BJPS

Brazilian Journal of
Pharmaceutical Sciences
vol. 46, n. 2, abr./jun., 2010

Article

# Chemical waste risk reduction and environmental impact generated by laboratory activities in research and teaching institutions

**Elizabeth de Souza Nascimento[1,*], Alfredo Tenuta Filho[2]**

*[1]Department of Clinical and Toxicological Analysis, Faculty of Pharmaceutical Sciences University of São Paulo,*
*[2]Department of Food and Experimental Nutrition, Faculty of Pharmaceutical Sciences University of São Paulo*

The environmental impact caused by teaching and research with regard to chemical waste is of increasing concern, and attempts to solve the issue are being made. Education and research-related institutions, in most laboratory and non-laboratory activities, contribute to the generation of small quantities of waste, many of them highly toxic. Of this waste, some is listed by government agencies who are concerned about environmental pollution: disposal of acids, metals, solvents, chemicals and toxicity of selected products of synthesis, whose toxicity is often unknown. This article presents an assessment of the problem and identifies possible solutions, indicating pertinent laws, directives and guidelines; examples of institutions that have implemented protocols in order to minimize the generation of waste; harmonization of procedures for waste management and waste minimization procedures such as reduction, reuse and recycling of chemicals.

**Uniterms:** Laboratory chemical waste/management in universities. Environmental safety. Environmental education.

O impacto ambiental acarretado por atividades de pesquisa e ensino no que se refere aos resíduos químicos vem sendo cada vez mais discutido e tentativas de solucionar a questão vêm sendo apresentadas. As instituições de ensino e pesquisa, em quase todas as atividades e não somente as laboratoriais, contribuem para a geração de pequenas quantidades de resíduos, muitos deles altamente tóxicos. Destes, alguns constam em listas de agências governamentais que se preocupam com a qualidade do meio ambiente: descartes de ácidos, metais, solventes, agentes químicos de elevada toxicidade e ainda os produtos de síntese, cuja toxicidade é frequentemente desconhecida. Este artigo apresenta uma avaliação do problema identificando possíveis soluções, a partir da apresentação de legislações pertinentes, exemplos de instituições que vêm implantando protocolos que minimizam a geração de resíduos, sistemas de harmonização de processos de gerenciamento de resíduos e procedimentos de minimização de resíduos, como a redução, reutilização e reciclagem dos produtos químicos.

**Unitermos:** Resíduos laboratoriais/gerenciamento em universidades. Segurança ambiental. Educação ambiental.

## INTRODUCTION

The environmental impact of chemical waste produced by teaching and research is a topic that has been of great concern and discussion for at least two decades, as illustrated in the book by Ashbrook and Reinhardt (1985) on the generation of hazardous wastes in academic institutions. In the book, the authors stressed the need to implement a practice for the treatment of chemical waste in educational institutions, which in most laboratory and non-laboratory activities, contribute to the generation of small quantities of waste, many of them highly toxic. Some of this is listed by governmental agencies who are concerned about the quality of the environment. Examples include the disposal of toxic acids, metals, solvents, chemicals and also products of synthesis whose toxicity is often unknown. Furthermore, it is noteworthy that the composition of waste from research labs constantly changes according to

***Correspondence:** E. S. Nascimento. Departamento de Análises Clínicas e Toxicológicas, Faculdade de Ciências Farmacêuticas, Universidade de São Paulo. Av. Prof. Lineu Prestes, 580 - 05508-000 - São Paulo - SP, Brasil. E-mail: esnasci@usp.br

each project being developed. This situation can no longer be ignored by academic institutions, and various research and educational institutions in Brazil are concerned about this problem and are integrating hazardous waste management into their activities. Some of these activities are available in frequent articles published in the Química Nova Journal, numbering among them articles by: Jardim, 1998; Cunha, 2001; Amaral *et al.,* 2001; Afonso, *et al.*, 2003; Alberguini *et al.*, 2003; Bendassolli, 2003; Afonso, 2004; Gerbase, *et al.*, 2005; Imbroisi, *et al.*, 2006. There are also several books by Brazilian authors addressing the management of chemical waste in universities (Alberguini *et al.*, 2005; Figueredo, 2006).

The work by Nolasco *et al.* (2006), analyses the implementation of programs for managing laboratory chemical waste in Brazilian universities, and states that several programs are responding to the requirements of the pillars of sustainability and ecological awareness, which were the main proposals of Agenda 21. The authors also mention that in the last decade, some of the oldest and most prominent Federal and State universities have been adapting and establishing proper measures for control waste.

These institutions include the Center for Nuclear Energy in Agriculture, University of São Paulo (Tavares, 2004), the University of Campinas - UNICAMP (Gerbase *et al*, 2005), the Institute of Chemistry of the University of Rio de Janeiro - IQ / UERJ - (Barbosa *et al.*, 2003), the Department of Chemistry, Federal University of Parana - DQ / UFPR (Cunha, 2001), the Institute of Chemistry of the Federal University of Rio Grande do Sul - IQ / UFRGS (Amaral *et al.*, 2001), the Regional Integrated University of High Uruguay and Missions - URI (Demaman *et al.*, 2004), and the Federal University of Rio de Janeiro - UFRJ (Afonso *et al.*, 2004). In addition to these sites, other initiatives are being carried out in other educational institutions, for example Borghesan *et al.* (2003), cited the University of São Paulo, São Carlos, while Mortari (2003) mentioned the Franciscan University Center.

Otenio *et al.* (2008) also described a case study associated with the management of biowaste for milk at Embrapa Gado and pools the opinion of researchers, analysts and trainees on the problem of waste generated in biological research. The advantages of establishing and maintaining programs for waste management in universities, teaching and research institutions, both governmental and private, largely outweigh the operational costs that these entail.

One of the most significant advantages is undoubtedly the fact that students are taught how to adequately deal with the waste produced in research and in classrooms, thereby minimizing damage to the environment. Moreover, another advantage, which should not be overlooked is that of working in a safe, healthy and clean environment, in line with the principles of ecology (Armour, 1996).

The United States of America's legislation related to environmental care in educational institutions is the Resource Conservation and Recovery Act (RCRA), also known as "Solid Waste" Disposal Act, which came into force in 1976, and is an interesting example of the concern over the risks associated to ecological damage. Its objectives are to protect human health and the environment, reduce the generation of all types of waste, toxic or otherwise, and to promote the conservation of energy and natural resources. This law gives the U.S. Environmental Protection Agency (EPA) the power to regulate the disposal of toxic waste in the U.S.A, and authorization to bring civil and criminal charges against whoever violates this law. There have already been cases of not only industries, but also various American universities, being charged, condemned and subject to severe penalties. According to the amendment to this law, dated October 1990, (USA) individuals charged with this type of violation, can be personally prosecuted, convicted and sentenced to imprisonment in State or Federal prisons. Another penalty of significant importance to educational and research institutions committing this type of violation, is that they may no longer receive funds or subsidies from government organizations to support or sponsor their research.

In 2006, EPA proposed alternative and more flexible standards for the management of hazardous waste generated in academic institutions, as the environmental agency considered that the legislation, which had formerly been established for industries, needed to be adapted in various aspects. Academic institutions present different characteristics to those of industry, since the amounts of waste generated are smaller, diverse and distributed across various laboratories, manipulated by students in various situations that are not always supervised by trained individuals. Thus, the revised legislation came into force in 2008 (Monz, McDonough, 2006; Archer *et al.*, 2000).

As stated above, although the amount of waste generated in academic institutions is small, less than 1% of the total generated nationally, waste in education institutions is considered heterogeneous, and may include highly toxic compounds. Therefore, any teaching and research institution committed to its employees' and students' health must consistently uphold the laws related to workers' chemical safety, and laws on management of hazardous waste released by its laboratories.

The concept of waste minimization encompasses any action that reduces the amount and/or toxicity of anything to be discarded as hazardous waste. It is therefore essential that the waste is properly handled, stored and disposed of. When the waste generating source has been identified, whether highly hazardous or otherwise, protocols or operational procedures aimed at their appropriate disposal should be implemented.

Most of what is used in university laboratories, albeit related to research or teaching at some point, can become hazardous. Examples are solvents, glassware, reagents, packaging of dangerous products, biological material, out of order, broken or obsolete equipments, broken thermometers, and outdated or obsolete computers. A visitor to most unpretentious academic laboratories would see such material, which can cause safety problems and have an impact on environmental health if disposed of in an indiscriminate manner. Thus, it is important to urgently address this problem, where this can be done by cutting down on waste production, and properly treating and disposing of the waste which is produced.

## HARMONIZATION OF WASTE MANAGEMENT PROCEDURES

The last few decades have seen great development in the creation of standards and quality systems in several professional activities many of them aimed at improving harmonization of procedures, the quality of manufactured products, and professional activities. Among these systems are the ISO - International Standards Organization, whose function is to ensure the desirable characteristics of products or services such as quality, environmental care, safety, reliability and efficiency. Most of the ISO guides are specified for products, processes or materials. ISO 9000 procedures focus on quality and ISO 14000 on the environment, and are considered generic systems of management standardization. The term generic used here has the connotation of allowing these systems to be applied to any organization, large or small, in order to carry out any activity in any sector of the economy, public administration, or government organizations. The ISO 9001 standard provides a series of requirements for implementing a quality management system, while the ISO 14000 pertains to an environmental management system (www.iso.org).

When organizations follow the spirit of ISO 14000, it means that they promote changes in attitude, operational procedures and in management, which then yields many benefits. This standardized protocol provides common sense information to help reduce the negative impact of several activities on the environment, therefore reducing costs by cutting down on waste and preventing pollution, in addition to contributing to the quality of the communities in which the organization operates (Rondinelli *et al.*, 2000).

Thus, institutions both private and public can benefit from the implementation of such systems that significantly improve the environment in which they are located. A program of waste management is an integral part of the environmental care recommended by ISO 14000. Such programs can and should be implemented in educational institutions, and this necessarily includes constant evaluation of laboratory activities and processes, aimed at reducing the generation of disposable material and increasing recycling.

The waste generated by academic institutions such as universities, institutes and high schools can be classified into four main categories: household, biological and chemical waste, and radiation. The last three may or may not be considered dangerous. Those considered hazardous should be discarded as such and not as common garbage, seeking to minimize environmental impact and to adhere to specific waste management laws enforced by European, American, and Brazilian legislations (**Council Directive 91/689/EEC,** USEPA, 1996; Brazil, 2002).

Hazardous chemicals normally found in academia and requiring proper treatment are:

- chemical wastes generated in research laboratories, and during teaching activities;
- old chemical agents, considered an institutional liability, often difficult to identify and abandoned in the laboratory;
- chemical agents surpassing their expiration date and therefore in need of re-evaluation of their effectiveness, and need for disposal;
- bottles of chemicals without labels or with wrong or unreadable labels;
- material in a state of deterioration or in packages which are deteriorated, or damaged;
- unknown residues in chemicals containers;
- laboratory waste such as paper towels and rags;
- personal protective equipment: aprons, glasses, masks, gloves contaminated with harmful biological, chemical or radioactive material;
- non-recyclable batteries and gas cylinders;
- photographic film processing solutions;
- pesticides, equipment containing toxic compounds, different types of waste oils, used solvents, Thinner, oil remover, wood preservers;
- formaldehyde, formalin, acrylamide waste in liquid or gel form;
- mercury and other metals with high toxicity;
- defunct electronics, computers and thermometers;
- sharp devices such as: needles, syringes, chromatography needles, Pasteur pipettes, tips;

- bleach, ammonia, cleaning solvents, liquid wood polish;
- chemical bottles (glass and plastic) empty but contaminated;
- contaminated broken (or damaged) laboratory glass;
- mercury-contaminated, broken (or damaged) thermometers;
- carcinogenic and radioactive chemicals, pathogenic microorganisms.

## RELEVANT LAWS RELATED TO WASTE DISPOSAL

Although very little legislation is directly related to the management of hazardous waste in teaching and research activities, there are many laws, rules and ordinances in a Federal, State and local realm related to the subject in question. An interesting portal to be consulted for information on health laws and regulations is the site: http://www.cvs.saude.sp.gov.br/publ_leis3.asp.

Examples of pertinent legislation:

- Resolution RDC 306/2004 (ANVISA) - technical regulations for the management of health services waste;
- Resolution CONAMA 357/2005 - sets the conditions and standards for effluents release;
- Resolution CONAMA 358/2005 - treatment and final disposal of health services waste;
- State Decree 8468/1976 - provides for environmental pollution prevention and control; Law No. 12300/2006 - establishing the Solid Waste State Policy (São Paulo State);
- Resolution SMA - 31, 22-7-2003 -management of chemical waste from health service establishments in São Paulo State;
- Nuclear Energy National Commission - Standards. 6.05 (Management of Radioactive Waste in radioactive facilities), CNEN resolution 19/85, Federal Official Gazette, 17/12/1985;
- Nuclear Energy National Commission – Standards. N. 6.09 (Acceptance Criteria for Disposal of low and average Radiation Levels), Resolution CNEN 19/09/2002, Brazilian Federal Official Gazette, 23/09/2002;
- ANVISA - DRC 306 and Ministry of Health and the Environment - CONAMA 358/2005 - Treatment of waste containing biological or pathogenic material.

In the case of chemical waste from laboratories, there is no specific legislation for their classification, treatment and disposal, thus one should use the NBR 10004:2004 - Standard for classification of solid waste, along with other resolutions and decrees, State or Federal, above mentioned organization (State Environmental Authority - SP: CETESB) is in charge of controlling this activity.

There are also other technical standards such as those released by the Brazilian Association of Technical Standards (ABNT) (www.abnt.org.br) listed below:

- NBR 12807 - Medical Waste Residues - Terminology;
- NBR 12808 - Medical Waste Residues- Classification;
- NBR 12809 - Handling Waste Health Residues Procedures;
- NBR 12810 – Disposal of Waste Health Residues Procedures;
- NBR 12980 – Collection, sweeping and packaging of solid waste - Terminology;
- NBR 8419 - Projects of landfills for Urban Solid Waste Residues;
- NBR 9191 - Plastic bags for waste;
- NBR 10004 - Solid Waste - Classification;
- NBR 10005 – Procedure for Waste residue leaching;
- NBR 10006 – Procedure for Solubilization of Waste residues;
- NBR 10007 – Waste Sampling Procedure;
- NBR 10157 - Hazardous Waste Landfill - Procedure Criteria for Design, Construction and Operation.

### Resolutions Conama n. 358 and ANVISA n. 306

Resolutions CONAMA n.358 of 29 April 2005, and the Ministry of Environment and ANVISA in the DRC 306, 7 December 2004, seek to minimize occupational hazards and protect the health of workers and the general population. This resolution, in its Article 1, specifies that its application is related to all services that include assistance to human or animal health, laboratories of analysis for health products and, subject to this chapter, health educational and research institutions, among others. This resolution classifies the various types of waste into 5 categories, and indicates how each one should be handled:

I - GROUP A: Waste with the possible presence of biological agents that, by its characteristics of greater virulence or concentration, may pose a risk of infection.

a) A1:

1. Microorganisms cultures and stocks; residue waste of biological products manufacture except hem-

derivatives; disposal of attenuated or live microorganisms, vaccines, culture medium of microorganisms and instruments used to transfer, inoculation or mixing of cultures, residue waste from laboratories of genetic manipulation;

2. Waste resulting from individuals or animal health care suspect or certain of contamination including class 4 risk biological agents, microorganisms of epidemiological relevance and risk of dissemination, or able to cause of emerging diseases that could become of epidemiologically importance, or when its transmission mechanism is unknown;
3. Bags containing blood or blood transfusion rejected due to contamination or poor storage, or expired validated date;
4. Remains of laboratory samples containing blood or body fluids, containers and materials resulting from health care processes, containing blood or body fluids.

The generating unit should treat this type of waste before disposing of it.

b) A2:

Carcasses, body parts, other waste residues from animals used in experimental processes involving inoculation of microorganisms, and the corpses of animals suspected of being carriers of microorganisms of relevance and epidemiological risk of dissemination.

The generating unit should treat this type of waste before disposing of it.

c) A3:

Human body parts, products of fecundation weighing less than 500g and/or less than 25 cm, with gestation age less than 20 weeks:

The generating unit should organize for material to be cremated, incinerated, or buried.

d) A4:

1. Kits of arterial, intravenous and dialysis lines, when discarded;
2. Filters for air and gases aspirated from contaminated areas; filter membrane from hospital, clinical and research equipment, among others;
3. Remains of laboratory samples and their containers of feces, urine and secretions from patients that do not contain, nor are suspected to contain risk class 4 agents, and neither have relevance and epidemiological risk of dissemination, or microorganism causing emerging disease that has become important epidemiologically or their transmission mechanism is unknown, or suspected of prion contamination;
4. Fat residue waste from liposuction, liposculpture or other plastic surgery procedure that generates this type of waste;
5. Containers and materials resulting from health care processes, which contains no blood or body fluids;
6. Anatomical parts (organs and tissues) and other waste from surgical procedures or of anatomical and pathological studies or diagnostic confirmation;
7. Carcasses, anatomical parts, or other waste from animals not submitted to experimentation processes with inoculation of microorganisms;
8. Empty or semi used blood bag for transfusion.

The generating unit should discard this material without prior treatment at sites previously designated for Health Services waste disposal.

e) A5:

Organs, tissues, body fluids, piercing or sharp material and other materials from human or animal health care, suspected or certain of contamination with prions.

The generating units must incinerate them.

II - GROUP B: Waste containing chemicals that may present risk to public health or the environment, depending on its characteristics of flammability, corrosivity, reactivity and toxicity.

a) Hormonal, antimicrobial, cytostatic, anticancer, immunosuppressant, digitalis, immunomodulatory, anti-retroviral products, when discarded by health services, pharmacies, drugstores and distributors; medicines and pharmaceutical raw materials residue waste;
b) Sanitizing, disinfectants waste; waste containing heavy metals, laboratory reagents, including containers contaminated with these materials;
c) Image processor effluent (developers and fixers);
d) Effluent of automated equipment used in clinical testing;
e) Other products considered dangerous, under classification of the ABNT NBR 10004 (toxic, corrosive, flammable and reactive).

The generating unit should treat them for final specific disposal, unless they are subjected to reuse, recycling or recovery processes.

III - GROUP C: Any material resulting from human activities containing radionuclides in quantities exceeding the limits specified in the rules for disposal of the National Commission of Nuclear Energy-CNEN and for which the reuse is inappropriate or not provided for. Any materials resulting from research and educational labs, health, clinical and laboratory testing services, nuclear and radiation medicine containing radionuclides exceeding limits of elimination fall into this group.

The generating unit should follow the rules of the Nuclear Energy National Commission - CNEN - for the treatment of radioactive waste.

IV - GROUP D: Biological, chemical or radiological waste not causing health or environmental risk, can be treated as household waste.

a) Sanitary paper, diapers, sanitary napkin, disposable pieces of clothing, food remains from patient, material used in anti-sepsia, and other similar material not classified as A1;
b) Food and food preparation scraps;
c) Cafeteria food scraps;
d) Waste from administrative areas;
e) Sweeping waste, flowers and gardens;
f) Residue waste gypsum from health care.

V - GROUP E: piercing or sharp material, such as shaving blades, needles, scalp, glass ampoules, drills, endodontic files, diamond burs, scalpel blade, lancets, capillary tubes, micropipettes, and spatulas; also all the broken glass utensils from laboratory (pipettes, blood collection tubes and Petri dishes) and others.

This legislation considers agents of class 4 exposure (high individual risk and high risk to the community) the pathogens that represent major threat to humans and animals, and which pose great risk to whom might handle it; or likely to be transferred from one individual to another; and those without preventive measures or treatment.

Hazardous chemical waste are those listed in Group B, as per CONAMA resolution 283 of 12 July 2001, and classified as hazardous, according to NBR 10004, by presenting characteristics of toxicity, reactivity, flammability and/or corrosivity. The non-hazardous chemical waste are the result of institutions' laboratory activities for provision of health services that do not exhibit the above characteristics, defined as follows:

- Flammability: any liquid whose flash point is less than 60 ºC, compressed gas with a high degree of ignition, oxidants, substances capable of catching fire, under normal pressure and temperature, by processes of friction, absorption of moisture or spontaneous changes;
- Corrosivity: aqueous solutions with pH below 2 or above 12.5, or compounds with high reactivity in water or forming potentially explosive mixture with water, or usually unstable, or those that generate fumes, smoke or toxic gases when mixed with water, or cyanide residues or sulfide gas generators, smoke or toxic fumes in pH between 2 and 12.5, or explosive compounds, and if capable of corroding steel at the rate of 6.55 mm per year, in temperature of 55 ºC;
- Reactivity (causes irritation): non-corrosive chemical agents which by contact with skin or mucosa, can cause inflammation. It is worth noting that corrosive substances at low concentrations may be irritating; hydrophilic agents such as ammonia, are irritating to the upper respiratory tract; organic solvents are irritants due to dissolution of the dermal lipid layer.
- Toxicity: toxic metals, pesticides, organic compounds, polychlorinated biphenyls, dioxins, among other residues. The toxicity is proven from toxicological *in vivo* and *in vitro* tests, adopting harmonized and internationally accepted protocols (USEPA, OECD). The University of Houston suggests a procedure for chemical safety and risk management, based on Title 40, Code of Federal Regulations, Protection of the Environment, (U.S. Environmental Protection Agency). According to EPA definition, pollution prevention is a reduction of waste at source and environmentally correct recycling, thus any plan to tackle this problem must consider the 3 Rs, of *Reduce, Reuse* and *Recycle;*
- *Reduce* the use of hazardous material and, where possible, use small quantities of chemical agents;
- *Reuse* material, i.e., transfer or share the use of hazardous material between the various laboratories of the institution, or store it properly to be used when necessary;
- *Recycle* which uses filtration and distillation systems, among others, that allow the reuse of solvents.

Another important way to minimize waste generation is to consider the use of less toxic chemicals, both in research laboratories and in the classroom. Avoid the use of unnecessary ingredients, such as emulsifiers in solvents to be used or discarded, and separate the different types of solvents for reuse or recycling. The university laboratories tend to generate a considerable amount of chemical waste as they often use outdated techniques and a large volume of solvents. Other suggestions designed to minimize the generation of waste are: replace the use of mercury thermometers for digital thermometers; replace sulfochromic solution or alcoholic solution of potassium hydroxide or potassium hydroxide for sonication, when possible for the cleaning laboratory glassware; replace tests with acids and strong bases, therefore more toxic, for vinegar and ammonia; replace carbon tetrachloride by cyclohexane, according to the process described below:

## REDUCTION

In the process of waste reduction at source, the goal is to facilitate any activity that reduces or eliminates the generation of hazardous chemical waste. This activity can be implemented with good management when acquiring materials; when replacing toxic material with less harmful ones, and with good laboratory practice. Here are some suggestions that allow the reduction of waste at source according to the University of Florida:

- implement a policy of minimizing waste in the university research and students practice laboratory, and train all those involved in these activities. The reduction at the source can be achieved through improvement of methods or processes and replacement of ineffective equipment. In educational institutions, this is not always possible, but one should consider using more modern extraction techniques, such as solid phase extraction, or supercritical fluid, to minimize waste by using smaller volumes of organic solvents;
- do not mix dangerous classes of waste with non-hazardous ones;
- consider the possibility of using less toxic reagents, substituting for products with lower toxicity. In this context, it is possible to consider the replacement of products such as benzene, used as a solvent, with hexane or xylene; formalin or formaldehyde, used as a preservative for specimens in the laboratory, with ethanol; halogenated solvents in the extraction process with non-halogenated solvents; sodium dichromate with sodium hypochlorite, in some oxidation reactions; in studies using radioactive material, replace liquid scintillation-based toluene with a non-flammable solvent; in qualitative tests for heavy metals, replace sulfide ion with ion hydroxide. Replacement is not always possible because some substitutes do not always produce fully satisfactory results, or are toxic or too expensive. Thus, it is necessary to evaluate if the replacement material is suitable and delivers acceptable results. A common practice is to make an inventory of the compounds used in laboratories and to identify the likely replacement. The laboratory technician responsible for the use of these compounds needs to evaluate the possible replacements, using the information given by suppliers in the material safety data sheet (MSDS - Material Safety Data Sheet);
- centralize the acquisition of chemicals, and biological and radiation materials;
- dating all received material, thus facilitating earlier use of the oldest ones;
- make an inventory of purchased and used chemical agents in the laboratory: maintain a file containing their location, which should be updated annually. This facilitates the reduction of the quantity stored, and avoids the purchase of unnecessary material;
- provide employees with updated MSDS - Material Safety Data Sheet of the chemicals used in laboratories;
- acquire any chemical, biological and radiation materials in the least possible amount. The motto of the American Chemical Society (2008), is "Less is better", it is safe and environmentally correct to buy less material, use less and, ultimately, dispose of less, allowing a reduction in risk of accidents, fires, or harm to human health, and at the same time reduces costs;
- purchase the equipment needed for immediate use and avoid purchasing materials in large quantities, even it seems to be economically advantageous, since stocking can be expensive, or dangerous, and may lead to products exceeding their expiration date. A significant part of disposal done by universities is related to the purchase of unnecessary equipment;
- label all reagents to allow their ready identification. Borrow material from other labs, or buy it in small quantities. There is a successful story about a chemicals redistribution program at the University of Wisconsin - Madison, which has existed since 1980. About 30% of excess chemical purchased for each quarter are redistributed by the university, which allows an economy of $ 10-20,000.00 on disposal of chemicals for the university. Thus, the institution donates chemicals to those who need them and at the same time, reduces the amount to be discarded, and all benefit from this type of procedure;
- consider the possibility of testing in micro-scale, using new glassware and techniques that reduce quantities used to milligrams, which yields many benefits such as lower costs, since small-scale experiments using fewer solvents and other chemical

agents are generally processed more quickly, because it is faster to heat or cool small volumes, reduces exposure to harmful agents and reduces harmful emissions. However, please note that this technique can only be implemented to achieve the analytical proposed objective;

- consider the alternative of presentations/demonstrations on video, computer modeling and simulations, which eliminate environmental impacts, as substitutes for laboratory tests in the classroom. These multimedia simulations allow the student to observe more complex procedures than would be possible in traditional activities in the laboratory;
- consider prior separation of reagents and weighing in the laboratory, avoiding contamination of several rooms and environments;
- avoid using reagents containing toxic metals such as lead, chromium, arsenic, mercury, barium, silver, cadmium and selenium;
- do not use sulfochromic solutions: substitute them for less toxic solutions such as biodegradable detergents like Alconox or Pierce RBS35. Evaluate the possibility of using hot water and detergent for cleaning glass, instead of solvents;
- always keep the laboratory clean and in order;
- discard waste for disposal in the sink leading to the sewage system. Some organic and inorganic compounds may be discarded in the sewage system, in quantities of 100g and diluted 100 times. Generally, water-soluble organic compounds which have lower boiling temperature of approximately 50ºC should not be discarded in this manner. Some compounds are hydrophilic, when present at levels up to 3% and have low toxicity. The compounds listed below are readily biodegradable and can be discarded in the sink:

Organic compounds: alkyl alcohols with less than 5 carbon atoms:

*t*-myl alcohol; Alkanediols with less than 8 carbon atoms: glycerol, sugars alcoxi alkanes with less than 7 carbon atoms: *n*-C4H9OCH2CH2OCH2CH2OH, 2-Chloroethanol;

Aldehydes: Aliphatic compounds with less than 5 carbon atoms;

Amides: RCONH2 and RCONHR with less than 5 carbon atoms; RCONR2 with less than 11 carbon atoms;

Amines: aliphatic compounds with less than 7 carbon atoms; aliphatic diamines with less than 7 carbon atoms, benzilamina, pyridine carboxylic acids: alkanoics acids with less than 6 carbon atoms; hydroxy alkanoics acids with less than 6 carbon atoms; amino alkanoic acid with less than 7 carbon atoms; class of ammonia salts , sodium and potassium salts of the acids mentioned above, with less than 21 carbon atoms; chloralkanoic acid with less than 4 carbon atoms;

Esters: esters with less than 5 carbon atoms; isopropyl acetate. The compounds that have unpleasant odor, such as dimethylamine, 1,4-butanediamine, butyric and valeric acid, must be neutralized and their salts should be discarded in the sink into sewage drain diluted with at least 1,000 volumes of water;

Ketones with less than 6 carbon atoms;

Nitriles: acetonitrile, Propionitrile;

Sulfonic acid: sodium or potassium salts of these acids are acceptable.

## Reuse and recycling

Reuse and recycle processes when possible in a new way, or treat and reuse it in the same way, or in another type of activity. Some examples of recycling are:

- distillation of used solvents;
- in cleaning processes, the glassware can be initially washed with used solvents;
- purchase only compressed gas cylinders from manufacturers that accept the return of empty or partially used ones;
- in pesticide studies, it is advisable to establish the practice of returning any unused material to the research sponsor;
- avoid the contamination of fuel with solvents or heavy metals;
- share chemical agents among the various university units;
- control the use of metallic mercury.

If the above procedures are not suitable for specific situations to minimize waste, an alternative may be the final chemical treatment of the generated hazardous waste. The techniques routinely used in reducing chemical waste are: neutralization, precipitation, oxidation, reduction and distillation, practices to be conducted by trained laboratory technicians.

## Neutralization

The most common treatment is to neutralize highly acidic or alkaline solutions, leading to a desirable pH of 6 to 9. Thus, if this solution does not contain other toxic compounds it can be treated as regular trash and discarded in the sewage. Strong acids or bases must be neutralized before being released into the sewage, including those with the following cations: $Al^{3+}$, $Ca^{2+}$, $Fe^{2+}$, $Fe^{3+}$, $H^{+}$, $K^{+}$, $Li^{+}$, $Mg^{2+}$, $Na^{+}$, $(NH_4)^{+}$, $Sn^{2+}$, $Sr^{2+}$, $Ti^{3+}$, $Ti^{4+}$, $Zr^{2+}$; and anions: $(BO_3)^{3-}$, $(B_4O_7)^{2-}$, $Br^{-}$, $(CO_3)^{2-}$, $(HSO_3)^{-}$, $(OCN)^{-}$, $(OH)^{-}$, $I^{-}$, $(NO_3)^{-}$, $(PO_4)^{3-}$, $(SO_4)^{2-}$, $(SCN)^{-}$, $Zn^{2+}$.

### Precipitation, oxidation and reduction

These processes can remove hazardous components of chemical waste and the final product can be discarded as common trash. Precipitates derived from these reactions may require more effective waste treatment. The application of these procedures for chemical treatment in laboratories, apart from reducing hazardous waste, allows its incorporation as a common practice in teaching the students responsible management of chemical waste, fostering future generations of scientists with a better understanding of proper waste disposal.

The recycling of solvents, among other materials used in technical analysis, allows the reuse of material, which otherwise would be discarded as hazardous waste. These techniques require planning, when they are incorporated into the teaching laboratories activities. Solvent recycling, if well done, brings advantages to the academy in terms of risk reduction, harmful waste reduction, lower costs, and is also beneficial for the students because as previously mentioned, it allows them to learn about waste management in a responsible manner and understand the university commitment to hazardous waste reduction.

According to IZZO, 2000, coordinating hazardous waste management at a university can be very complex, as most universities are decentralized, most research laboratories have an unstable workforce, relying heavily on graduate students and postdoctoral associates who are usually at the university for limited time, and the type of waste generation changes frequently, as the focus of the research changes.

As mentioned earlier, educational and research institutions generate pollution because they produce harmful waste, discard hazardous materials in the sink, allow the evaporation of solvents, among other activities detrimental to the environment. The recommended process of reducing production of harmful wastes is not always feasible, because the concept of research implies the study of new compounds and their disposal if the result is neither interesting nor relevant. This type of activity is quite different from industrial processes, where there are routine activities, constant use of raw materials and well known waste products. In research, the multitude of non-routine activities is inherently more difficult to control. Nevertheless, the suggestions described here may contribute to the prevention of environmental pollution, and minimize costs with health and the environment. The proper disposal of hazardous waste involves direct costs to the universities, as is the case at the University of Bristol which produced 1,209 tonnes of waste between August 07 and July 08, excluding construction waste. Of this 1,861 tonnes, the amount recycled or reused was 704 tonnes (39%). The total cost of waste management in 2008 was over £200,000. By increasing the amount of waste that can be reused and recycled it is possible to reduce the amount going to landfills and save money in the process (Bristol University, http://www.bristol.ac.uk/environment/waste/). Thus, while reducing the production of waste and encouraging recycling, they also reduce costs.

## COMMITTEES/PROGRAMS FOR WASTE MANAGEMENT IN EDUCATIONAL INSTITUTIONS

Common sense dictates that the universities should maintain a committee, or program to minimize waste, which actively seeks ways to reduce it in their teaching and research units. This is being practiced in various academic institutions in America, Australia and Europe, among others, which can be checked out by visiting their electronic portals. Some examples are found at:

University of Delaware www.udel.edu/OHS/chemical.html

Northwestern University http://www.research.northwestern.edu/ors/safety/chemical/waste/

University of Western Australia www.fm.uwa.edu.au/about/policies/chemical_waste

University of Lousville http://louisville.edu/dehs/waste/waste/Guide/chap3.html

The University of Illinois www.drs.uiuc.edu/wasteguide/

University of Minnesota www.dehs.umn.edu/hazwaste_chemwaste_umn_cwmgbk.htm

University of Florida http://www.ehs.ufl.edu/HMM/wmin.htm

Columbia University http://www.ehs.columbia.edu/WasteMgt.html

University of Wisconsin http://www2.fpm.wisc.edu/chemsafety/GUIDE2005/chapter%206.pdf

Duke University www.safety.duke.edu/SafetyManuals/University/Q-Chemwastemgt.pdf

Arizona State University http://www.asu.edu/uagc/EHS/chemical1.htm

University of Bath http://www.bath.ac.uk/internal/waste/wastespecchem.htm

Toronto University www.ehs.utoronto.ca/Resources/wmindex/wm5_2.htm

University of Minnesota http://www.dehs.umn.edu/hazwaste.htm

Bowling Green State University http://www.bgsu.edu/offices/envhs/page18356.html

University of Colorado http://ecenter.colorado.edu/greening_cu/2000/page6.html

Universidade de Clenson http://ehs.clemson.edu

Some universities also have Brazilian electronic portals that can be visited to evaluate their procedures for collection of chemical waste chemicals in their campi:

Universidade de São Paulo - Campus de São Carlos http://www.sc.usp.br/residuos/rotulagem/downloads/normas_recolh.pdf

Universidade Federal de São Paulo http://www.unifesp.br/reitoria/residuos/index.php

Universidade Estadual Paulista http://www.unesp.br/pgr/manuais/residuos.pdf

Universidade de Campinas http://www.cgu.unicamp.br/residuos/sobre/gerquim.htm

Universidade Federal de Santa Catarina http://www.cga.ufsc.br/programas/residuos.htm

Universidade de Brasília www.unb.br/resqui

Hazardous waste management programs encourage the minimization of waste in universities and provides incentives to these institutions to reduce the health environmental risks, and at the same time decrease the amount of hazardous waste to be handled, stored and transported, as well as reduce the cost of packaging, transportation, and disposal.

The University of Clenson (http://ehs.clemson.edu/) offers an example of a safety and environmental health plan in the campus that applies to all faculty units, staff and students, as well as to all activities undertaken there. This plan includes the following: general safety on campus; accordance with the laws of occupational and environmental health, disaster management, emergency response to hazardous products, air quality in the external and internal environment of the university, management of lead used in the edifications throughout the university; ergonomic plan, plan for prevention, control and measures of chemicals spillage, policies against violence in the workplace; hygiene in the use of chemicals; biosafety manual; risk communications; nanotechnology manual; manual for management disposal of chemical agents; manual for respiratory protection, and control of exposure to blood borne pathogens, industrial hygiene and manual of radiation protection.

An example of pioneering initiatives in this area is the School of Pharmaceutical Sciences of the University of São Paulo that is taking on board the values outlined above on health and environmental quality, having decided to implement an environmental management system to establish a more suitable environmental performance, according to more modern canons.

## CONCLUSION

Green chemistry was a concept introduced by EPA in the 1990s, a more sustainable chemistry in collaboration with the American Chemical Society (ACS) and the Green Chemistry Institute. This green chemistry concept is related to the invention, development and application of methodologies that reduce or eliminate the use of dangerous chemicals and sub-products, harmful to human health or the environment. Several European countries, the U.S. and Japan, among others, are encouraging the implementation of this concept in industries and activities of teaching and research, including rewarding companies and researchers for developing chemical processes, services and products that not damage the environment. In fact this concept does not introduce anything new, because it encompasses values that have being discussed since the 1970s. However, incorporate values and the parameters of sustainability discussed in Agenda 21, the Protocol of Kyoto and Rio +10. However, the relevance of this green chemistry is to incorporate their concerns into the concept of danger or toxicity of chemicals. It is worth noting that, the concept of toxicity is the potential capability that the substances have to present a hazard to life and the environment under certain conditions (Klassen, 2007). The concept of green chemistry is to avoid this hazard. Thus, in avoiding this hazard you can make use of the basic paradigm of Toxicology that is the concept of risk, which includes the hazard or toxicity, which is likely to produce harm under specific conditions, namely:

Risk= Hazard (or toxicity) x Exposure

This risk approach allows the intrinsic toxicity of chemical compounds and also their conditions of exposure to be dealt with (Klaassen, 2007). Thus, while advocating the use of substances of lower toxicity, it is also creating a policy of damage prevention for humans and the environment. In the process of creating control over chemical exposure, alternatives to minimize chemical risk are also created. The laws related to minimizing chemical risk are based on maximum permissible or tolerable levels of exposure, the use of preventive measures to minimize exposure, the use of personal protection equipment, and also, measures to control technology and treatment of effluents. Since chemical safety is the opposite of chemical risk, any of the above presented alternatives such as the replacement of a less intrinsically toxic compound, or alteration of exposure conditions are welcome. If low risk products are used, no additional costs will be needed to secure conditions of exposure (Tundo, 2000).

In conclusion, the implementation of constant training of university teachers and students with regard to safety in the use, storage and disposal of dangerous products, is key for all above mentioned procedures of health and management quality to become a reality.

## REFERENCES


AFONSO, J. C., NORONHA, L. A.; FELIPE, R. P.; FREIDINGER, N. Gerenciamento de resíduos laboratoriais: recuperação de elementos e preparo para descarte final *Quim. Nova,* v.26, p.602-611, 2003.

LEITE, Z. T. C.; ALCANTARA, S.; AFONSO, J. C. A gestão de resíduos de laboratório na visão de alunos de um curso de graduação de química e áreas afins. *Quim. Nova*, v.31, p.1892-1897, 2008.

ALBERGUINI, L. B.; SILVA, L. S.; REZENDE, M. A. O. Laboratório de Resíduos Químicos do Campus USP - São Carlos – Resultados da experiência pioneira em gestão e gerenciamento de resíduos em um campo universitário. *Quim. Nova*, v.26, p.291-295, 2003.

AMARAL, S. T.; MACHAD, P. F. L.; PERALBA, M. C. R.; CAMARA, M. R.; SANTOS, T.; BERLEZE, L.; FALCÃO, H. L.; MARTINELLI, M.; GONÇALVES, R. S.; OLIVEIRA, E. R.; BRASIL, J. L.; ARAÚJO, M. A.; BORGES, A. C. Relato de uma experiência: recuperação e cadastramento de resíduos dos laboratórios de graduação do Instituto de Química da Universidade Federal do Rio Grande do Sul. *Quim. Nova*, v.24, p.419-423, 2001.

AMERICAN CHEMICAL SOCIETY. Available at: <http://membership.acs.org/c/ccs/pub_9.htm >. Accessed on: 7 jul. 2009.

ARMOUR, M. A. *Hazardous laboratory chemicals disposal guide.* Boca Raton: Lewis, 1996. 546 p.

ARCHER, M.; BALF, T.; HOWARD, S.; GRAHAM, Z. S.; STUART, R. The new England Laboratories Project XL: An experiment in laboratory regulation. *Chem. Heal. Saf.*, v.7, p.32-40, 2000.

ASHBROOK, P. C.; REINHARDT, P. A. Hazardous wastes in academia. *Environ. Sci. Technol.*, v.19, p.1150-1155, 1985.

BARBOSA, D. P. Gerenciamento dos resíduos dos laboratórios do Instituto de Química da Universidade Estadual do Rio de Janeiro como um projeto educacional e ambiental. *Eng. Sanit. Ambient*., v.8, p.114-119, 2003.

BENDASSOLLI, J. A.; MÁXIMO, F.; TAVARES, G. A.; IGNOTO, R. F. Gerenciamento de resíduos químicos e águas servidas no Laboratório de Isótopos Estáveis do CENA/USP. *Quim. Nova*, v.26, p.612-617, 2003.

BORGHESAN, L.; ALBERGUINI, A.; SILVA, L. C.; OLIVEIRA REZENDE, M. O. O. Laboratório de resíduos químicos do campus USP - São Carlos – resultados da experiência pioneira em gestão e gerenciamento de resíduos químicos em um campus universitário. *Quim. Nova*, v.26, p.291-295, 2003.

BRASIL. Resolução CONAMA nº 303, de 20 de março de 2002. Available at: <http://www.mma.gov.br/port/conama/res/res02/res30302.html>. Accessed on: 06 may 2010.

BRASIL. Resolução SMA - 31, de 22-7-2003 Gerenciamento de resíduos químicos provenientes de estabelecimentos de Serviços de saúde. *Dispõe sobre procedimentos para o gerenciamento e licenciamento ambiental de sistemas de tratamento e disposição final de resíduos de serviços de saúde humana e animal no Estado de São Paulo.* Available at: <http://www.resol.com.br/textos/SMA%2031.pdf>. Accessed on: 05 jun. 2010.

COUNCIL DIRECTIVE of 12 December 1991 on hazardous waste (91/689/EEC). Available at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31991L0689:EN:HTML>. Accessed on: 06 may 2010

CUNHA, C. J. O programa de gerenciamento de resíduos laboratoriais do departamento de química da UFPR. *Quim. Nova*, v.24, p.424-427, 2001.

DEMAMAN, A. S.; FUNK, S.; HEPP, L. V.; ADÁRIO, A. M. S.; PERGHER, S. B. C. Programa de gerenciamento de resíduos dos laboratórios de graduação da Universidade Regional Integrada do Alto Uruguai e das Missões - Campus Erechim. *Quim. Nova*, v.27, p.674-677, 2004.

FIGUEREDO, D. V. *Manual para gestão de resíduos químicos perigosos de instituições de ensino e de pesquisa.* Belo Horizonte: Conselho Regional de Química de Minas Gerais, 2006. 364 p.

GERBASE, A. E., COELHO, F. S., MACHADO, P. F. L, FERREIRA, V. F. Gerenciamentos de resíduos químicos em instituições de ensino e pesquisa. *Quim. Nova,* v.28, p.3, 2005.

IMBROISI, I.; GUARITÁ-SANTOS, A. J. M.; BARBOSA, S. S.; SHINTAKU, S. F.; MONTEIRO, H. J.; EAST PONCE, G. A.; FURTADO, J. G.; TINOCO, C. J.; MELLO, D. C. Gestão de resíduos químicos em universidades: universidade de Brasília em foco. *Quim. Nova,* v.29, p.404-409, 2006.

IZZO, R. M. Waste minimization and pollution prevention in university laboratories*. Chem. Health Safety*, v.7, p.29-33, 2000.

JARDIM, W. F. Gerenciamento de resíduos químicos em laboratórios de ensino e pesquisa. *Quim. Nova*, v.21, p.671-673, 1998.

KLAASSEN, C. D.; AMDUR, M. O.; DOULL, J. (Eds.). 6.ed. *Casarett and Doull's Toxicology*: The basic science of poisons. New York: Mc Graw Hill, 2007. p. 20.

MONZ, D. J.; MCDONOUGH, F. M. EPA´s proposed Academic Laboratories Rule: A more flexible approach to the management of hazardous waste. *J. Chem. Health. Saf.,* v.13, p.5-8, 2006.

MORTARI, S. R.; MACHADO, J. C.; BOLSI, J. H. Programa de gerenciamento de resíduos químicos do Centro Universitário Franciscano. In: ENCONTRO NACIONAL DE QUÍMICA ANALÍTICA, 12., São Luis, 2003. *Resumos*. São Luís: UFMA, 2003. AB105. (1 CD-ROM).

NOLASCO, F. R.; TAVARES, G. A.; BENDASSOLLI, J. A.; Implantação de programas de gerenciamento de resíduos químicos laboratoriais em universidades: análise crítica e recomendações*. Eng. Sanit. Ambient*., v.11, p.118-124, 2006.

OTENIO, M. H.; SANTOS, A. O.; GUIMARÃES, M. F. M.; OTENIO, C. C. M.; NOGUEIRA, C. P. Gerenciamento de resíduos biológicos em instituições de pesquisa científica. Um estudo de caso. *Infarma*, v.20, p.35-40, 2008.

RONDINELLI, D. R, VASTAG, G. Panacea, common sense, or just a label?: The value of ISO 14001 environmental management systems. *Eur. Manag. J.,* v.18, p.499-510, 2000.

TAVARES, G. A. *Implementação de um programa de gerenciamento de resíduos químicos e águas servidas nos laboratórios de ensino e pesquisa do CENA/USP.* Piracicaba, 2004. 131 p. [Tese de Doutorado. Centro de Energia Nuclear na Agricultura. Universidade de São Paulo].

TUNDO, P.; ANASTAS, P.; BLACK, D.; STC., BREEN, J.; COLLINS, T.; MEMOLI, S.; MIYAMOTO, J.; POLYAKOFF, M.; TUMAS, W. Synthetic pathways and processes in green chemistry: Introductory overview. *Pure Appl. Chem*., v.72, n.7, p.1207-1228, 2000

U.S.A. Environmental protection Agency. Resource Conservation and Recovery Act (RCRA) Available at: <http://www.epa.gov/epawaste/inforesources/online/index.htm>. Accessed on: 14 jan. 2008.

U.S.A. Environmental Protection Agency Available at: <http://www.epa.gov/greenchemistry/>. Accessed on: 07 jul. 2009.

U.S.A. Environmental Protection Agency Presidential Green Chemistry Challenge (PGCC) Awards Program. Available at: <www.epa.gov/greenchemistry/pubs/pgcc/presgcc.html>. Accessed on: 11 aug. 2009.

U.S.A. Environmental Protection Agency Detalhes sobre a premiação e informações sobre o programa de incentivo à Green Chemistry da RSC. Available at: <http://www.chemsoc.org/networks/gcn/awards.htm>. Accessed on: 11 aug. 2009.

Received for publication on 23rd January 2009
Accepted for publication on 11th October 2009