The Improvement of Recycled Plastics Produced in Jordan through the Use of A Synchrotron Accelerator

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Introduction

In the country of Jordan, the recycling industry needs improved management. Jordan not only needs to make its waste management system more environmentally sustainable but also needs improved regulations on the quality (degree of excellence, not characteristic) of recycled products. These products may contain harmful elements that can further pollute the environment.

Jordan is especially limited in regulating the recycling of plastics. The Ministry of Environment reports that Jordan generates about 2 million tons of municipal solid waste every year and plastics take about 16% of the waste.[1] Only about 7% of the waste is recycled, suggesting the necessity to increase recycling.[2] Still, even these recycled plastics can cause harm to the environment if they are left without investigation. Recycled plastics need especially careful investigations because, as Experientia Supplementum books series reveal, many recycled plastics contain heavy metals,[3] which are metallic chemical elements that have relatively high densities and are toxic or poisonous at low concentrations.[4] Since plastics take a significant portion of waste and a lot of recycled plastics contain heavy metals, the analyses of recycled plastics and improvement of their quality are necessary.

Synchrotron accelerators may be used to investigate recycled plastics. A synchrotron accelerator is a type of cyclic particle accelerator in which the accelerating particle beam travels around a fixed closed-loop path.[5] There have been studies about how synchrotron accelerators effectively detect elements without harming the sample. The 10th International Conference on Accelerator and Large Experimental Physics Control Systems concluded that synchrotron

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[1] Alhyasat, Ahmad G., Zaidoun Al-Nsourand, and Hajar M. Majar. *Country report on the solid waste management in Jordan.* Report. April 2014.
[2] Ibid.
[3] Tchounwou, Paul B., Clement G. Yedjou, Anita K. Patlolla, and Dwayne J. Sutton. *Molecular, Clinical and Environmental Toxicology Volume 3: Environmental Toxicology*. Edited by Andreas Luch. 2012 ed. Vol. 3. Experientia Supplementum (Book 101). Basel: Springer Basel, 2012.
[4] "Heavy Metals." Lenntech.
[5] Cleaves , Henderson J., II. "Synchrotron Accelerator." *Encyclopedia of Astrobiology.* 2011.

accelerators can serve as powerful imaging tools by emitting particle beams that can penetrate a sample and create a high-resolution image.[6] Researchers at the Australian synchrotron further prove the above claim, suggesting that X-ray fluorescence microscopy beamline (a type of beam emitted by the synchrotron accelerator) can be used for analyses in various research fields.[7] Synchrotron accelerators have great potentials for industrial use, especially materials analysis. However, there is little research proving significant benefits of using synchrotron accelerators for improving the quality of recycled plastics. Due to this limitation, it would benefit Jordan to research the extent a synchrotron accelerator detects heavy metals and improves the quality of recycled plastics produced in Jordan.

While Jordan needs to work on its regulation of recycled plastics, it has SESAME (Synchrotron-Light for Experimental Science and Applications in the Middle East), a synchrotron accelerator laboratory that has potentials for investigating recycled plastics. This research intends to reveal the technological benefits of synchrotron accelerators in enhancing the quality of recycled plastics in Jordan. Based on this research, the recycling companies will be provided an insight into the benefits of using synchrotron accelerators. Furthermore, the Jordanian government would be advised by this research as it refines its system of regulating recycled plastics.

Lit Review

Research on improvement of recycled plastics' quality through the use of synchrotron accelerators requires analysis of existing body of knowledge. Studies reveal that Jordan needs to improve its waste management system. According to the Ministry of Environment, Jordan generates

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[6] Chevtsov, P. *10th ICALEPCS Int. Conf. on Accelerator & Large Expt. Physics Control Systems*. Proceedings, Geneva. October 2005.

[7] Paterson, D., M. D. De Jonge, D. L. Howard, W. Lewis, J. McKinlay, A. Starritt, and M. Kusel. *American Institute of Physics Conference Proceedings*. Proceedings of The X-ray Fluorescence Microscopy Beamline at the Australian Synchrotron. 2011.

about 2 million tons of municipal solid waste every year.[8] Plastics take at least 15% of the total waste, and only about 7% of the waste is recycled.[9] In order to sustain the environment, Jordan needs to effectively manage the waste, including plastic waste. Though some recycling centers exist in Jordan, an article from T*he Open Waste Management Journal* states that Jordan uses landfills as a major method of disposing of waste.[10] As a result, Jordan suffers from environmental pollution, especially groundwater and air pollution.[11] Moreover, the article argues that the current waste management strategy in Jordan is not environmentally sustainable, and encourages the increase in recycling and in recoveries of recyclable material.[12] These findings support the claim that improvements of waste management system and recycling industry are necessary in Jordan. However, these studies omit the discussions of possible hazards in recycled products. An article from Resources, Conservation and Recycling discusses the need to regulate plastic bottle recycling in Europe.[13] Harmful materials that can cause health hazards - mostly heavy metals - were detected from recycled plastic bottles. This study suggests that recycled plastics require more careful investigations because a lot of them contain especially toxic heavy metals. Although this finding did not target Jordan, harmful elements can also be detected from recycled plastics in Jordan; therefore, it is necessary to research heavy metals in recycled plastics produced in Jordan.

The heavy metals from recycled plastics may be detected by using synchrotron accelerators. Technological capabilities of synchrotron accelerator have been researched in the past. The 10th International Conference on Accelerator and Large Experimental Physics Control Systems concluded

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[8] Alhyasat, Ahmad G., Zaidoun Al-Nsourand, and Hajar M. Majar. *Country report on the solid waste management in Jordan.* Report. April 2014.
[9] Ibid.
[10] Aljaradin, Mohammad, and Kenneth M. Persson. "Environmental Impact of Municipal Solid Waste Landfills in Semi-Arid Climates - Case Study – Jordan." *The Open Waste Management Journal* 5, no. 1 (2012): 28-39. doi:10.2174/1876400201205010028.
[11] Ibid.
[12] Ibid.
[13] Welle, Frank. "Is PET bottle-to-bottle recycling safe? Evaluation of post-consumer recycling processes according to the EFSA guidelines." *Resources, Conservation and Recycling* 73 (April 2013): 41-45. doi:10.1016/j.resconrec.2013.01.012.

that Synchrotron Light Interferometers were successful in imaging without invading the sample.[14] The machines use electron beam diagnostic tool to obtain optimized images. These beams, by penetrating the sample, can provide precise images without harming the sample. This study highlights the technological advantage of using synchrotron accelerators for the investigation of a sample. Although this finding is outdated, researchers at the Australian synchrotron prove that the beams from synchrotron accelerators have unlimited scan range.[15] These beams help create X-ray fluorescence spectra, abbreviated as XRF spectra, that indicate the amount of each element in the sample. X-ray is a form of light and fluorescence means emission of light. When an electron hits a sample with high enough energy, the electrons in the samples' atoms are first excited and then return to ground state, emitting light. The light pattern is unique for each element, so spectra of elements can be generated from XRF data. The study is positive with synchrotron accelerators' potentials to be applied to various research fields, including materials analysis. However, these studies don't discuss the direct benefits of investigating recycled plastics through the use of synchrotron accelerators. Synchrotron accelerators are proved to be highly effective for investigating samples, but they have not yet been rigorously used for investigating heavy metals in recycled plastics.

Previous studies prove that improved analysis of recycled plastics in Jordan is necessary and a synchrotron accelerator may be a candidate since it can detect heavy metals in recycled plastics. However, these studies fail to address direct connections between recycled plastics in Jordan and the use of synchrotron accelerators. Moreover, these studies fail to present actual benefits gained from using synchrotron accelerators for detecting heavy metals in recycled plastics. This leads to a gap between the analysis of recycled plastics in Jordan and the detection of their heavy metals through

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[14] Chevtsov, P. *10th ICALEPCS Int. Conf. on Accelerator & Large Expt. Physics Control Systems*. Proceedings, Geneva. October 2005.

[15] Paterson, D., M. D. De Jonge, D. L. Howard, W. Lewis, J. McKinlay, A. Starritt, and M. Kusel. *American Institute of Physics Conference Proceedings*. Proceedings of The X-ray Fluorescence Microscopy Beamline at the Australian Synchrotron. 2011.

the use of synchrotron accelerators. This study attempts to bridge recycled plastics in Jordan and synchrotron accelerator application.

This research will aid the analysis of recycled plastics in Jordan by highlighting how the use of synchrotron accelerator is useful for recycling companies in Jordan. The results of this research will indicate whether the precise detection of heavy metals by synchrotron accelerators has significant technological benefits for improving the quality of recycled plastics in Jordan. With this knowledge, recycling companies will be given a choice for using this precise detecting device. The Jordanian government will have more insight into how it should regulate recycled plastics. Altogether, Jordan will be guided how it should improve recycled plastics and protect the environment.

Hypothesis

The need to be aware of heavy metals in recycled plastics was discussed in pre-existing research. The potential harms in recycled plastics produced in Europe were acknowledged by the investigation of heavy metals in them.[16] Likewise, Jordan may benefit by improving the quality of recycled plastics through the investigation of heavy metals. Since synchrotron accelerators diagnose objects with high precision, as concluded by the 10th International Conference on Accelerator and Large Experimental Physics Control Systems,[17] I believe synchrotron accelerators would bring significant technological benefits for the enhancement of recycled plastics in Jordan by detecting heavy metals in them.

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[16] Welle, Frank. "Is PET bottle-to-bottle recycling safe? Evaluation of post-consumer recycling processes according to the EFSA guidelines." *Resources, Conservation and Recycling* 73 (April 2013): 41-45. doi:10.1016/j.resconrec.2013.01.012.

[17] Chevtsov, P. *10th ICALEPCS Int. Conf. on Accelerator & Large Expt. Physics Control Systems*. Proceedings, Geneva. October 2005.

Methodology

In order to achieve the goal of this research, the analyses of the current circumstances of plastics-recycling companies in Jordan and the data from the SESAME laboratory are necessary. The information about the quality of recycled plastics helps to determine the needs of each recycling company, with the goal of refining the recycled products.

For the purpose of understanding the plastics-recycling processes and the circumstances of recycling companies in Jordan, I conducted semi-structured interviews with the companies. Semi-structured interviews are interviews with freedom of organization and standardized questions.[18] Since detailed information regarding the recycling process and analysis of the products was not present at the companies' websites, I decided to talk to them personally. Furthermore, I specifically chose semi-structured interviews since they are often used for collection of somewhat controversial data; the extent of the benefits from a synchrotron accelerator may differ by different companies. While conducting semi-structured interviews, I followed the guidelines of the Research And Development Corporation whose mandate is to strengthen the focus, quantity, and relevance of research.[19]

I chose companies - three in total - near Amman (the capital of Jordan) because their proximities to the capital would allow them to play important roles in the country's[20] recycling industry. When I conducted the interviews, I began with asking their thoughts about environmental management in Jordan and the companies' present circumstances. These questions were asked to help my understanding of the thoughts of leading recycling companies regarding the environment in Jordan and their roles in the recycling industry. Then, I incorporated questions about the Jordanian government's regulations of recycled plastics and each company's efforts for enhancing the quality

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[18] Harrell, Margaret C., and Melissa A. Bradley. *Data Collection Methods.*Technical paper. National Defense Research Institute. 2009.
[19] Ibid.
[20] "Revealed: The 20 Cities UAE Residents Visit Most." Arabian Business. May 1, 2015.

of recycled plastics. This format was intended to allow companies to provide detailed responses and avoid potential biases.

In order to check the quality of recycled plastics and ascertain whether the use of a synchrotron accelerator provides technological benefits for their improvement, I collected samples of recycled plastics from the companies and sent them to the SESAME laboratory. The samples were collected in forms of pellets since products made of recycled plastics commonly start as pellets. For each company, all of the pellets were produced under the same conditions; therefore, I was able to assume that the pellets were homogeneous in each sample set. Beforehand, a compressor was used to press the pellets because a synchrotron accelerator requires the samples to be very small.

Then, XRF (X-ray fluorescence) analysis was conducted to reveal the compositions of heavy metals in each sample. XRF analysis is a non-destructive analytical technique used for elemental mapping of materials.[21] This research method helped me collect data about the heavy metals in the samples and thus, the samples' quality. All of the samples were examined by the synchrotron accelerator with the use of hard X-rays at an energy of 14 keV - beams of equal intensities. Then, qualitative and semi-quantitative XRF data was collected. (Qualitative XRF data is the data of photon counts per photon energy and semi-quantitative XRF data is comparative spectral data.[22] A photon is the smallest discrete amount of light.[23]) Using this data, XRF spectra were created, indicating the types and the amounts of heavy metals. Obtaining these pieces of information allowed me to make comparisons among elements within each sample and comparisons among samples.

I had originally planned to collect experimental data from the recycling companies. This was intended to compare the use of the synchrotron accelerator and pre-existing methods. However, the companies replied that it was difficult for them to conduct highly advanced experiments on the

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[21] "XRF Technology." Thermo Fisher Scientific.
[22] "Quantitative XRF, Semi-Quantitative and Qualitative XRF Data; How Are They Different? An XRF Data Primer." Bruker.
[23] Puiu, Tibi. "What Exactly Is a Photon? Definition, Properties, Facts." ZME Science. June 23, 2017.

recycled plastics. Because I was unable to collect data from the companies, I decided to use the data from the laboratory to analyze the trends for each of the companies and provide suggestions.

Based on the interviews and the XRF data, needs assessments were conducted. Needs assessment is a research method used to determine the needs of certain groups.[24] I used the Office of National Marine Sanctuaries (ONMS) Science Needs Assessment as a reference. Since the ONMS is also interested in scientific research for the protection of the environment, its research method aligns with my research about the refinement of recycled plastics through the use of a synchrotron accelerator. I integrated the information from the interviews and the lab data, assessing the needs of each recycling company: the extent to which the companies must be aware of the heavy metals in order to improve the quality of their recycled plastics. This method of analysis would show how the analysis of recycled plastics through the use of synchrotron accelerators provides technological benefits to recycling companies in Jordan.

[24] "Overview of ONMS Science Needs Assessment." National Oceanic and Atmospheric Administration Office of National Marine Sanctuaries.

Findings and Analysis

The recycling companies in Jordan revealed information about the country's recycling industry and their circumstances. The interviews were integrated with the data from the synchrotron accelerator laboratory in order to determine the companies' needs and assess how the use of a synchrotron accelerator benefits the companies.

Interviews

Since the interviews were semi-structured, the types of questions were very similar for all of the companies. The companies' responses were summarized to make their long responses more concise. The tables below categorized the responses into questions that covered different aspects of recycling. To protect anonymity, the three companies' names were replaced with Company 1, Company 2 and Company 3.

Table 1: Interview Question 1

	What do you think about the environmental management in Jordan and the current circumstances of your company?
Company 1	We reach out to the public through our connections to shopping malls. We hope to change the mentality of the public who is not familiar with the concept of segregating waste. We believe it is necessary to segregate the waste instead of dumping it all into landfills. Although recycling can greatly support the movement to protect the environment, we think it is essential to first reduce consumption. We help distribute the plastic waste to different recycling sites. We started small and continued growing slowly but steadily.
Company 2	The efforts to protect the environment must not be driven by profit. We hope to change the tendency to seek material profits as a motivation for recycling. Our recycling site neighbors several dump sites. We produce about 20~30 tons of recycled plastics per month.
Company 3	Recycling has limits because products that have been recycled over a long time may not be as competitive as newly produced products. Therefore, we put heavy emphasis on ensuring that our products have high quality. We hope to seek new methods to generate the electricity (like solar panels) due to the heavy cost of the electricity.

Table 2: Interview Question 2

	To what extent does the Jordanian government regulate products made from recycled plastics?
Company 1	There is no process for treating hazardous waste. We believe the government needs to regulate the use of plastics. There is no process of receiving waste by individual household, and most recycling sites are only allowed to be located far away from highly populated regions. We are only licensed to be at Amman because of our connection to shopping malls. We think the government must provide more support to the recycling industry in Jordan.
Company 2	Currently, there are few rules regulating the quality of recycled plastics. However, the Ministry of Environment (a branch of the Jordanian government) told us they may set new rules in the future, requiring certain materials to be put in the products. The materials were not specified yet.
Company 3	Though all of the recycling companies must be licensed by the government, there are no specific regulations on chemical compositions of locally recycled plastics. Still, the government began to recommend the products to be biodegradable.

Table 3: Interview Question 3

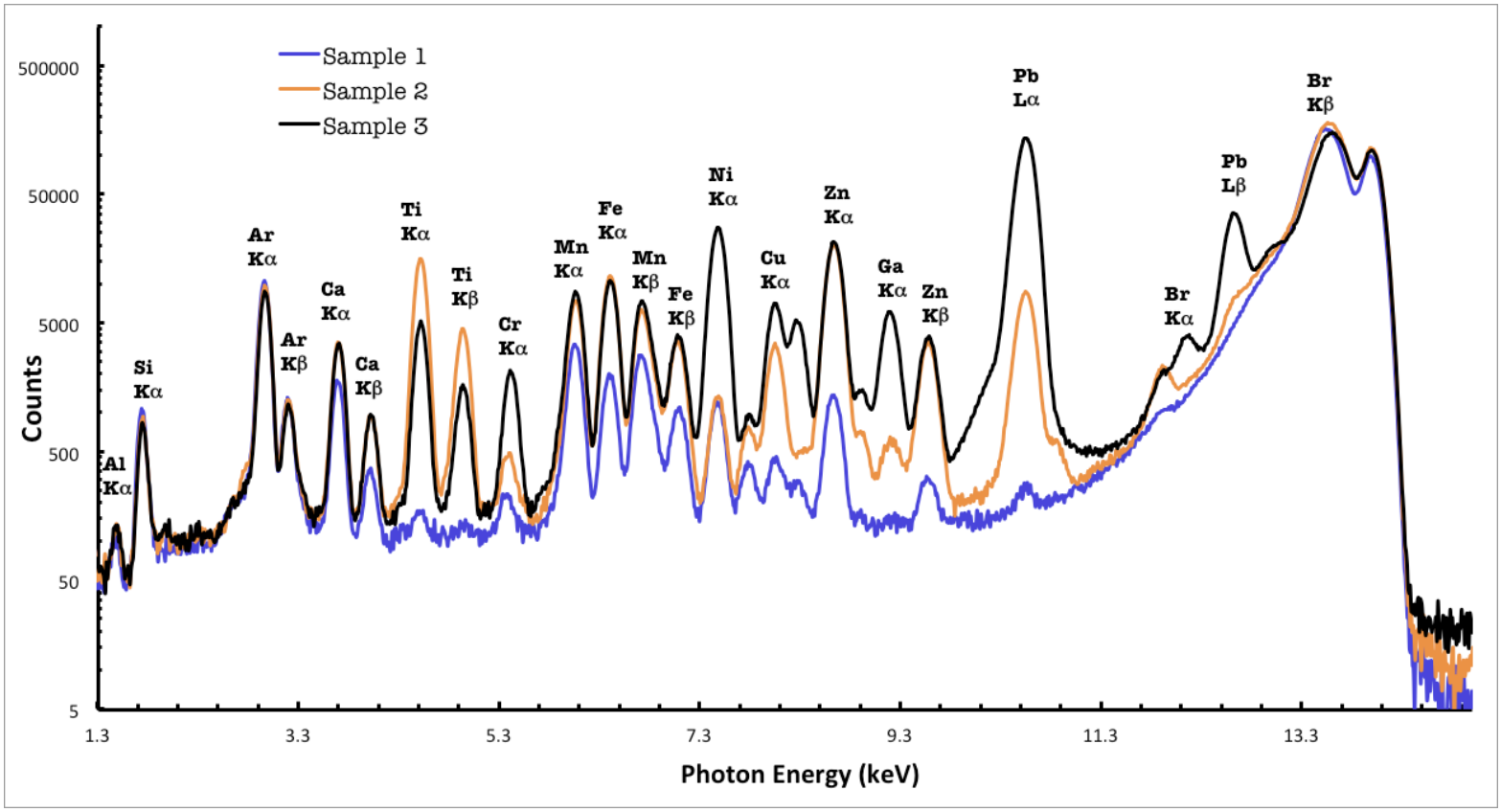
	Please describe your efforts to enhance the quality of recycled plastics.
Company 1	We first bail the waste and separate it depending on the type. We then store the waste and send it to factories. Sometimes, we use pressing machines to save space. No labs are conducted.
Company 2	At the initial stage, we sort the plastics to prevent them from mixing with one another. As we recycle, we use water baths and detergent to clean the pre-recycled plastics. When there are failed products, we shred and recycle them again. No labs are conducted.
Company 3	At the initial stage, we sort the plastics and remove foreign material so that the products are not damaged. As we recycle, we carefully choose different types of plastics depending on their properties. No labs are conducted.

The interviews reveal that the Jordanian government does not have specific regulations about the chemical compositions of recycled plastics. The size of the recycling industry in Jordan is also quite small. The general trend among the companies is that highly advanced experiments are usually not conducted on recycled plastics. Still, the use of synchrotron accelerators may be beneficial for the improvement of recycled plastics by helping the companies determine heavy metals in their products.

Sample Data Results

Data of the elements in the samples was obtained from the SESAME laboratory. The data was analyzed by using PyMca (Python Multichannel Analyzer), a software used for XRF data analysis.[25] The data was first calibrated and then different theoretical models fit into the data. Using the data, XRF spectra were generated. The graph below combines the spectra, and it supports the visualization of heavy metal compositions in all three samples of recycled plastics. A logarithmic scale (scale based on multiplication) was used because it allows for a large range of data, making it effective for the representation of photon data.[26]

Graph 1: Photon Counts vs Photon Energy for all three samples



This graph shows the element symbols. Refer to the Appendix for the name of each element.

[25] "PyMca." PyMca.
[26] "Linear vs Logarithmic." Cool Cosmos.

The graph above reveals the amounts of heavy metals in the samples. Each sample had different amounts of heavy metals. The data analysis for each sample was organized in the table below, including the comparisons among the elements in each sample and comparisons among samples. These comparisons serve the purpose of indicating notable heavy metals in each sample and the significance of the amounts of heavy metals in regards to their amounts in peer samples. Furthermore, it allows the companies to acknowledge what further improvements are necessary in their products.

Some information from the graph was not discussed. Firstly, the discussion of elements that are not heavy metals (Aluminum, Silicon, Argon, Calcium and Titanium) was omitted because this research paper only considers compositions of heavy metals. Secondly, the discussion of photons of types Kβ and Lβ was omitted. Photons of types Kβ and Lβ are photons emitted from electron shells different from the electron shells from which photons of types Kα and Lα are emitted.[27] Still, these photons are mostly emitted from the same atoms and photons of types Kα and Lα are the primarily emitted photons. Therefore, the counts of photons of types Kβ and Lβ can be regarded as negligible.

Table 4: XRF Data Analysis for each sample

	Heavy Metal Composition
Sample 1	The smallest photon counts were detected, indicating the lowest amount of heavy metals. The photon counts range from about 200 (for chromium, zinc and lead) to 2000 (for iron and manganese). Iron and manganese, with the highest photon counts of about 2000, are heavy metals that are the most abundant in sample 1. Still, their amounts in sample 1 are lower than their amounts in samples 2 and 3, which have about 10,000 photons emitted from each iron and manganese. Very small amounts of arsenic and cobalt were detected, which can be seen from the absence of the peaks at their corresponding photon energies.
Sample 2	Though the amount of iron is the highest in sample 2 (photon counts of about 10,000) out of the three samples, the amounts of most heavy metals range in the middle of the three samples. The amount of nickel in sample 2 is similar to its amount in sample 1 (photon counts of about 1,500), while the amounts of manganese and zinc in sample 2 are similar to their amounts in sample 3 (photon counts of about 10,000 and 5,000, respectively). Iron, manganese and lead, with

[27] "Characteristic X-Rays." HyperPhysics.

	the highest photon counts of about 10,000, are heavy metals that are the most abundant in sample 2. Very small amounts of arsenic and cobalt were detected, which can be seen from the absence of the peaks at their corresponding photon energies.
Sample 3	In general, the largest photon counts were detected, indicating the highest amount of heavy metals. The range of the photon counts is the highest, spanning from about 1,500 (for chromium) to 100,000 (for lead). Lead, with the highest photon counts of about 100,000, and nickel and zinc, with the photon counts of about 50,000, are heavy metals that are the most abundant in sample 3. Although iron and manganese are not the most notable heavy metals in sample 3, their amounts were similar to or greater than their amounts in other samples; the peaks of iron and manganese for sample 3 were similar to or higher than their peaks for other samples. Very small amounts of arsenic and cobalt were detected, which can be seen from the absence of the peaks at their corresponding photon energies.

Needs Assessment

Then, a needs assessment was done on each company. The analyses of the interviews and the lab data informed the need of each company. The needs assessment revealed the extent to which the use of synchrotron accelerator would be technologically beneficial for each recycling company. Since these companies are greatly involved in the recycling industry in Jordan, the needs assessments were assumed to be generally applicable for most of the recycling companies in Jordan.

Company 1: The company's main concern is the lack of initiatives to voluntarily reduce consumptions or segregate household waste, not the enhancement of recycled plastics. Still, it mentions Jordan's lack of regulations upon management of hazardous waste, which is related to the elimination of toxic heavy metals in recycled plastics. Though the company does not conduct laboratory experiments, its product has comparatively low quantities of heavy metals, shown by the lowest photon counts range from about 200 to 2000. The data shows that the company may not need to put heavy emphasis on the investigations of heavy metals in their products; therefore, the company would not have a high demand for precise investigations by synchrotron accelerators.

Company 2: Although the company mainly emphasizes the need to change the reasoning behind recycling (e.g. seeking profits from recycling), it is also interested in the quality of recycled plastics. Its knowledge of the new laws about materials put in recycled products or its use of water baths and detergents prove its efforts to sustain the quality of its products. However, the company does not conduct laboratory experiments. The data reveals that the product has abundant amounts of heavy metals. There are especially greater amounts of manganese, iron and lead, with photon counts of about 10,000 for each metal. It is advised that the company put more attention to these metals while it recycles or investigates. The neighboring dump sites or the detergents may be possible sources of the heavy metals. The company would further benefit from the investigation of the substances put in during manufacturing or brought in from the surrounding area, which would indicate what the company should be aware of during the recycling process. Therefore, the company would have a high demand for these investigations by synchrotron accelerators.

Company 3: According to the interview, this company has extensive knowledge of and interest in the quality of recycled plastics. For example, the company is aware of the fact that recycled products may not be as competitive as newly produced products or that different types of plastics have different properties. These pieces of evidence prove the company puts a lot of effort into ensuring the quality of their products. However, laboratory experiments are not conducted. The data reveals this company's product has the highest amount of heavy metals, shown by the highest range of photon counts from about 1,500 to 100,000. Lead (photon counts of about 100,000), nickel and zinc (photon counts of about 50,000 for each) are heavy metals that are the most abundant, so it is advised that the company put more attention to these metals while it recycles or investigates. The interview implies that the surrounding environment seems to be the source of the heavy metals. The company would benefit from the investigation of their surroundings, which would indicate what the

company should be aware of during the recycling process. Therefore, the company would have a high demand for the investigations by synchrotron accelerators.

Conclusion

Based on the information collected from the interviews and the SESAME laboratory and the needs assessments, it is proven that synchrotron accelerators provide significant technological benefits to recycling companies in Jordan. My hypothesis that synchrotron accelerators would technologically benefit Jordan's recycling companies by detecting heavy metals in recycled plastics was proven to be true. The data from the SESAME lab indicates the elements that the companies may want to be more aware of, which serves as a guide to the companies for the elimination of toxic heavy metals and improvement of the quality of recycled plastics. Though the data from Sample 1 shows that Company 1 does not need investigation tools as precise as synchrotron accelerators, this conclusion was possible from using a synchrotron accelerator. The interviews show that although there were many similarities between the companies, some specifics were different. The data from synchrotron accelerators would significantly support the companies as the companies interpret the data individually, depending on their circumstances or recycling processes.

The results from this research have multiple implications. Firstly, the plastics recycling companies in Jordan have insights to the technological advantages that the use of a synchrotron accelerator brings. This allows them to consider using a synchrotron accelerator as an option for investigating their products. Additionally, recycling companies that treat other types of waste or recycling companies in other countries can be introduced to the use of a synchrotron accelerator. Secondly, the results help guide the synchrotron accelerator laboratory to focus on certain types of hazardous elements in future investigations of similar products. Finally, the Jordanian government is encouraged to recognize the roles of the synchrotron accelerator and use the results as a reference as they continue to seek ways to further protect the environment from harmful elements in recycled plastics.

Although the synchrotron accelerator was proven to provide technological benefits during the investigations of recycled plastics, there are some limitations in the conclusion. This research

primarily focused on the technological aspects of the use of a synchrotron accelerator. Firstly, while the accelerator is a powerful imaging tool, it may not be easily accessed by the recycling companies. According to a report by International Centre for Theoretical Physics, the average cost for a complete analysis with a synchrotron accelerator is about €40,000,[28] which can be financially burdening. The discussion of financial feasibility was omitted because it deviates from the topic of this research: technological benefits from synchrotron accelerators for the investigation of recycled plastics in Jordan. Secondly, it is difficult to compare the XRF data to the pre-existing standards for each heavy metal. Due to the difficulty to obtain samples of known concentration, obtaining the exact values of the concentrations of each heavy metal was impossible. There also was a lack of heavy metal standards that were comprehensive enough for application to recycling companies. Despite these limitations, the research method used in this paper allowed me to get enough information to support the claim that synchrotron accelerators are technologically beneficial during the investigation of recycled plastics in Jordan.

The results from this research show the general trends of heavy metals in recycled plastics produced in Jordan. The trend would help researchers to analyze the elements that require more extensive research in the future. For example, all three samples had some amounts of manganese, iron, nickel and zinc. Although there were differences in these amounts among the companies, the types of notable heavy metals were similar. It is advised to do further research relating the recycling industry in Jordan and these commonly appearing heavy metals. The materials put into the recycled products or the environment around the recycling sites are some aspects of the recycling industry that may need further analyses. Additionally, the same element can have different toxicities depending on the molecular structure or the nuclear structure. This means that some elements may require more in-depth investigation, especially about their forms. These future studies would continue to inform the recycling companies of what's necessary to improve the quality of recycled plastics.

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[28] *ICTP Full Technical Report 2014.*Technical paper. 2014.

Even if recycled plastics potentially contain hazardous substances, the harm that unrecycled waste brings to the environment cannot be ignored either. A synchrotron accelerator cannot break down molecules and form new substances. Since the synchrotron accelerator was the only running particle accelerator in Jordan when I conducted this research, it was difficult to research the dissociations of plastic molecules using a particle accelerator. Jordan plans to finish constructing other particle accelerators in the future, including ones that can break down molecules. In order to have a full insight of the benefits that particle accelerators bring to the recycling industry, future studies of the benefits from using particle accelerators at different stages of recycling - instead of only analysing the quality of the finished product - is necessary.

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"XRF Technology." Thermo Fisher Scientific.

Appendix

Element Symbol	Element Name
Al	Aluminum
Si	Silicon
Ar	Argon
Ca	Calcium
Ti	Titanium
Cr	Chromium
Mn	Manganese
Fe	Iron
Co	Cobalt
Ni	Nickel
Cu	Copper
Zn	Zinc
Ga	Gallium
Pb	Lead
Br	Bromine
As	Arsenic