System improvement of protection of employees against ionizing radiation from orphan sources in scrap metal collection facilities

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Summary

Ensuring the safety and health of employees working in scrap metal collection facilities is one of the basic duties of each founder. It must assess all risk factors. One of the risk factors is the ionizing radiation from orphan sources when capturing and handling scrap metal. The operator of the facility for collecting scrap metal must accept the means that are optimal for its operation. The measures taken should be chosen based on a differentiated approach according to the character of the operation. Organizational, technical and system measures can be included in these funds. These measures are the subject of that article.

Keywords: *contamination, employee, metal, protection, radiation, waste*

Introduction

Health and Safety protection during working duties should be one of the priorities not only of every employer but also of an employee. This is also true in the area the protection of life and health in scrap metal collection facilities, where workers are at risk not only from physical, chemical but also radioactive risks. Employees in these areas may be at risk of ionizing radiation from orphan sources that are brought to these areas by vehicles. Employers should identify, eliminate and, where appropriate, minimize the risk factors in accordance with applicable legislation [1], [2], etc. To eliminate or minimize them, they should use appropriate technical and mode protection features to prevent contaminated metal waste from entering the landfill. In the Czech Republic, a system has been in place for a long time to minimize the consequences associated with finding and seizing these orphan sources or other radioactive substances through current legislation in the field of radiation protection and security of radionuclide sources [3] and [4]. On protection in the event of the seizure of such scrap iron or municipal waste deals in particular [5]. Some problems related to the contamination of iron scrap in the Czech Republic and their solutions are mentioned in [6], [7] and [8].

The aim of the authors was to point out the importance of early identification of orphan sources of ionizing radiation going to the places of their deposition and subsequent transport to the processing sites. Furthermore, to propose specific measures to minimize risks by the founder of facilities for the collection of scrap metal with an emphasis on the Zlín Region.

The use of ionizing radiation sources, despite all supervision and efforts to secure them, is associated with a certain significant risk of losing the source and in this context, the potential risk of exposure to persons or the uncontrolled release of radioactive substances into the environment will increase. The occurrence of a resource that is not supervised and therefore not handled in accordance with the requirements of the applicable legislation in this area can occur virtually anywhere. Long years of experience have shown that in places with greater metal scrap accumulation, this risk is higher. These may be sources of ionizing radiation of both artificial and natural origin. [9]

At present, scrap metal is an important starting source material for industrial metal production. Its proportion in the end product, for example, for steel, is up to 50 %. In addition to NORM – type materials, radioactivity found in scrap metal is primarily due to orphan sources of ionizing radiation (SIR). If SIR penetrates into the melting process, contaminated product may be formed. The consequences of such emergencies are predominantly economic and the cost of removing them is in the order of millions of euros. Another problem may be the loss of confidence in the quality of the metal product. [9]

During the period 2009 – 2018, more than 460 extraordinary cases related to the management of SIR were investigated through the State Office for Nuclear Safety (SONS) in the Czech Republic (Table 1). At the entrances to metallurgical plants or scrap yards, 238 vehicles transporting scrap metal were detected positively, which represents about 51 % of the total number of seizures orphan by SIR. In the period under review, 170 waste collection vehicles with municipal waste containing SIR were captured at the incineration entrances.

Table 1: Exceptional cases related to the handling with SIR (2009 – 2018) [modified [10]]

Year	Extraordinary cases total	Of which seizures:		Other
		scrap metal transport vehicles	municipal waste collection trucks	
2009	44	20	16	8
2010	49	23	18	8
2011	55	32	16	7
2012	66	32	24	10
2013	72	41	24	7
2014	52	34	16	2
2015	36	20	10	6
2016	22	8	11	3
2017	42	19	17	6
2018	31	9	18	4
Total	469	238	170	61

Regarding the percentage of different types of materials, the statistics of the Nuclear Research Institute Řež, a.s. show that contaminated medical material is prevalent in SIR seizures and findings, however, the total proportion of military equipment containing an ionizing radiation source, other orphan sources and metal objects made of material already contaminated by radioactivity, as example, between 2003 – 2015 accounted for 40 % of extraordinary cases. [11]

The contaminated hospital waste is typically captured at the entrance to municipal waste incineration plants, while the military equipment, or other orphan SIRs and metal objects made from material already contaminated with radioactivity are mainly found in transports to facilities for scrap metal collecting, processing and melting.

Usually, if a source of ionizing radiation is found, the primary objective is to minimize the possible exposure of natural persons, prevent unauthorized use and prevent uncontrolled release of radionuclides into the environment. [8]

The highest value of dose equivalent power (DEP) on the detected SIR was recorded by a radio tube, which was discovered in the playground in Prague – Podolí in 2011. The total activity of SIR containing ^{226}Ra radionuclide reached 452 MBq, DEP was measured at 200 mSv/h on the SIR surface and 20 mSv/h on the ground surface. The highest value of total SIR activity was measured in 2004. During unloading, control of the barrel of radiopharmaceuticals containing radionuclide ^{131}I at the Prague – Ruzyně airport with a total activity of 15 GBq, was lost. [11]

In the case of SIR seizures, for example, a car was inspected in 2007, the load of which contained a metal target with ^{57}Co and ^{58}Co radionuclides. The source showed a total activity of 63 MBq and 580 MBq. A DEP of 30 mSv/h (bottom of the vehicle), 50 μSv/h (side of the vehicle) and 0.33 μSv/h in the driver's cabin were measured. This case was the capture with the highest DEP value on the car between 2003 – 2015.

The capture of the orphan SIR with the highest value of the total source activity was recorded in 2015 at the entrance to the scrap metal facility. In the delivery was captured an orphan source – the level meter with a sealed ^{137}Cs radionuclide emitter with a total activity of 690 MBq and a weight of 22 kg. [11] That special case was the SIR with the highest value of total activity recorded in the Czech Republic between 2003 – 2015.

This critical capture was initiating a new model of employees' exposure measurement and system improvement of ionizing radiation protection and simulates the consequences to be more aware at the entrance to the collector and at the entrance to the scrap metal facility smelters. Such capture has indeed occurred in the past.

Experimental part

The individual effective dose received by each individual assessed is generally determined as the sum of the effective doses over all significant exposure routes, including exposure from natural sources. Exposure routes include external exposure and internal exposure due to inhalation and/or ingestion of radionuclides. For the purposes of assessing the effective dose received as a result of the activities performed, the model only considers external exposure.

During modelling were used scenarios with specialized software RESRAD – RECYCLE, intended for the evaluation of radiation exposures arising from the recycling of contaminated scrap. The software was developed by Argonne National Laboratory with the support of U. S. Department of Energy. Methodology used in RESRAD – RECYCLE is similar to a methodology developed separately U.S. Nuclear Regulatory Commission and U. S. Environmental Protection Agency.

The software identifies eight critical activities during the iron scrap recycling process:

- Scrap transport,
- Scrap loading/unloading,
- Scrap sorting/cutting,
- Batch melting,
- Ingot casting,
- Ingot handling,
- Ingot transport,
- Slag handling. [12]

Activities such as scrap transportation, loading and unloading were further refined according to their location (collection facilities, smelters) and other potentially hazardous activities were added to the exposure scenarios:

- weighing and storing scrap in a collection facility,
- Temporary storage of scrap in collection facilities.

In the course of several activities the possible shielding of the ionizing radiation source was taken into account.

Irradiation of individuals who handled scrap before its transport to a collection point is not addressed in the model, as is the intervention of other users of products after metallurgical processing of contaminated scrap. During the melting process, scrap metal radionuclides may be separated into ingots, slag and dust particles, depending on the chemical properties of the radionuclides, the metallurgical composition of the scrap metal, the presence of slag – forming substances added to the melt, the temperature and the melting process (Table 2). The radionuclides that oxidize tend to concentrate in the slag. [13]

Table 2: Radionuclide separation factors [13]

Radionuclide	Ingot	Waste after cutting	Scoria	Filter dust
	Residual part of input weight [%]			
^{60}Co	98,29	0,06	1,65	0,0001
^{125}Sb	99,27	0,08	0,65	0,0001
^{134}Cs	0	0	100	0
^{137}Cs	0	0	100	0,00001
^{154}Eu	0	0	100	0

The ^{137}Cs radionuclide, which contains a level meter in the model, is exclusively slag, which is widely used in construction, as a road material for winter road maintenance and partly also for the production of industrial phosphate fertilizers. Thus, the risk of irradiation is eliminated during operations where the finished ingot is being handled, but at the same time it is transferred to workers handling the slag.

Results and discussion

Estimation of effective dose E [mSv], that received by the endangered worker was calculated according to the relationship [14]:

$$E = w\mathcal{R}\left(\frac{A\Gamma}{r^2}\right)t\ ,$$

Where: *wR* is a dimensionless radiation weighting factor (for photons applies *wR = 1*), *A* total source activity [GBq], *Γ* „gamma constant“ – h value kerm increment per hour at 1 m from source about activity 1 Bq (for radionuclide ^{137}Cs applies *Γ = 0,084* mGy.m^2.h^{-1}.GBq^{-1}), *r* distance from the source of ionizing radiation [m] a *t* exposure time [h].

The thickness of the absorption layer of the shielding materials for *γ* radiation was approximately determined by the energy value of the photons emitted by the radionuclide ^{137}Cs, therefore 662 keV. [15]

The average distance from the source of ionizing radiation and exposure time are based on the nature of the activities performed.

In the exposure scenario „Storage at the collection point” it is assumed that scrap shipment is carried out once a month. The scenario „Steelworks Storage" assumes the addition of scrap to pig iron to the hearth furnaces at weekly intervals. Exposure scenarios „Ingot Casting”, „Ingot Handling” and „Ingot Transport” do not assume any contamination of the material by ionizing radiation, as they only follow the slag tapping in the „Melting batch” (Table 3).

Table 3: Calculation of effective doses for given exposure scenarios

Exposure scenario	Endangered worker	Shielding			Distance [cm]	Time [h]	Half layer [cm]	Dividing factor [%]	Activity [GBq]	Effective dose [mSv]
		Means	Material	Thickness [cm]						
Transport of scrap metal collection point	customer	cabin	steel	0,3	150	0,5	0,4	100	0,460	0,009
Unloading scrap in the collection pointy	customer	–	–	–	20	0,1	–	100	0,690	0,145
Weighing and storing scrap	service	–	–	–	100	0,2	–	100	0,690	0,012
Storage at the collection point	service	container	steel	0,4	10 000	150	0,4	100	0,345	0
Storage at the collection point	customer	container	steel	0,4	5 000	0,3	0,4	100	0,345	0
Scrap sorting / cutting	sorter	–	–	–	150	3,5	–	100	0,690	0,09
Scrap loading	driver	–	–	–	200	1,5	–	100	0,690	0,022
Transport of scrap to metallurgical plant	driver	cabin	steel	0,3	150	1,5	0,4	100	0,460	0,026
Unloading scrap	driver	–	–	–	200	3,5	–	100	0,690	0,051
Storage in smelters	warehouseman	container	steel	0,4	10 000	38	0,4	100	0,345	0
Melting the charge	melter	cloak	refractory concrete	75	150	6,5	3,5	100	0,016	0,004
Ingot casting	molder	–	–	–	100	0,7	–	0	0	0
Ingot handling	molder	form	steel	8	50	1,5	0,4	0	0	0
Transport of ingot	warehouseman	–	–	–	200	0,2	–	0	0	0
Slag handling	slagger	dish	steel	1,2	50	0,2	0,4	100	0,115	0,008

Evaluation rate of workers' exposure to ionizing radiation

Although the results of the model of worker exposure to ionizing radiation are only indicative, the activities during which the highest external exposure occurs (Figure 1) are the customer's unloading and scrapping of scrap metal by the operator. During manual handling operations, the distance from the unshielded SIR is very small and a short exposure time is sufficient to achieve a high effective dose. If the SIR was directly gripped by the hand, even for a few seconds, the effective dose received would rise sharply to tens of mSv. Thus the annual limit of effective doses from external exposure and effective doses from internal exposure for radiation workers may be exceeded.

Irradiation of the operator of the collection point during the storage of scrap metal is negligible despite a long exposure period, including the intervention of another customer who visited the collection point to hand over other secondary raw materials. Again, the distance from the SIR and its shielding by the container is decisive.

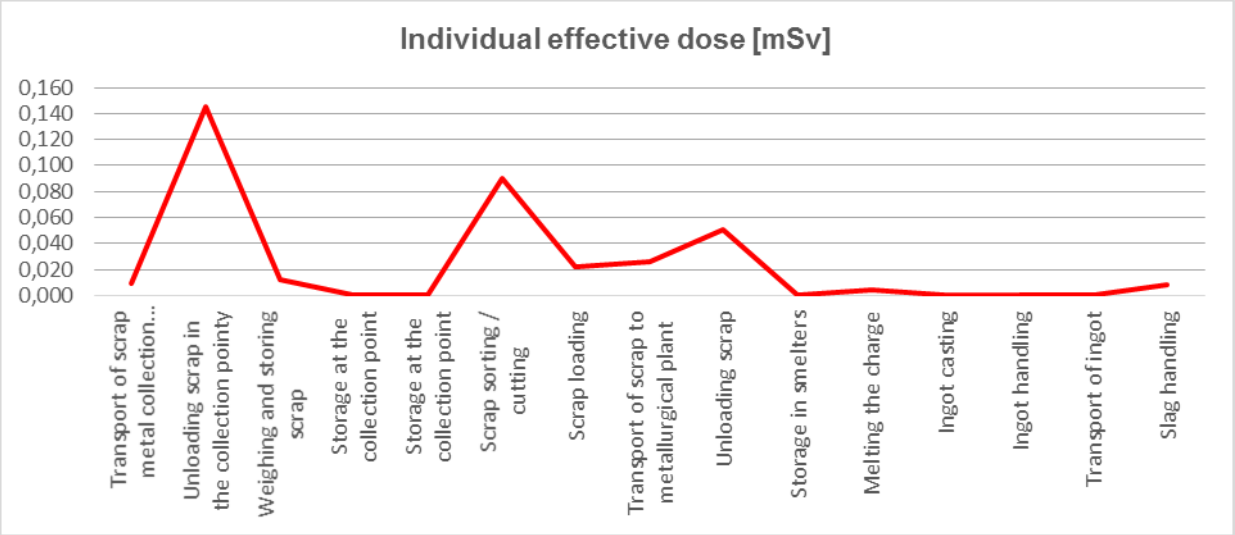

Figure 1: Effective doses for scrap metal recycling operations

For the target group of the researched facilities, the authors propose to introduce the following organizational measures in the areas of protection against the effects of ionizing radiation, detection, staff training, operating documentation and system measures.

Detection equipment

For efficient control of shipments and possible capture of orphan sources are used devices operating in continuous mode, which provide continuous information on the instantaneous dose rate value: handheld portable radiometric instruments, stationary detection systems and detectors installed on handling equipment. [3]

For passive personal dosimeters, the monitoring of persons is integral, the values are measured over time, and the dosimeter retains the information for the entire time the radiation detector has been exposed. [16]

Although passive dosimetry cannot detect an acute threat, its use in the detection of ionizing radiation in the area of scrap metal treatment is justified not only because of the low cost of detectors, but also for the possibility of backward tracing of the orphan source before its capture.

Last year, the National Radiation Protection Institute (NRPI) launched three new projects to expand radiation monitoring in the event of a nuclear accident, a terrorist attack using radioactive materials, and also to limit the spread of fake reports of a fictional radioactive threat:

- project RAMESIS: Civil Radiation Network intended for citizens, schools and other institutions to ensure timely information and safety of citizens,
- system JodDet for mass measurement of radioiodine ^{131}I in the thyroid gland,
- Low – cost passive dosimeter to assess external exposure. [17]

In the latter project, we managed to develop a simple low – cost dosimeter allowing the evaluation of personal exposure. It is a small plastic case containing a capsule with common kitchen salt. The salt when exposed to ionizing radiation exhibits luminescence that can be easily induced in the laboratory, evaluated, and the dose of radiation can be calculated from the amount of light emitted. [18]

The originally intended use of this detector for detecting individual doses of fire – fighters intervening, for example, in a traffic accident where a source of ionizing radiation has been transported, or customs staff who may encounter illegal shipments of radioactive material during their work can be extended to collection staff, who control the entry of vehicles into the area, unload or load scrap metal and sort it.

The dosimeter requires no special maintenance and can be carried in your pocket. In the production of 10 000 pieces, the production costs can be reduced to 20 CZK/dosimeter. The radiation indicator is based on only 3 CZK, and the salt needs to be changed approximately every 10 years. [19]

The authors recommend to equip the operator of the collecting device with a passive dosimeter with a salt capsule, which would carry it in the pocket of work clothes for the whole time of their work. In case of an event suspected of possible exposure of the operator to ionizing radiation, or at specified intervals to conduct periodic occupational medical examinations, the dosimeter would be sent to the NRPI laboratory for evaluation.

Events with increased risk of operator exposure can be considered, for example, when:

- an orphan source has been captured at another link in the distribution chain, to which the scrap collection facility also supplies the scrap metal,
- In the course of transport to another facility, the orphan source was captured on the wagon at the transporter, who supplies the metal scrap regularly to the assessed collection facility.

If the laboratory is found to have indeed irradiated, appropriate measures will be taken, depending on the dose received (provision of the necessary medical care, exclusion of the worker from activities or examinations that could lead to further exposure, or control of other personnel, who could also come into contact with an orphan source).

Staff training

The risk of failure of the system protection system can be further mitigated by increasing emergency preparedness through training measures for the staff concerned. In accordance with Section § 91 [3], an operator of equipment for melting, collecting and processing scrap metal shall take measures to locate an orphan source and a worker who may be exposed to ionizing radiation from an orphan source:

- report on the effects of ionizing radiation on the human body,
- learn how to visually recognize an orphan source,
- instruct about orphan source finding or suspicion of its presence,
- Regular training on up the above facts.

If the workplace is equipped with radiometric instruments, training in the operation of radiometric instruments and checking their functionality should be part of the training. [3]

Based on a recommendation SONS (DR – RO – 4.1, revision number 1.0) and as a result of the assessment of the risk of failure of the regime protection system, a thematic plan was drawn up, including a training syllabus (Table 4) and training schedule for the operation of equipment for the collection and processing of scrap metal in the range of two hours. [20] The training syllabus comprises a total of eight thematic units which, by their scope, completely cover the training requirements of the staff of such a facility. [20]

The authors propose to include training in a separate block beyond the mandatory training of employees in the areas of occupational health and safety, fire protection and hazardous waste management. It is recommended that the employee's duty to attend the proposed training at least once a year be recorded in the operating rules of the relevant facility and to record the training in the operating log.

Table 4: Training syllabus

Topic 1: Ionizing radiation and its effects on humans: ➢ radiation sources (natural, artificial), ➢ Types of ionizing radiation (α, β, γ, X, neutron), ➢ exposure routes (external exposure, body surface contamination, inhalation, ingestion), ➢ Biological effects of radiation on humans (acute, stochastic).
Topic 2: Related legislation: ➢ Law no. 263/2016 Sb., atomic law (§ 91 responsibilities, § 191 offenses), ➢ Decree no. 422/2016 Sb., on radiation protection and security of the radionuclide source (§ 3 general limits, § 12 – 16 categorization of resources).
Topic 3: Technical equipment for radiometric control: *Adapt content to specific workplace equipment. If a portable radiometric device is used in the workplace, the trainer shall simultaneously train the operator and demonstrate the functionality of the device:* ➢ portable radiometric instruments, ➢ stationary detection system, ➢ mobile detection system on handling equipment, ➢ Passive dosimetry.
Topic 4: Visual identification of orphan sources: *Use image attachment no. 5 recommendation* SONS *(DR – RO – 4.1):* ➢ ionization fire detector sensors, ➢ industrial gauges and their working containers, ➢ defectoscopic instruments and their components, ➢ medical devices and sources, ➢ transport packaging sets and components therefor, ➢ chemicals and radioactive paints, ➢ Warning symbols, signs and signs, shading bricks and semi – chambered chambers.
Topic 5: Procedures for detecting and finding orphan sources: *Use attachments no. 1 and 2 recommendation* SONS *(DR – RO – 4.1):* ➢ diagram of the procedure for capturing an orphan source in a vehicle, ➢ overview of connections to the locally relevant workplace SONS, ➢ indicative definition safety zone, ➢ procedure for finding an orphan source in the facility, ➢ Radiation protection of individuals.
Topic 6: Documentation kept at the workplace: *Use attachments no 3 a 4 recommendation* SONS *(DR – RO – 4.1):* ➢ record of radioactive material capture, ➢ internal instructions for the procedure to suspect the capture of an orphan source, ➢ Information posters.
Topic 7: Discussion: ➢ Questions and Answers, ➢ clarification of ambiguities, etc.
Topic 8: Examination, conclusion

Typical project of collecting yard

If an orphan source is found inside an area of the facility for melting, collecting and processing scrap metal, and if the original owner is not found within 60 days of discovery, the operator of the facility becomes the owner of that SIR. The operator then bears all the costs associated with the search, safe handover, storage, preparation for further use or disposal of the orphan source. [3]

There is a risk that operators will not take a responsible approach to orphan SIRs precisely because of the potential burden of increased cost of their capture, and will try to meet the requirements [3] very laxly, referring to a tiered approach at their discretion and that the SONS recommendations are not legally binding. It is therefore desirable to take measures to reduce this risk where the power to grant and extend the consent to operate such equipment is located.

Facilities for the recovery, disposal, collection or purchase of waste may be operated only on the basis of a decision of the regional authority granting consent to operate this facility and its operating rules. [2]

According to the Waste Act, the municipality is obliged to set up a system of salvage and collection of waste in its territory and to determine the places where citizens can dispose of sorted and dangerous components of municipal waste. For this purpose, the Zlin Region commissioned a type design of a collecting yard including an accompanying and summary technical report and a draft operating rules for the collecting yard that municipalities or other potential operators can use as a model for their facilities. [21]

Although the document in question is non – binding, the regional authority can assess the degree of its conformity with the issued type project when deciding on an application for a permit to operate. Applicants who are certainly interested in the smooth running of the procedure are aware of this and will try to bring the type project as close as possible.

The authors propose amendments to Annex 5.3 of the type design of the collection yard – „Operating rules of the collecting yard – model“. It is a supplement to information and measures so that the operator of a “small” facility meets the requirements [3] using a graduated approach. The proposed changes for the Zlín Region are shown in the table 5.

The regional authority may create reasonable pressure on existing operators, for example by sending out an information leaflet that will invite the operator to revise the rules of operation with regard to the requirements [3] and recommend an annex to the type design of the collection yard as a model. [21] The revised Operating Rules are then subject to re – approval under Section §14 [2], thereby ensuring its legitimacy and proportionality.

The proposed method does not affect collection yards that are operated by municipalities solely for the needs of citizens of the municipality and are established through a generally binding decree. Such a collecting yard need not be authorized to operate pursuant to Section §14 [2], and if it is not treated with hazardous waste, then neither consent under Section §16 [2]. Here the authors recommend that the regional authority appeals directly to the municipal authorities.

Table 5: Proposal for changes in the operating rules of the collecting yard

Chapter	Name	Description of changes
1.6	Telephone numbers for emergencies events	*At the end of the chapter add:* Regional Centre of the State Office for Nuclear Safety Tř. kpt. Jaroše 5, 602 00 Brno, telephone 515 902 771).
6.3	Waste acceptance	*In the list of tasks of the authorized worker under „visual inspection of waste" insert:* – If it is a metal waste, check with a manual ionizing radiation detector.
11	Monitoring of plant operation and its impact on the environment	*In subchapter 11.1 to the list of operator control activities under „the provision of means of collection…" add:* – Regular monthly inspection of metal waste containers with a manual ionizing radiation detector.
15	Extraordinary and emergency measures	*In subchapter 15.1 add to the list of extraordinary or emergency situations during the operation of the collecting yard:* – Capture or discovery of an orphan ionizing radiation source.
16	Solution extraordinary and emergency situations	*Add a new subchapter:* 16.5 Detection or handhold of ionizing radiation source Determining the occurrence of an ionizing radiation source at the acceptance of waste or periodic inspection of the facility requires expert judgment and decision on further action. The case is immediately reported to the SONS Regional Centre by telephone and the finder proceeds according to the instructions of SONS employees. As an immediate precaution, the movement of persons in the safety zone around the source is excluded. Measure the dose equivalent power of the handheld detector along a circle at a distance of 1 – 2 m from the radiation source. The approximate boundary of the safety zone in meters shall be determined as twice the measured value in μSv/h (μGy/h) in the direction from the radiation source through the appropriate measurement point.
17	Operational safety and health protection	*In subchapter 17.4 add to the list of PPE:* – Passive dosimeter with salt capsule.

System measures

Unconditional use of hand – held dosimetry instruments for the acceptance of waste in 'small' scrap metal collection and treatment facilities will most likely be achieved only through an amendment to the relevant legal regulation. The acquisition of a dosimeter represents an investment of several tens of thousands of CZK for the operator, regardless of other costs associated with the eventual service of the device. The authors do not assume that this measure will be applied voluntarily by operators. Emergency dosimeter U – RAD 115, which is a part of common instrumentation of units of the Fire Rescue Service of the Czech Republic, can be purchased for about 40 thousand CZK incl. VAT. [22]

Commercial sensitivity devices that are currently used by some outlets in the Zlin Region to search for orphan SIRs, such as a scintillation detector RadEye™ PRD, are in similar prices.

The obligatory obligation of the operator to carry out detection of ionizing radiation at the acceptance of metal waste may be incorporated by the legislature in Annex 2 [23].

To uniquely identify the entity (other than the facility for melting scrap metal) who is required by the provision §91 [3], it would also be appropriate to give its definition egg to [2].

Conclusions

The protection of the life and health of workers who work in scrap metal collection sites against the effects of ionizing radiation should be one of the main responsibilities of each landfill site manager. The authors pointed out some factors that would improve the safety and health protection of employees. The most important measures include the introduction of organizational measures in the areas of protection against the effects of ionizing radiation, detection, staff training and operational documentation. It would be a recommendation to equip the operator of the collecting device with an affordable passive dosimeter. Furthermore, the article contains a proposal of training content for the operation of equipment intended for the collection and processing of scrap metal on the proposal of training content. And last but not least, a proposal for changes to the operating rules of the type design of the collection yard. In the area of systemic measures, the authors also considered the desired changes in legal requirements.

Acknowledgement

This article was created within the project RVO/FLKŘ/2019/001 Project of Excellence of the Institute of Population Protection.

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Zkvalitnění ochrany zaměstnanců před ionizujícím zářením z opuštěných zdrojů v zařízeních určených pro shromažďování kovového šrotu

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Souhrn

Zajištění bezpečnosti a ochrany zdraví při práci zaměstnanců pracujících v zařízeních určených pro shromažďování kovového šrotu je jednou ze základních povinností každého jejího zřizovatele. Ten musí posoudit všechny rizikové faktory. Jedním z rizikových faktorů je ionizující záření z opuštěných zdrojů při záchytu a manipulaci s kovovým šrotem. Provozovatel zařízení určeného ke shromažďování kovového šrotu musí přijmout taková opatření, které budou pro jeho provoz optimální. Přijatá opatření by měla být volena na základě odstupňovaného přístupu podle charakteru provozu. K těmto opatřením lze zařadit i opatření organizační, technická a systémová. Uvedená opatření jsou předmětem daného článku.

Klíčová slova: *kontaminace, kov, odpad, ochrana, radiace, zaměstnanec, záření*