on the left side of **Section B**. Finally, by pressing the 'Final Score' button (**C1**), the software calculates the ultimate score. Users can also choose the level of expertise for the tested personnel, whether it's 'Rocky,' 'Certified,' or 'Expert.' Keep in mind that higher expertise levels entail more stringent test requirements. See Figure 15.

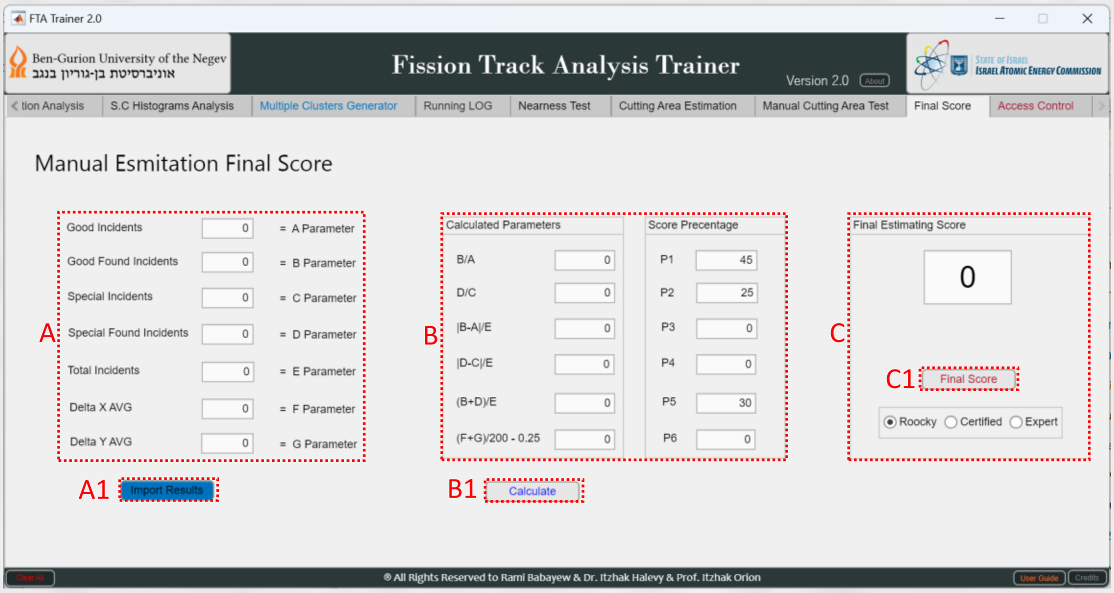


Figure 15. Manual Estimation Final Score Tab

2.13. Access Control Tab

This tab provides users with control over the accessibility of critical functions within the application. Additionally, it offers users the ability to assess their computer's memory usage, providing an indication of the application's performance during simulations, whether it will run smoothly or with potential slowdowns.

Section A: In this section the user can change access level from Employee level to Administrator level. By default, the application running with Employee level access, to change it the user need to enter a 6-digit password: "220495" and press the 'Enter' Button.

In FTA Trainer Version 2.0, there are only 2 functions that accessible by switching to Administrator level:

a) The option to do comparison between user's estimation cuts and the ideal cuts in the "Manual Cutting Area Test" Tab.
b) Change values in all the fields of the 'Manual Estimation Final Score' Tab.

Section B: In this section it's possible to check the Read Access Memory of the computer by clicking the 'Check Usage' button. It is strongly advised to inspect memory usage before launching the application. If memory usage exceeds 60%, it is advisable for the user to consider freeing up memory space before initiating any simulations. See Figure 16.

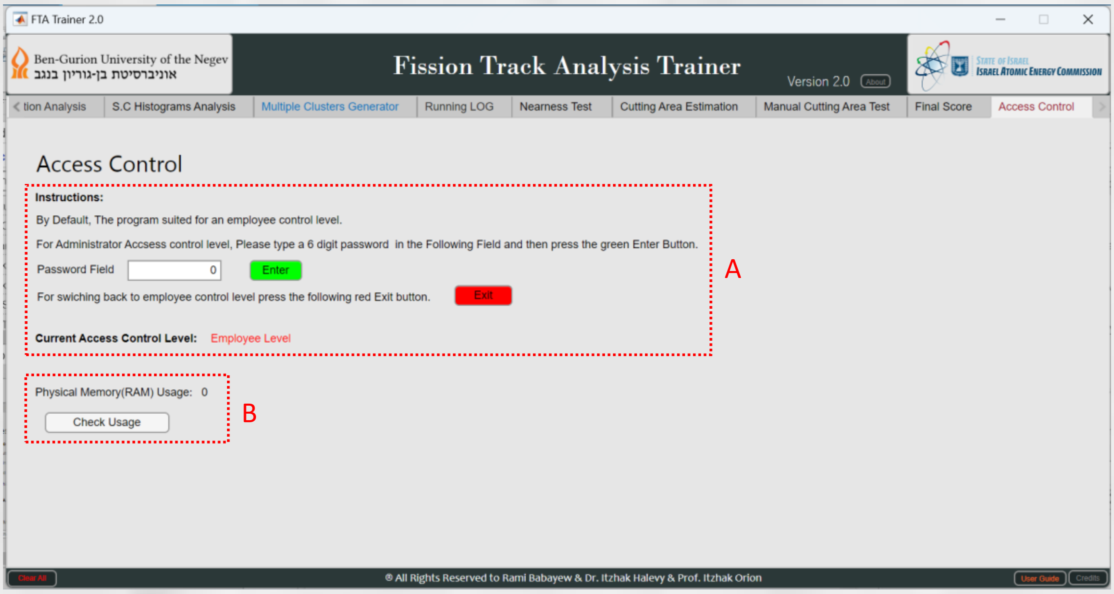


Figure 16. Access Control Tab

2.14. FTA Trainer General Buttons

The application has 4 general buttons:

Button A: "Clear All" button, serves as a function to reset the fields across all Tabs. It effectively erases the software's memory and restores all background parameters to their initial state, acting as a form of system restoration.

Button B: "About" button, in providing users with information about the application itself. After clicking the button, its shows essential details about the application, such as its name, version number, and copyright information. This helps users quickly identify which version of the application they are using. "About" button serves as an information hub, offering transparency, contact options, and valuable resources to users. It enhances the user experience by providing access to essential information.

Button C: Users may want to know who developed the application. The "Credits" section includes information about the companies and the individuals responsible for the software's creation.

Button D: Users can access the User guide by pressing the button.

See Figure 17.

Figure 17. FTA Trainer General Buttons

3. Troubleshooting

3.1. Application Launch Issues

Problem: The application fails to launch.

Solution:

Ensure that your system meets the minimum requirements specified in the system requirements section of this user guide.

Check for any error messages during the launch and refer to the "Error Messages" section below for guidance.

3.2. Error Messages

Problem: Error messages are displayed during the operation of the application.

Solution:

Carefully read the error message to identify the issue.

Refer to the "Error Message Descriptions" section in this user guide for explanations and possible solutions to common error messages.

3.3. Unresponsive Application

Problem: The application becomes unresponsive or freezes.

Solution:

Check if your system resources (CPU, memory) are under heavy usage by other applications. Close unnecessary applications and try running the application again.

If the issue persists, restart the application and contact our support team.

3.4. Unexpected Behavior

Problem: The application behaves unexpectedly.

Solution:

Check if you are using the latest version of the application. Visit our website for updates.

Review the user guide to ensure that you are following the correct steps for operation.

If the issue persists, contact our support team with details about the unexpected behavior.

3.5. General Performance Issues

Problem: The application is slow or laggy.

Solution:

Check your system's hardware specifications against the recommended requirements.

Close unnecessary background applications to free up system resources.

Consider updating your graphics drivers.

3.6. Additional Support

If you encounter issues not covered in this troubleshooting section, please visit our support page at https://halevyitzhakdr.wixsite.com/bguforensics or contact our support team at ramibab@post.bgu.ac.il / halevy.itzhak.dr@gmail.com.

4. Updates and Maintenance

keeping your application up to date is crucial for optimal performance and to access the latest features. This section provides guidance on how to manually update the application and outlines our approach to ongoing maintenance.

4.1. Checking for Updates:

Users can manually check for updates by navigating to our site.

4.2. Manual Update Installation:

If an update is available, the site will guide you through the installation process.

Make sure to follow the prompts and instructions for a seamless update experience.

5. Feedback and Suggestions

We value your input and strive to enhance your experience with our application. Your feedback helps us understand your needs and improve our product. Please use the following channels to share your thoughts, suggestions, or report any issues:

5.1. Feedback Submission Through our Website:

Visit our website and locate the "Feedback" or "Contact Us" page.

Fill out the feedback form with your comments, suggestions, or concerns.

5.2. Customer Support

If you encounter technical issues or need assistance, our customer support team is ready to help. Contact our support team via email.

5.3. Reporting Bugs

If you come across any bugs or unexpected behavior in the application, please report them promptly. Visit the "Bug Report" section on our website to provide details about the issue.

5.4. Feature Requests

We welcome your suggestions for new features or improvements to existing ones. Use the "Feature Request" form on our website or submit your ideas directly through the application.

6. Conclusion

In concluding this user guide, we extend our heartfelt gratitude to the esteemed institutions and individuals who have contributed to the development and support of this application.

6.1. University Acknowledgment

We express our sincere appreciation to Ben Gurion University of the Negev (Israel), specifically the Nuclear Engineering Unit for providing invaluable resources and facilities. The conducive environment and academic support have been instrumental in the creation of this application.

6.2. Israeli Atomic Energy Commission

Our gratitude extends to the Israeli Atomic Energy Commission for their guidance and support throughout the development process. Their expertise and insights have played a pivotal role in ensuring the quality and integrity of this application.

6.3. Acknowledgment to Professors

We extend our thanks to our esteemed professors, whose mentorship and expertise have been a source of inspiration. Their dedication to academic excellence and commitment to fostering innovative projects have greatly influenced the development of this application.

6.4. User Community

To our users, we appreciate your engagement and feedback. Your experiences and insights have been invaluable in shaping the evolution of this application. We remain committed to continuous improvement based on your input.

6.5. Future Developments

As we look to the future, we are excited about the potential growth and enhancement of this application. Your ongoing support and collaboration will undoubtedly contribute to its continued success.

Once again, thank you to everyone who has been part of this journey. Your collective contributions have made this application possible, and we look forward to the continued success of our collaborative efforts.

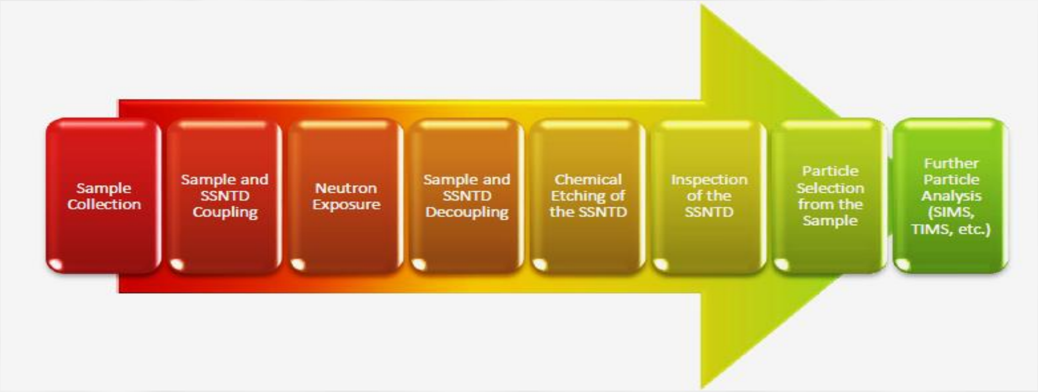
Best regards,

Rami Babayew, Ph. D Student,

Nuclear Engineering Unit, Ben Gurion University of the Negev, Israel

7. Appendix

7.1. Appendix A – Manual FTA Procedure Steps

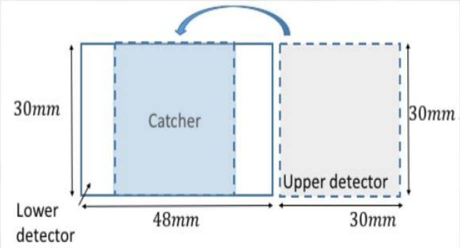


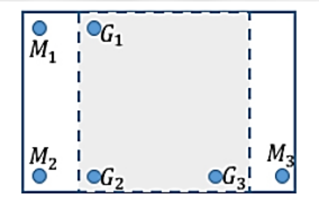
In example, 10 mg of IAEA-314 reference material undergo the following steps:

1. Dissolving in 0.75mL of heptane.
2. Adding 0.5 g LEXAN dissolved in Dichloro-methane & Dichloro-ethane.
3. Ultrasonic mixing for 5 min.
4. Poured onto 25 mm x 25 mm glass slide
5. Drying for 24 h

Resulting 15 µm thick "Catcher" foil.

Once fully dried, the "Catcher" centered on a 48x30 mm^2 LEXAN SSNTD (LOWER Detector). Second 30x30 mm^2 LEXAN SSNTD (UPPER Detector) then placed above the "Catcher". Glue and adhesive tape used for the process.





The Catcher + SSNTDs "Sandwich" irradiated in 10^{12} n/cm^{2}s thermal flux in a nuclear reactor.