Sensor based sorting methods for detection of light nuclides

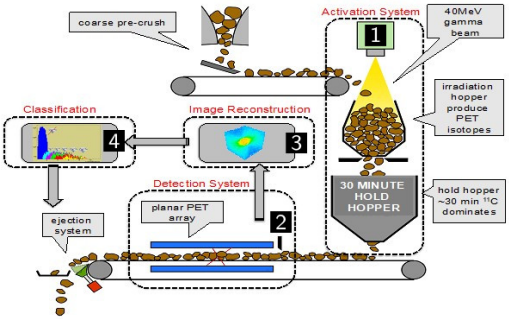
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PhD in Mechanical Engineering Science

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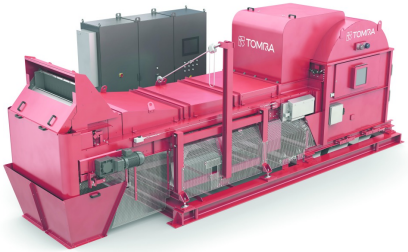


Introduction and context



- High-throughput Sensor-Based-Sorting (SBS) for light Z minerals.
- Comparative study of XRT and MinPET technologies for application in diamond mining.

State of the art



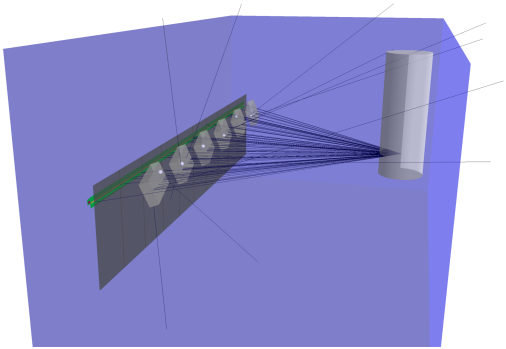
- Commercial vendors offer XRF and XRT based sorters to the diamond industry.
- Dual-energy XRT uses differences in X-ray opacity between materials (diamond vs kimberlite) that can be used to concentrate diamonds.
- Multi-energy and full photon counting can increase the resolving power of XRT but are not fully mature in this sector.
- A Tagged Neutron Method has had some interest but presents many difficulties in economical application.

Research problem



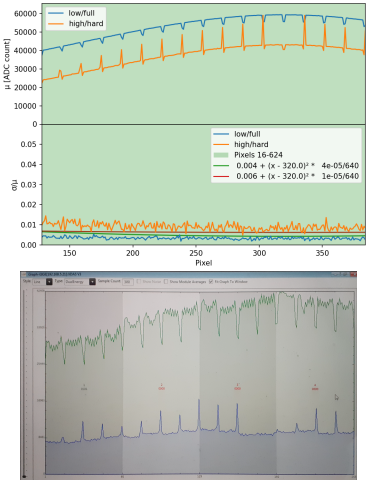
- Optimisations of XRT technology offer marginal gains over current dual-energy XRT - Mining operators need a step-change in performance to justify upgrade.
- Nuclear methods offer better detection capability (inside-out vs. outside-in).
- Whilst simulation codes exist, they target research and medical applications more than industrial uses.
- The commercial viability and benefits of MinPET need to be made clear.
- Previous research has focussed on proof of principle, diamond damage and release of radioactivity to the environment.

Research objectives



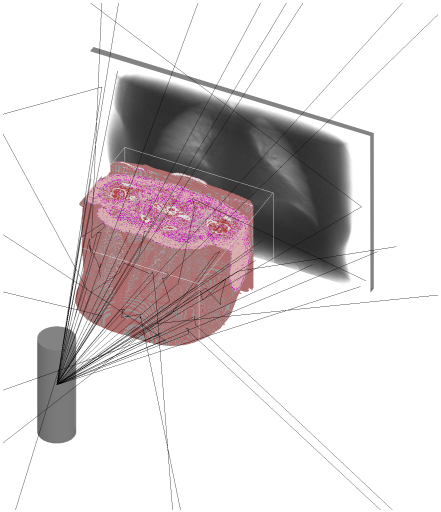
- Develop a photon-by-photon physically accurate simulation of XRT platforms that can be used to experiment easily.
- Assess the current and near term capabilities of XRT based technology.
- Refine digital twins of XRT and MinPET sorters for head to head comparison at scale.

Proposed solution



- Use Geant4 to build digital twin of XRT sorter.
- Benchmark against existing commercial systems.
- Compare final reconstructed images (2D XRT, 3D MinPET).

Significance and impact



- A holistic comparison of MinPET to current technologies can provide the basis of future commercialisation of the technology.
- Detector technology developed for MinPET can also be adapted to use for enhanced XRT, small-scale medical PET, etc.
- Digital twin simulation can be leveraged in other contexts such as our chest X-rays for training Computer Aided Diagnosis (CAD) for Tuberculosis.

Resourcing plan



- CERN has donated a High Performance Compute cluster used for digital twin simulations.
- Gem diamonds have commissioned assessments of current XRT platforms.
- UJ has financed GPU workstations and detector prototypes for lab performance testing.

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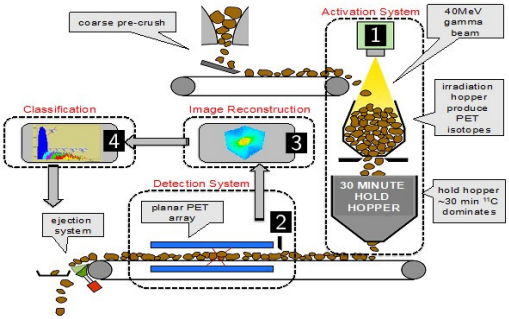
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MinPET Overview



- Coarse crush rock in feed (~100 mm top size)
1. Activate ^{12}C in material with gamma beam (RI), wait for decay of other isotopes (^{15}O, ^{53}Fe, ^{38}K, ^{13}N) ~30 minutes in hold hopper - Thendo, Gideon
2. Scan activated material with planar PET detector array (NET) - Tiego
3. Reconstruct 3D activity map from coincident 511 keV photon pairs - Tim
4. Analyse activity map to classify diamonds and return position on belt - Nicholas
- Select candidate rocks for further processing

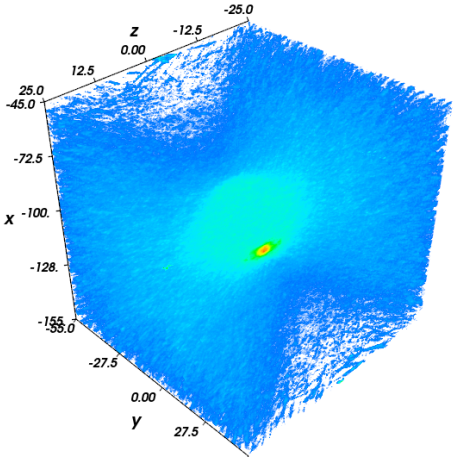
Activation Simulation

- Geant4 simulation of beam particles activating material
- RI accelerator on rock in Sicon® double pocket belt
- Partitioning rocks into voxels for uniformity studies and input to decay simulation
- Stand-alone irradiation simulations for analysis of Aarhus experimental results
- Input to FISPACT-II simulations for time evolution of nuclide inventory

Decay Simulation

- Geant4 simulation of $^{11}\mathrm{C}$ decay via positrons in activated rocks
- NET gamma detector simulated with output in same format as real-world components
- Analysis of event timing and pile-up effects
- Separate occupational exposure simulations

Reconstruction Tools



- Existing Astra reconstruction
- Custom MLEM codebase with GPU acceleration
- Evaluating other open source reconstruction packages

XRT Sensor Based Sorting

- Simulated three diamond detection systems
- Matched image statistics to real data
- Assessed competitiveness with MinPET technique
- Analysed new Photon Counting Detector technology for future applications
- One system is being donated to the group courtesy of Gem Diamonds to further research in this area

Pulmonary Tuberculosis Detection

- Collaboration with PHRU, AHRI, HiP-CT
- Preveshin Maduray, Profs Connell and Harley
- Produce synthetic Chest X-ray (CXR) radiographs to be input to train Machine Learning Computer Aided Diagnosis (CAD) tool
- TB features to be measured with HiP-CT
- Developing lung Digital Twin
- Modulate TB pathologies in healthy lung
- Geant4 based re-projection from 3D model to simulated Chest X-Ray (CXR)

Computer Systems Administration

- Central management of group compute resources (Foreman, Puppet)
- Compute cluster set up and management (HTCondor)
- Monitoring of performance (Prometheus, Grafana, Alertmanager)
- Software management (CVMFS)
- Data management (Globus)
- User management (IPA/LDAP)
- Wiki maintenance (PMWiki)