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Metal Contamination in Low-Cost Jewelry and Toys in Cambodia

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Background. The existence of lead-contaminated consumer products is a global issue. Toys and low-cost jewelry may contain toxic metals and Cambodia is known to have consumer products with toxic metals.

Objectives. It is important to inform Cambodians about sources of toxic metals so that they can reduce their exposure risk, particularly for children.

Methods. Student volunteers purchased, or brought from home, low-cost jewelry and toys to either the University of Health Science or a Don Bosco Institute in Phnom Penh, Cambodia, where they were analyzed using X-ray fluorescence (XRF). The initial analysis was performed in 2011. A subset of the 2011 samples was re-analyzed in 2015 using new preparation techniques and a new x-ray fluorescence (XRF) unit.

Discussion. The analysis of low-cost jewelry in Phnom Penh in 2015 indicated that lead in jewelry clasps is a more serious health concern than was first perceived in 2011. Mercury, nickel, cadmium and copper were also found in toys, and occasionally these toys had been produced by well-known companies. Sources of jewelry production of samples in the present study are unknown. Lead in clasps in low-cost jewelry appeared to be the greatest risk to children in our sampling.

Conclusion. One-third of toys and low-cost jewelry exceeded the United States and European Union guidelines for heavy metals. XRF analysis allows for rapid screening of lead and other toxic metals and could be used to reduce the sales of low-cost jewelry and toys containing toxic metals.

Competing Interests. The authors declare no competing financial interests.

Keywords. Toxic metals, lead, toys, cosmetic jewelry, Cambodia

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Introduction

Cambodia imports most of its consumer products from nearby countries and the rate of economic growth of Cambodia has produced a high demand for consumer products.¹ This influx of consumer products requires a more rapid, effective system of quality control. Consumer products that are imported and sold in Cambodia can contain chemical contaminants that pose serious adverse health effects to consumers. About one-third of the skin creams analyzed in Phnom Penh contained mercury (Hg) in amounts higher than

the Association of Southeast Asian Nations (ASEAN) recommended guideline of 1 $\mu\text{g/g}$.^{2,3} Ninety percent of the enamel paints sampled in Cambodia exceeded a voluntary standard of 100 $\mu\text{g/g}$ lead (Pb) of the producing country, Thailand.⁴ The problem is not limited to Cambodia, as studies in the US, India, and China have found elevated Pb in children's toys, low-cost jewelry, and paints.^{5,6,7}

Elemental Pb is added to paints and plastic toys as a coloring agent and to prevent free radicals from reacting to

form hydrochloric acid.^{7,8} Sources of metals used to make low-cost jewelry include recycling facilities for lead acid batteries and electronic wastes.^{9,10} Such recycled metals lower the cost of manufacturing and imitate shiny, better quality jewelry.

Common effects of Pb in children include reduced intellectual capacity, anemia, kidney damage and a suppressed immune system.^{11,12,13,14,15} Blood lead levels (BLL) as low as 3 $\mu\text{g/dl}$ were associated with neurobehavioral deficits in visual

motor integration, attention, reaction time and off-task behaviors.¹⁶ Bellinger¹⁷ found that adverse outcomes such as reduced IQ performance and academic deficits occurred at BLL <10 µg/dl, and at prolonged exposure there was association with attention deficit hyperactivity disorder (ADHD). Similarly, children aged 2 through 5 years had an 18-point increase in the Total Behavior Problem Score (TBPS) if their BLLs were higher than >15 µg/dL.¹⁸

Lead in Inexpensive Jewelry

In the United States, there are at least 4 million households with children who have been exposed to Pb, and approximately half a million US children one to five years old with BLLs above 5 µg/dL.¹⁹ Recognizing that Pb exposure can affect every system in the body, the United States (US) Centers for Disease Control and Prevention (CDC) initiated a Childhood Lead Poisoning Prevention Program which is committed to eliminating BLLs > 10 µg/dL by 2020.¹⁹ However, despite efforts to eliminate Pb exposure in children, there have been numerous cases reported in which workers and children have been the victims of Pb exposure. One of the lead exposure pathways is low-cost jewelry items, which are imported into the US from developing countries such as China.⁶

A study conducted by Weidenhamer and Clement⁶ found that 77 out of 130 inexpensive jewelry samples imported from China to the US exceeded the former United States Consumer Product Safety Commission (USCPSC) guideline of 0.06% (600 µg/g).²⁰ Moreover, out of 311 inexpensive jewelry samples purchased, Maas *et al.*²¹ found more than 50% of samples contained more than 3.0% Pb in at least one portion of

| Abbreviations | | | |
|---------------|----------------|-----|--------------------|
| As | Arsenic | Ni | Nickel |
| Cd | Cadmium | Pb | Lead |
| Cr | Chromium | Sb | Antimony |
| Cu | Copper | Sn | Tin |
| EU | European Union | XRF | X-ray fluorescence |
| Hg | Mercury | Zn | Zinc |

the jewelry piece, while 39.5% of the samples contained more than 50% Pb and 29.2% contained more than 75% Pb.

The above findings were highlighted by the death of a four-year old child in Minnesota after ingesting a charm composed of 99.0% Pb and stress the need to improve monitoring and regulation of imported Pb-containing products in the US.²² In 2011, the Consumer Product Safety Commission (CSPC)²³ issued a recall of 150 million pieces of metallic toy jewelry due to concerns over Pb levels.

A similar, serious incident was reported in 2009 when an American-born child of Cambodia-born parents was found to have been wearing an amulet obtained from a monk in Cambodia that contained more than 45% Pb. The level of Pb in his blood was 20 µg/dL.²⁴ Subsequently, the CDC²⁴ advised parents who had traveled to foreign countries and may have had their children wearing amulets or inexpensive jewelry items obtained from these countries to register for a BLL test out of concern over potential Pb contamination.

A recent analysis of low-cost jewelry in China found items with 65% Pb, 71% copper (Cu) and 37% cadmium (Cd), and 3-7 other samples had high levels of metals.²⁵ A survey in Seattle of children's jewelry in 2015 indicated that lead was still present in 23% of samples; the highest Pb concentration of 50,100 µg/g was lower than found in some earlier surveys, probably reflecting improved monitoring and management.²⁶

Lead in Plastic Toys

In plastic toys, Pb is used as a pigment for color or as a stabilizer to provide rigidity and high heat stability.⁹ Toys are an integral part of a child's development.¹⁰ Children with their hand-to-mouth habits can chip off parts of the surface of the contaminated toy, or leach the toxic element in their mouths. Because toys play an important role in a child's development during the hand-to-mouth stage, toys contaminated with Pb can obstruct a child's neurological development.²⁷

Similar to inexpensive jewelry, over the past few years there have been multiple recalls of toys because of

chemical safety hazards.²⁸ Table 1 reviews selected recalls on children's toys containing excessive Pb concentrations between 2004 and 2016. In India, Kumar and Pastore¹⁰ tested 111 non-branded toy samples and found a level of Pb ranging from

0.65 – 2104 $\mu\text{g/g}$ with the Mumbai average having the highest level (278.3 $\mu\text{g/g}$). Twenty percent of the painted toy samples analyzed exceeded the US Environmental Protection Agency (USEPA) guideline at the time of 600 $\mu\text{g/g}$. In Turkey, Aliyev *et al.*²⁹

collected 50 toys, 19 of which were manufactured in Turkey and 31 were imported from China. The results from the atomic absorption spectrometry analysis indicated that the mean Pb on the surface of the toys imported from China was 85.3 $\mu\text{g/g}$, compared

| Distributor | N | Description | Substrate | Origin | Year |
|--------------------------|---------|----------------------|-------------|--------|--------------------|
| Four firms | 1500000 | Toy jewelry | Paint | India | 2004 ²³ |
| Fisher-Price | 967000 | Toys | Paint | China | 2007 ³⁵ |
| Mattel Inc. | 253000 | Toy cars | Paint | China | 2007 ³⁶ |
| Greenbrier | 300000 | Beads & cars | Paint | China | 2008 ³⁷ |
| Toys "R" Us | 16000 | Military figures | Paint | China | 2008 ³⁸ |
| S.U. Wholesale | 5000 | Toys | Paint | China | 2008 ³⁹ |
| Oriental Trading Co. | 220000 | Toy banks | Paint | China | 2008 ⁴⁰ |
| Sportime | 1000 | Sports balls | Paint | China | 2010 ⁴¹ |
| Playmates toys | 252000 | Jewelry | Metallic | China | 2010 ⁴² |
| Blip toys | 15000 | Toys | Paint | China | 2010 ⁴³ |
| Jide Trading | 2100 | Military toys | Paint | China | 2010 ⁴⁴ |
| S&S Worldwide | 1000 | Wooden beads | Paint | China | 2010 ⁴⁵ |
| LM Import & Export | 1900 | Toy cars | Paint | China | 2011 ⁴⁶ |
| Build a Bear Workshop | 28900 | Toys | Paint | China | 2011 ⁴⁷ |
| Cost Plus Inc. | 1000 | Toy drum | Paint | China | 2011 ⁴⁸ |
| G.A. Gertmenian | 600 | Toy bowling | Paint | China | 2011 ⁴⁹ |
| Dillon Importing | 6970 | Toy guns | Paint | China | 2012 ⁵⁰ |
| Lee Carter Co. | 7000 | Wrestling figures | Paint | China | 2012 ⁵¹ |
| Discount School Supply | 3700 | Educational game | Paint | China | 2014 ⁵² |
| Minga Fair Trade Imports | 135 | Toys | Paint | Peru | 2014 ⁵³ |
| Things Remembered | 10000 | Jewelry | Metallic | China | 2014 ⁵⁴ |
| GSI Outdoors | 6700 | Water bottles | Lead solder | China | 2016 ⁵⁵ |
| Far East Brokers | 6000 | Children's furniture | Paint | China | 2016 ⁵⁶ |
| LaRose Industries | 170000 | Jewelry | Metallic | China | 2016 ⁵⁷ |
| KHS America | 150 | Musical toy | Paint | Israel | 2016 ⁵⁸ |

Table 1—Toys Recalled Due to Lead Contamination—US Consumer Safety Product Commission

2004-2008 are examples of recalls, whereas 2010-2016 are inclusive of recalls by CPPC

| Color* | Standard value | LPA-1 XRF | XRF 3t |
|--------|------------------------|-----------|--------|
| Yellow | 1.0 mg/cm ² | 8765 | 8389 |
| Green | 1.9 mg/cm ² | 16450 | 15555 |

Methods

XRF Calibration

The XRF analyzer (Niton Thermo Fisher, Billerica, MA; model XL3t) used in the initial analysis in 2011 was calibrated in the Thermo Fisher Scientific Laboratories (Billerica, Massachusetts, USA), verified several times in Phnom Penh with certified reference materials supplied by Thermo Fisher Scientific, and validated by comparison with another independent portable analytical tool, LPA-1 XRF, provided by the Environmental Health and Safety Office of Buffalo State, State University of New York. The LPA-1 XRF had been compared to other analytical procedures.³² Consumer products were measured using either a general metals or plastic mode setting. The validation results are shown in Table 2.

In 2015, a new Niton XL3T970 handheld XRF analyzer was used to re-evaluate the clasps of jewelry collected in 2011. In 2015, we developed a simple technique to increase the size

Table 2— Calibration of XRF XL3t and LPA-1 XRF with a Certified Reference Material

Note: Values are in µg/g

*NIST Certified Reference Material, RMD Inc. Colors refer to paint reference materials.

with 41.4 µg/g for the toys made in Turkey. The difference in Pb content between these two groups of toys was significant (P<0.05).

Despite several federal recalls on toys contaminated with high levels of Pb, the following study continued to find excessive Pb content in children’s plastic toys. Greenway and Gerstenberger⁷ analyzed 535 toys collected from 10 different daycare centers in Las Vegas, Nevada using an XRF analyzer (XLt 797 2W) and found 29 toy samples (5.4%) contained a Pb concentration higher than the USCPSC standard in 2008 of 600 µg/g. There have been several reviews of an acceptable Pb level for toy surface coatings and paints, and the current

US Pb guideline has been reduced to 90 µg/g.³⁰ The European Union (EU) has three categories for heavy metals in toys with the scraped-off category (160 µg/g for Pb) (Table 3) being the most relevant to toys in our study. Although significant, the concentrations of Pb in plastic toys in the literature are generally much less than that found in low-cost jewelry.

The purpose of this study was to use a handheld X-ray fluorescence analyzer (XRF) to evaluate the lead content in inexpensive jewelry and plastic toys that are sold in markets in Phnom Penh, Cambodia and compare the findings with the European Standard EU EN 71-3:2013 for scraped-off materials.³¹

| | As | Cd | Cr | Cu | Hg | Ni | Pb | Sb | Sn | Zn | |
|------------------|--------------|------|------|-----|--------|--------|--------|--------|-------|--------|-------|
| LOW-COST JEWELRY | Max detected | 1704 | 3786 | 290 | 827366 | 677 | 477694 | 706510 | 66890 | 987706 | 21267 |
| | EU Guideline | 47 | 17 | 460 | 7700 | 94 | 930 | 160 | 560 | 180000 | 46000 |
| | % EU Guide | 4.5 | 12.5 | 0 | 18.2 | 3 | 13.6 | 19.1 | 15.9 | 1.1 | 0 |
| | % 100x EU | 0 | 1.1 | 0 | 2.3 | 0 | 0 | 11.2 | 1.1 | 0 | 0 |
| TOYS | Max detected | 4160 | 107 | 434 | 495469 | 204479 | 95551 | 3520 | 590 | 12239 | 90685 |
| | EU Guideline | 47 | 17 | 460 | 7700 | 94 | 930 | 160 | 560 | 180000 | 46000 |
| | %EU Guide | 6.3 | 4.8 | 0 | 6.3 | 26 | 7.9 | 4.2 | 1.8 | 0 | 31.8 |
| | % 100x EU | 0 | 0 | 0 | 0 | 6 | 1.5 | 1.4 | 0 | 0 | 0 |

Table 3—Heavy Metal Content of Low-Cost Jewelry and Toys

Max detected is the maximum detected concentration of metal.

% EU Guide is the percentage of samples that exceeded the EU guideline for scraped-off metals.

% 100x EU is the percentage of samples that exceeded the EU guideline for scraped-off metals by 100x.

of the clasps. The new XRF analyzer was calibrated in the Thermo Fisher Scientific laboratories, Hong Kong, and verified several times in Phnom Penh with certified reference materials supplied by Thermo Fisher Scientific. Furthermore, in 2015 a new Niton XL3T970 XRF analyzer with “small spot” capability was used at Cleverich Inc., Bangkok, to assess the added value of this instrument enhancement for this type of analysis.

Lead Content in Low-Cost Jewelry

Inexpensive jewelry pieces were purchased by student volunteers randomly from three markets in Phnom Penh, while other jewelry owned by female students attending a vocational training institute at the time (Don Bosco Vocational Training Institute) was analyzed in 2011. In total, there were 89 jewelry pieces, most of which cost less than US \$5 each. Although the origin of these jewelry pieces could not be geographically determined, it is likely that they were imported from neighboring countries and China, but some might have been made in Cambodia.

Prior to and after the analysis, jewelry pieces were kept in plastic bags to prevent cross contamination. Because the jewelry pieces were different from one another in terms of length, composition and style, the jewelry part analyzed varied from one sample to another. Because we were concerned the jewelry clasps might be richer in lead (soft and dense) than the XRF results indicated, the 2011 clasps were stored for further analysis. In 2015, prior to XRF analysis, the clasps were flattened with a hammer into disks 7 mm to 10 mm in diameter. Subsequently, they were analyzed using the new model XRF in Cambodia and in Bangkok, using the “small spot” unit.

Lead Concentration in Toys

Seventy-one children’s toys were purchased by students from local markets, and some by the senior author in Thailand. After the toys were tested on Plastic or General Metals mode for 30 seconds, they were kept in plastic bags in the laboratory or returned to the donor. All were collected in 2011.

Results

Lead Concentration in Low-cost Jewelry

Of the 89 jewelry pieces tested, 35% failed the EU guidelines for heavy metals. Of these, 18% were found with more than 160 $\mu\text{g/g}$ Pb, the EU guideline for lead in scraped-off materials. Of concern is that 11% of these 88 samples contained 100 times the EU guidelines for lead.³¹ These results, presented in Table 3, illustrate the lead content as measured directly with the Niton XL3T970 in 2015. In 2011, the concentration of lead measured with a XRF XL3t in the same 10 jewelry clasps was significantly less (Figure 1). It appears that the older analyzer was not as accurate in measuring small pieces,

i.e. 4 mm in diameter or 10 mm by 4 mm. Furthermore, the analysis showed higher Pb levels in the clasps when they were flattened into a thin sheet and measured with the Niton XL3T970 in 2015 (Figure 1). The mean Pb concentration of the 10 clasps as measured in 2011 was $8.9 \pm 9.6\%$; $40.2 \pm 22.2\%$ in 2015 (unflattened); and $76.7 \pm 12.2\%$ in 2015 (flattened). These latter clasps exceeded the EU guidelines for Pb in scraped-off materials of 160 $\mu\text{g/g}$ Pb by 5000-fold. Although the increase in the diameter of the flattened clasp might appear to produce this effect, the details of the analysis suggest that the increased signal reflects a surface coating of copper and nickel (Ni) over a relatively pure lead core with minor impurities, especially antimony. In Figure 2, a relatively strong relationship between the lead and copper content of the clasps can be seen. The three outlying data points in Figure 2 are samples with about 40% nickel, which is considerably higher than the other clasps. These three outlying data points pull the line down from the rest of the data set. Excluding these outliers is one option, but an equivalent response is formed when the copper and nickel content are combined and plotted against the lead content, showing a strong relationship ($r^2 = .994$)

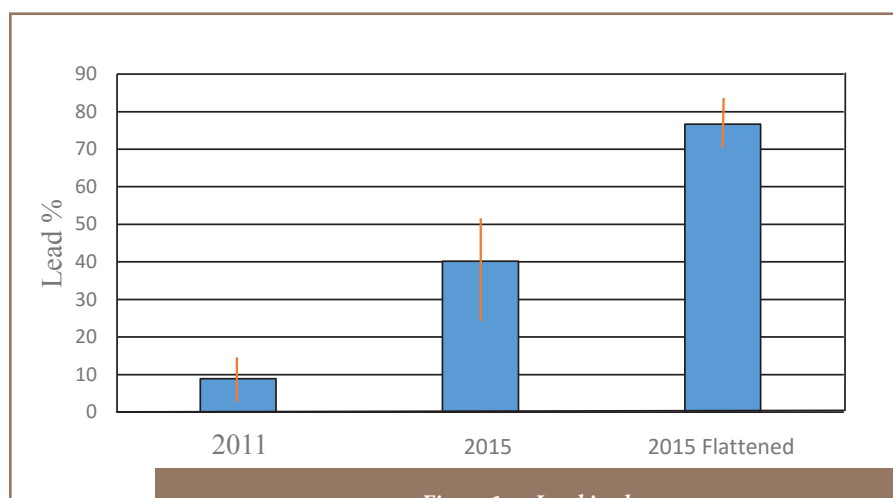


Figure 1 — Lead in clasps

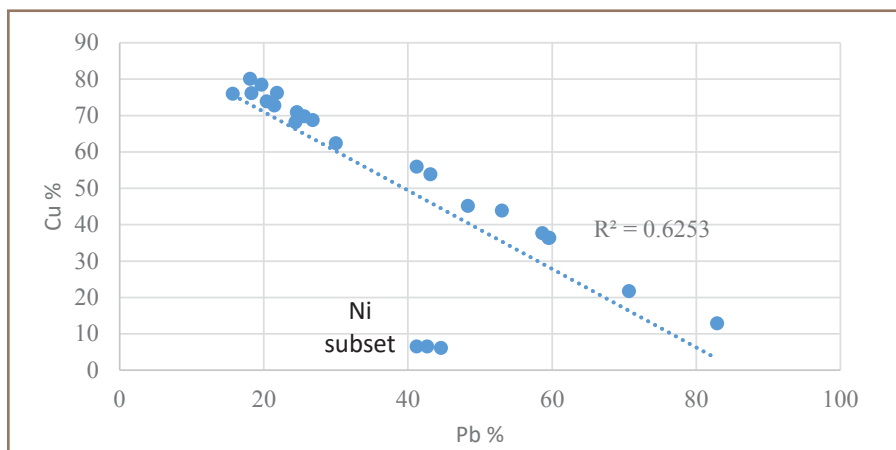


Figure 2—Lead clasps plated by copper

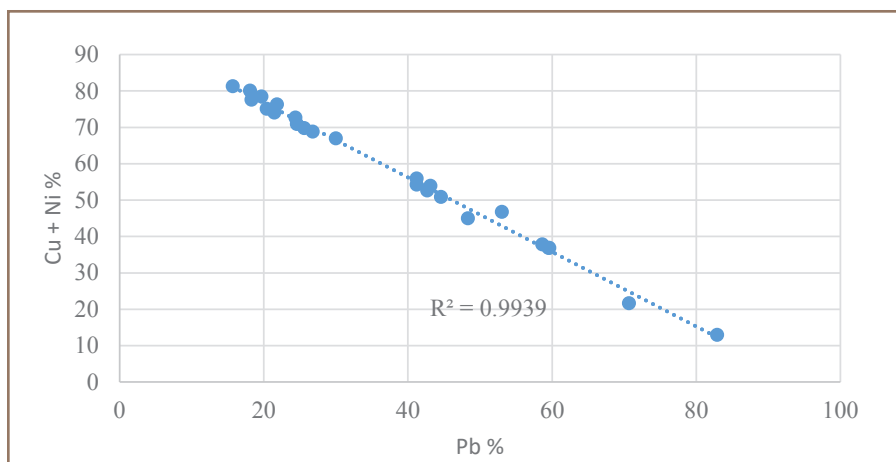


Figure 3—Lead clasps plated by copper and nickel



Figure 4—Toy car with paint chipped off

(Figure 3). When the clasps were flattened, sometimes the sides of the clasp looked quite different, with one side being much richer in lead and containing less copper and nickel. One flattened clasp was very different, with the lead content of one side at 39.3% and the other at 83%. Because of the high metal content, the analytical error was small. Prior to flattening, the 10 clasps processed in 2015 in triplicate had an average relative standard deviation of 10.2%. Further analysis supported this interpretation. We used another Niton XRF analyzer with “small spot” capability that can measure pieces 3 mm in diameter. For three jewelry clasps, in the “small spot” analysis, the lead content of the initial analysis and the flattened clasp was $61.9 \pm 26.9\%$ and $84.0 \pm 5.3\%$, respectively. It is not possible to compare the results of the earlier analysis in 2015 to the “small spot” analysis, as flattening the clasp is a one-way destructive process. Furthermore, flattening removes any uncertainty about small size weakening the analysis.

Jewelry clasps of necklaces contained the highest levels of Pb, but other jewelry pieces commonly contained some lead: hairclips, $88,224 \mu\text{g/g}$; earrings, $72,070 \mu\text{g/g}$; necklaces, $64,544 \mu\text{g/g}$; bracelets, $14,030 \mu\text{g/g}$; rings, $3,523 \mu\text{g/g}$; and anklets, $1,632 \mu\text{g/g}$.

Lead most commonly seriously exceeded the EU guidelines, but Ni, Cu, Cd and antimony (Sb) also commonly exceeded the EU guidelines (13% to 18% of samples). Only zinc and chromium did not exceed the guidelines.

Metal Contamination in Toys

Out of 71 toy samples tested, four toys (6%) contained more than 100-fold the EU Hg guideline, i.e. $>1\%$ Hg, and 26% of toys failed the EU guidelines due to mercury. In two toy cars, the mercury-containing paint (1-2%) readily chipped off (Figure 4). Nickel and lead were

also present in concentrations 100 times greater than the EU guidelines. Overall, 38% of toys failed the EU guidelines.

Discussion

The greatest health risk in low-cost jewelry is associated with lead, particularly in the clasps. Newer model XRF analyzers are very effective for screening lead, even with small pieces. At times, a surface coating can partially mask the actual lead content, but by flattening the item, a better estimate of the total lead content can be made. These coating interferences have been reviewed by Maas et al.²¹ Our limited analysis of the small spot feature indicated that this feature would not resolve an underestimation of lead, as often there are surface coatings. It is possible that higher energy XRF analyzers using radioactive sources of X-rays, such as is used to measure leaded paint under layers of paint, might do a better job of detecting high levels of lead under surface coatings. In university environments, particularly when the XRF analyzer is used in educational clinics, the use of more powerful XRF analyzers might create restrictions. For example, licensing of more powerful XRF analyzers is more difficult.

Students can learn a lot about toxic metals in educational clinics.³³ Students can also educate their families and friends, and thus reduce the general exposure to toxic metals. This is a very effective way to get important information to the people most at risk. Moreover, having students collect items for analysis can remove the bias associated with purchasing of consumer goods; vendors often detect professionals and avoid selling bootleg items.

Handheld XRF analyzers with x-ray tubes and lower energy x-rays are

sufficient for educational clinics and adequate for any review of toxic metals in such products. There is a great deal of variation in the coating on the clasps, including relatively pure lead, lead coated with a mixture of lead and copper, and primarily lead plated with nickel. It is possible that the nickel and copper might reduce the extraction of lead in gastric solutions, and this question should be resolved, but this would not make these clasps safe. There is still a high lead content on the surface of many clasps. Jewelry vendors at times admit to selling jewelry that can initiate skin irritations, and point out better quality jewelry that is a lot less likely to cause skin irritations. About 10-15% of women are known to be allergic to nickel³⁴, and individuals can commonly be sensitive to cadmium, copper, etc. However, some jewelry vendors are not so honest. In educational clinics at universities in Phnom Penh, we processed four “gold” rings that were sold as high quality gold, but were mostly copper. In our analysis of jewelry bought by students, we had very little opportunity to process expensive jewelry. Two attempts to work with owners of jewelry stores failed for different reasons. Initially, one vendor agreed that we could analyze his gold, but upon reflection, he changed his mind. We would not have been able to be onsite often to check the gold that he was buying, but we could likely have found counterfeit gold in his shop. Another vendor protested that all jewelry was the same, and if we found toxic metals in jewelry in her shop, she would lose many of her customers.

The problem of lead in jewelry requires further evaluation. The major source of the low-cost jewelry is not clear, but likely represents both local production in Cambodia and other countries in the region, including China. This significant issue has not been resolved

due to lack of resources. The case of the boy poisoned by a lead amulet in the US that was bought in Cambodia²⁴ probably represents a much bigger problem in Cambodia. Many men and boys wear religious amulets, usually around their waist, but at times around their neck. These amulets are made of lead and are inscribed by monks for good luck. Sometimes amulets around the waist are wrapped in plastic, but sometimes they are worn directly on the skin. Very little study has been done on dermal absorption of lead, but it is generally believed to be lower than oral absorption. The greatest risk is when an amulet is worn around the neck of a child and the child (or adult) sucks on the amulet. It would be a useful exercise to evaluate the lead content in the blood of people wearing such amulets to assess their potential health risk. Handheld XRF analysis lacks the sensitivity to measure lead in blood and an alternative technique such as atomic absorption spectrometry is required.

In our study of toys, the greatest health risk was associated with mercury used in paints to produce shiny surfaces. As in other studies (*Table 1*), we found toys with toxic metals produced by name brands/stores such as Mattel and Toys “R” Us with headquarters in the US. Bootlegging of consumer goods is widespread in Southeast Asia, so the producer is not always as labelled. It is also possible that retailers in Southeast Asia are selling old stock that was initially intended to be exported to the United States/EU and most likely would be detected in the developed world. However, a survey of jewelry in Seattle in 2015 found that lead was still present in 23% of samples.²⁶ It is likely that toxic toys continue to be present in the US, but hopefully as with the jewelry study in Seattle, at lower concentrations than found in earlier surveys.

Four toys (6%) contained more than 1% Hg and 26% of toys failed the EU guidelines for toys because of mercury. Overall, 38% of toys failed the EU guidelines. Technically, it is very easy to monitor mercury and other metals in paint, but the producing countries are not doing this very well. Future analysis in Southeast Asia should include assessment of mercury in paints used for other purposes. By far the most common cause for a CSPC recall of lead in the toy in the United States was associated with lead in paint (Table 1). Since much of the developing world still uses enamel paint with lead,⁴ painted toys in such countries should be expected to be occasionally contaminated with lead or even mercury. Although the four largest recalls of toys in the USA because of lead occurred between 2004 and 2008, the problem of lead contamination remains serious (Table 1).

No amount of Pb is considered safe for children, and there is a possibility they might chew and ingest the surface of a toy coated with Pb, contributing to elevated BLLs. Maas *et al.*²¹ cited two studies that showed handling of Pb-contaminated items with lower Pb weight percent than the jewelry pieces in this study can result in significant transfer of Pb to the skin. Additionally, up to 4 μg of Pb could be transferred from the skin to the surface of food items after a single handling of items contaminated with Pb.²⁰

Like the jewelry items, the Pb content of toys could not be determined by visual inspection. Different parts of the toy may or may not possess Pb or may contain uneven concentrations. The toys appeared in different colors and designs to which children are attracted. Only after using an XRF analyzer could the metals concentrations be determined quickly. Thus, XRF analyzers are reliable, robust tools for

screening environmental samples and consumable goods.

Conclusion

Because there is a lack of treatment facilities and experience with Pb poisoning in Cambodia, it is important to implement prevention measures and make the public aware of the health risks. Processing consumer goods in educational clinics in schools can be an effective method of education. Labeling of certified consumer goods could help inform parents whether toys or jewelry are suitable for children. Increased monitoring in the US, the EU and in the developing world with XRF analyzers could increase consumer protection.

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References

1. Cambodia economy profile 2014: economy – overview [Internet]. Charlotte, NC:

IndexMundi; 2014 [updated 2015 Jun 30; cited 2016 Mar 31]. [about 4 screens]. Available from: http://www.indexmundi.com/cambodia/economy_profile.html

2. **Murphy T, Lim S, Huong SP, Irvine K, Bayen S, Kelly BC, Wilson K.** Application of handheld x-Ray fluorescence analyzers to identify mercury in skin-whitening creams in Cambodia. *J Health Pollut [Internet]*. 2012 Jun [cited 2016 Aug 24];2(3):21-31. Available from: <http://www.journalhealthpollution.org/doi/pdf/10.5696/2156-9614-2.3.21>

3. **Murphy T, Lim S, Kim S, Chanra P, Wilson K, Irvine KN, Slotton DG, Allen L.** Mercury contamination of skin whitening creams in Phnom Penh, Cambodia. *J Health Pollut [Internet]*. 2015 Dec [cited 2016 Aug 24];5(9):33-46. Available from: <http://www.journalhealthpollution.org/doi/pdf/10.5696/2156-9614-5-9.33>

4. **Lim S, Murphy T, Irvine KN, Wilson K.** Leaded paint in Cambodia - pilot-scale assessment. *J Health Pollut [Internet]*. 2015 Dec [cited 2016 Aug 24];5(9):18-24. Available from: <http://www.journalhealthpollution.org/doi/pdf/10.5696/2156-9614-5-9.18>

5. **Yost JL, Weidenhamer JD.** Accessible and total lead in low-cost jewelry items. *Integr Environ Assess Manag [Internet]*. 2008 Jul [cited 2016 Aug 24];4(3):358-61. Available from: http://www.bioone.org/doi/abs/10.1897/IEAM_2007-071.1 Subscription required to view.

6. **Weidenhamer JD, Clement ML.** Widespread lead contamination of imported low-cost jewelry in the US. *Chemosphere [Internet]*. 2007 Mar [cited 2016 Aug 24];67(5):961-5. Available from: <http://www.sciencedirect.com/science/article/pii/S0045653506014147> Subscription required to view.

7. **Jeffries E.** E-wasted. *World Watch J [Internet]*. Jul/Aug 2006 [cited 2013 Feb 28];19(4): [about 3 screens]. Available from: <http://www.worldwatch.org/node/4108>

8. **Cox C, Green M.** Reduction in the prevalence of lead-containing jewelry in California following litigation and legislation. *Environ Sci Technol [Internet]*. 2010 Aug 15 [cited 2016 Aug 24];44(16):6042-5. Available from: <http://pubs.acs.org/doi/pdf/10.1021/es903745b>

9. **Greenway JA, Gerstenberger S.** An evaluation of lead contamination in plastic toys collected from day care centers in the Las Vegas Valley, Nevada, USA. *Bull Environ Contam Toxicol [Internet]*. 2010 Oct [cited 2016 Aug 24];85(4):363-6. Available from: <http://link.springer.com/article/10.1007%2Fs00128-010-0100-3>

Subscription required to view.

10. **Kumar A, Pastore P.** Lead and cadmium in soft plastic toys. *Curr Sci [Internet]*. 2007 Sep 25 [cited 2016 Aug 24];93(6):818-22. Available from: <http://www.calepa.ca.gov/cepc/2010/asltonbird/appaex10.pdf>
11. **Fels LM, Wunsch M, Baranowski J, Norska-Borowka I, Price RG, Taylor SA, Patel S, De Broe M, Elsevier MM, Lauwerys R, Roels H, Bernard A, Mutti A, Gelpi E, Rosello J, Stolte H.** Adverse effects of chronic low level lead exposure on kidney function--a risk group study in children. *Nephrol Dial Transplant [Internet]*. 1998 Sep [cited 2016 Aug 24];13(9):2248-56. Available from: <http://ndt.oxfordjournals.org/content/13/9/2248.long>
12. **Lanphear BP, Dietrich K, Auinger P, Cox C.** Cognitive deficits associated with blood lead concentrations <10 microg/dL in US children and adolescents. *Public Health Rep [Internet]*. 2000 Nov-Dec [cited 2016 Aug 24];115(6):521-9. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1308622/>
13. **Lidsky TI, Schneider JS.** Lead neurotoxicity in children: basic mechanisms and clinical correlates. *Brain [Internet]*. 2003 Jan [cited 2016 Aug 24];126(Pt 1):5-19. Available from: <http://brain.oxfordjournals.org/content/126/1/5.long>
14. **Canfield RL, Henderson CR Jr, Cory-Slechta DA, Cox C, Jusko TA, Lanphear BP.** Intellectual impairment in children with blood lead concentrations below 10 microg per deciliter. *N Engl J Med [Internet]*. 2003 Apr 17 [cited 2016 Aug 26];348(16):1517-26. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4046839/>
15. **Meyer PA, Brown MJ, Falk H.** Global approach to reducing lead exposure and poisoning. *Mutat Res [Internet]*. 2008 Jul-Aug [2016 Aug 26];659(1-2):166-75. Available from: <http://www.sciencedirect.com/science/article/pii/S1383574208000367> Subscription required to view.
16. **Chiodo LM, Jacobson SW, Jacobson JL.** Neurodevelopmental effects of postnatal lead exposure at very low levels. *Neurotoxicol Teratol [Internet]*. 2004 May-Jun [cited 2016 Aug 26];26(3):359-71. Available from: <http://www.sciencedirect.com/science/article/pii/S0892036204000212> Subscription required to view.
17. **Bellinger DC.** Very low lead exposures and children's neurodevelopment. *Curr Opin Pediatr [Internet]*. 2008 Apr [cited 2016 Aug 26];20(2):172-7. Available from: http://www.biologicaldiversity.org/campaigns/get_the_lead_out/pdfs/health/Bellinger_2008b.pdf
18. **Sciarillo WG, Alexander G, Farrell KP.** Lead exposure and child behavior. *Am J Public Health [Internet]*. 1992 Oct [cited 2016 Aug 26];82(10):1356-60. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1695858/>
19. **Lead [Internet].** Atlanta, Georgia: Center for Disease Control and Prevention; [updated 2016 Jan 29; cited 2013 Apr 4]. [about 5 screens]. Available from: <http://www.cdc.gov/nceh/lead/>
20. **US Consumer Product Safety Commission.** Advanced notice of proposed rulemaking. Federal Register 72:921-3. (2007).
21. **Maas RP, Patch SC, Pandolfo TJ, Druhan JL, Gandy NF.** Lead content and exposure from children's and adult's jewelry products. *Bull Environ Contam Toxicol [Internet]*. 2005 Mar [cited 2015 Aug 26];74(3):437-44. Available from: <http://link.springer.com/article/10.1007/s00128-005-0605-3> Subscription required to view.
22. **Berg KK, Hull HE, Zabel EW, Staley PK, Brown MJ, Homa DM.** Death of a child after ingestion of a metallic charm - Minnesota. *Morb Mortal Wkly Rep [Internet]*. 2006 Mar 31 [cited 2016 Aug 26];55(12):340-1. Available from: <https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5512a4.htm>
23. **23 CPSC announces recall of metal toy jewelry sold in vending machines firms agree to stop importation until hazard is eliminated [Internet].** Bethesda, Maryland: US Consumer Product Safety Commission; 2004 Jul 8 [cited 2016 Aug 29]. [about 5 screens]. Available from: <http://www.cpsc.gov/en/recalls/2004/cpsc-announces-recall-of-metal-toy-jewelry-sold-in-vending-machines-firms-agree-to-stop-importation-until-hazard-is-eliminated/>
24. **Mann M, Rublowska MN, Ehrlich JE, Sucusky MS, Kennedy CM.** Lead poisoning of a child associated with use of a Cambodian amulet - New York City. *Morb Mortal Wkly Rep [Internet]*. 2011 Jan 28 [cited 2016 Aug 26];60(3):69-71. Available from: <https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6003a2.htm>
25. **Cui XY, Li SW, Zhang SJ, Fan YY, Ma LQ.** Toxic metals in children's toys and jewelry: coupling bioaccessibility with risk assessment. *Environ Pollut [Internet]*. 2015 May [cited 2016 Aug 26];200:77-84. Available from: https://www.researchgate.net/publication/272520862-Toxic_metals_in_children's_toys_and_jewelry_Coupling_bioaccessibility_with_risk_assessment
26. **Sekerak S.** Cadmium and other metals in children's jewelry [Internet]. Olympia, Washington: Washington State Department of Ecology; 2016 Mar [cited 2016 Aug 26]. 7 p. Available from: <https://fortress.wa.gov/ecy/publications/documents/1603007.pdf>
27. **Omolaoye JA, Uzairu A, Gimba CE.** Heavy metal assessment of some soft plastic toys imported into Nigeria from China. *J Environ Chem Ecotoxicol [Internet]*. 2010 Oct [cited 2016 Aug 26];2(8):126-30. Available from: http://www.academicjournals.org/article/article1379515824_Omolaoye%20et%20al.pdf
28. **28Guney M, Zagury GJ.** Heavy metals in toys and low-cost jewelry: critical review of U.S. and Canadian legislations and recommendations for testing. *Environ Sci Technol [Internet]*. 2012 Apr 17 [cited 2016 Aug 26];46(8):4265-74. Available from: <http://pubs.acs.org/doi/abs/10.1021/es203470x> Subscription required to view.
29. **Aliyev V, Bozalan M, Guvendik G, Soylemezoglu T.** The potential health risk assessment of lead levels in children's toys. *Toxicol Lett [Internet]*. 2011 Aug [cited 2016 Aug 26];205(1):180-300. Available from: https://www.researchgate.net/publication/251588375_The_potential_health_risk_assessment_of_lead_levels_in_children's_toys Subscription required to view.
30. **30 Toys hazards recalls.** Bethesda, Maryland: US Consumer Product Safety Commission; 2011.
31. **EU new toy standard EN 71-3:2013 and EN 71-12:2013 published to cope with chemical requirements in EU toy safety directive.** Brussels, Belgium: European Commission; 2013 Jun 25 [cited 2014 Apr 24]. Available from: http://www.mts-global.com/en/technical_update/CPIE-024-13.html
32. **Lim S.** X-ray fluorescence (XRF) analyser - theory, utility, and QA/QC for environmental and commercial product samples in Cambodia [master's thesis]. [Buffalo, New York]: Buffalo State University of New York; 2013 Dec. 33 p.
33. **Finch LE, Hillyer MM, Leopold MC.** Quantitative analysis of heavy metals in children's toys and jewelry: a multi-instrument, multitechnique exercise in analytical chemistry and public health. *J Chem Educ [Internet]*. 2015 May [cited 2016 Aug 26];92(5):849-54. Available from: <http://pubs.acs.org/doi/abs/10.1021/ed500647w> Subscription required to view.
34. **Garg S, Thyssen JB, Uter W, Schnuch A, Johansen JD, Menné T, Belloni Fortina A, Statham B, Gawkrödger DJ.** Nickel allergy following European Union regulation in Denmark, Germany, Italy and the U.K. *Br J Dermatol [Internet]*. 2013 Oct [cited 2016 Aug 26];169(4):854-8. Available from: <http://onlinelibrary.wiley.com/doi/10.1111/bjd.12556/full> Subscription required to view.
35. **Fisher-Price recalls licensed character toys due to**

lead poisoning hazard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2007 Aug 2 [cited 2016 Aug 29]. [about 8 screens]. Available from:

<http://www.cpsc.gov/en/recalls/2007/fisher-price-recalls-licensed-character-toys-due-to-lead-poisoning-hazard/>

36. Mattel recalls "sarge" die cast toy cars due to violation of lead safety standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2007 Aug 14 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2007/Mattel-Recalls-Sarge-Die-Cast-Toy-Cars-Due-To-Violation-of-Lead-Safety-Standard/>

37. Children's toys recalled by Dollar Tree stores due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2007 Dec 13 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2008/Childrens-Toys-Recalled-by-Dollar-Tree-Stores-Due-to-Violation-of-Lead-Paint-Standard/>

38. Toys "R" Us recalls elite operations toys due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2007 Oct 31 [cited 2016 Aug 29]. [about 3 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2008/Toys-R-Us-Recalls-Elite-Operations-Toys-Due-to-Violation-of-Lead-Paint-Standard/>

39. Toy airplanes, cars, and motorcycles recalled by S.U. Wholesale due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2008 Mar 12 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2008/Toy-Airplanes-Cars-and-Motorcycles-Recalled-by-SU-Wholesale-Due-to-Violation-of-Lead-Paint-Standard/>

40. Ceramic banks recalled by oriental trading company due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2010 Dec 22 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2011/Ceramic-Banks-Recalled-by-Oriental-Trading-Company-Due-to-Violation-of-Lead-Paint-Standard/>

41. Sportime recalls sports balls due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2010 Apr 30 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2010/Sportime-Recalls-Sports-Balls-Due-to-Violation-of-Lead-Paint-Standard/>

42. Children's toy jewelry sets recalled by Playmates Toys; charms violate the total lead standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2010 Feb 2 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2010/Childrens-Toy-Jewelry-Sets-Recalled-by-Playmates-Toys-Charms-Violate-the-Total-Lead-Standard/>

43. Horse toy figures recalled by Blip Toys due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2010 Jan 26 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2010/Horse-Toy-Figures-Recalled-by-Blip-Toys-Due-to-Violation-of-Lead-Paint-Standard/>

44. Jide Trading recalls toy military figure due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2010 Jan 6 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2010/Jide-Trading-Recalls-Toy-Military-Figure-Due-to-Violation-of-Lead-Paint-Standard/>

45. Painted wooden beads intended for children's crafts recalled by S&S Worldwide due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2010 Mar 23 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2010/Painted-Wooden-Beads-Intended-for-Childrens-Crafts-Recalled-By-SS-Worldwide-Due-To-Violation-of-Lead-Paint-Standard/>

46. LM Import & Export recalls toy cars due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2011 Sep 28 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2011/LM-Import-Export-Recalls-Toy-Cars-Due-to-Violation-of-Lead-Paint-Standard/>

47. Build-A-Bear workshop recalls lapel pins due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2011 Aug 4 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2011/Build-A-Bear-Workshop-Recalls-Lapel-Pins-Due-to-Violation-of-Lead-Paint-Standard/>

48. Cost Plus Inc recalls wooden animal drum due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2011 Jun 30 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2011/Cost-Plus-Inc-Recalls-Wooden-Animal-Drum-Due-to-Violation-of-Lead-Paint-Standard/>

49. GA Gertmenian and Sons recalls toy story 3 bowling game due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2011 May 5 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2011/GA-Gertmenian-and-Sons-Recalls-Toy-Story-3-Bowling-Game-Due-to-Violation-of-Lead-Paint-Standard/>

50. Captain cutlass pirate toy guns recalled by Dillon Importing due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2012 Sep 27 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2012/Captain-Cutlass-Pirate-Toy-Guns-Recalled-by-Dillon-Importing-Due-to-Violation-of-Lead-Paint-Standard/>

51. Mexican wrestling action figures recalled by Lee Carter Co due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2012 Jan 24 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2012/Mexican-Wrestling-Action-Figures-Recalled-by-Lee-Carter-Co-Due-to-Violation-of-Lead-Paint-Standard/>

52. Discount school supply recalls sorting boards due to magnet ingestion risk and excessive lead levels (recall alert) [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2014 May 7 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/Recall-Alerts/2014/Discount-School-Supply-Recalls-Sorting-Boards/>

53. Minga Fair Trade Imports recalls wooden flipping acrobat toys due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2014 Mar 20 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2014/Minga-Fair-Trade-Imports-Recalls-Wooden-Flipping-Acrobat-Toys/>

54. Things remembered recalls children's jewelry due to violation of lead standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2016 Jul 19 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2016/Things-Remembered-Recalls-Childrens-Jewelry/>

55. GSI outdoors recalls children's water bottles due to violation of lead standard; sold exclusively at LL Bean [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2016 Jul 19 [cited 2016 Aug 29]. [about 2 screens]. Available from:

<http://www.cpsc.gov/en/Recalls/2016/GSI-Outdoors-Recalls-Childrens-Water-Bottles/>

56. Far East Brokers recalls children's chairs and swings due to violation of federal lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2016 Jun 9 [cited 2016 Aug 29]. [about 2 screens]. Available from: <http://www.cpsc.gov/en/Recalls/2016/Far-East-Brokers-Recalls-Childrens-Chairs-and-Swings/>

57. LaRose Industries recalls Cra-Z-Jewelz Ultimate Gem Jewelry Machine due to violation of lead standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2016 Jun 2 [cited 2016 Aug 29]. [about 3 screens]. Available from: <https://www.cpsc.gov/en/Recalls/2016/LaRose-Industries-Recalls-Cra-Z-Jewelz-Ultimate-Gem-Jewelry-Machine/>

58. KHS America recalls children's musical instrument due to violation of lead paint standard [Internet]. Bethesda, Maryland: US Consumer Product Safety Commission; 2016 Feb 4 [cited 2016 Aug 29]. [about 2 screens]. Available from:

59. <http://www.cpsc.gov/en/Recalls/2016/KHS-America-Recalls-Childrens-Musical-Instrument/>