RadMelt Early Warning System (RMEWS)

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ABSTRACT

Since the first reported accidental smelting of a highly radioactive Cobalt-60 gauge in an Electric Arc Furnace (EAF) in 1983 at Auburn Steel in Auburn, New York [1], the steel making industry has been plagued with smelting of highly radioactive gauges. An example of one of the most publicized smelting incidents occurred in May, 1998 in the South of Spain [2]. In this case at an Acerinox steel plant, a highly radioactive Cesium-137 gauge (mistaken as scrap metal) was smelted accidentally with other scrap metal in their EAF with a significant amount of the Cesium being expelled into the atmosphere and baghouse flue dust. The airborne radioactive plume spread as far as Switzerland with several processors being contaminated after processing the steel plants' radioactive slag and flue dust. This incident is a primary example of the serious consequences steel-making facilities encounter after a highly radioactive gauge is smelted in a furnace. In fact, accidental smelting of Cobalt-60 gauges are continuing all over the globe (recent reported incidents in Taiwan, Canada, India and China [3]), steel making facilities have to be on guard and protect themselves against the possibility of receiving a Cobalt-60 gauge in their scrap metal feed stock. Cobalt-6, when smelted, remains in the heat(s) [3], inevitably causing significant considerable radiation contamination to plant equipment, by-products and finished goods (Fig. 1). Outokumpu plants in Finland, Sweden and England all accidentally smelted Americium-241 gauges with their scrap feed stock in the EAF, with eventual detection occurring in the slag [5][6]. Outokumpus' latest reported Americium-241smelting incident was qualified as an "International Nuclear Event Scale radiation incident" [6] due to the fact that Americium-241 is extremely dangerous to the human body when ingested. Incidents involving highly radioactive gauge smeltings are continuing all over the globe even with the vast majority of steel making facilities monitoring their incoming scrap metal shipments at multiple locations with highly sensitive radiation detection systems. There a number of reasons why existing radiation detection systems fail to detect these radioactive gauges, but this is not the focus of this paper presentation.

As a result of the realization concerning the risk of not detecting a highly radioactive gauge in the scrap metal feed stock, an increasing number of steel making facilities have created and implemented <u>WRITTEN RAD-MELT ACTION PLANS</u>. These plans have been designed to protect personnel, minimize plant contamination, and prevent the processing and release of finished product after a radioactive gauge smelting in the furnace. These plans outline specific step-by-step procedures based on Exposure and/or Dose levels. In order to determine the Exposure and/or Dose levels after a smelting it requires a qualified person taking a calibrated handheld radiation detector to a preselected area in the plant to perform radiation measurements. It then requires this person to make a judgment call as to the severity of the smelting. based on localized readings. in order to take the next series of complex steps involved with the handling of the smelting. Initially, decision makers have to make these complex and very costly decisions centered around Exposure and/or Dose levels. Utilizing this manual way of handling a radioactive gauge smelting leads to <u>extended time delays</u> and <u>insufficient critical information about the smelted isotope</u>. Exposure and/or Dose is a only a small segment of information required to handle a smelting and primarily applies to the safety of plant personnel. Detailed live-time information about the Exposure and/or Dose, what type of isotope was smelted, and what is happening to the isotope during the smelting, is critical information decision makers must have as quickly as possible. Otherwise, serious mistakes can be made, such as, shutting down the furnace too soon, pouring the steel into the slag pit or unnecessarily opening the furnace cover.

The RAD-MELT EARLY WARNING SYSTEM (RMEWS), operates in live-time, addresses all of the critical issues associated with an accidental smelting of a radioactive source in the furnace, and consequently saves valuable time while minimizing plant contamination and taking the guess work out of the equation.

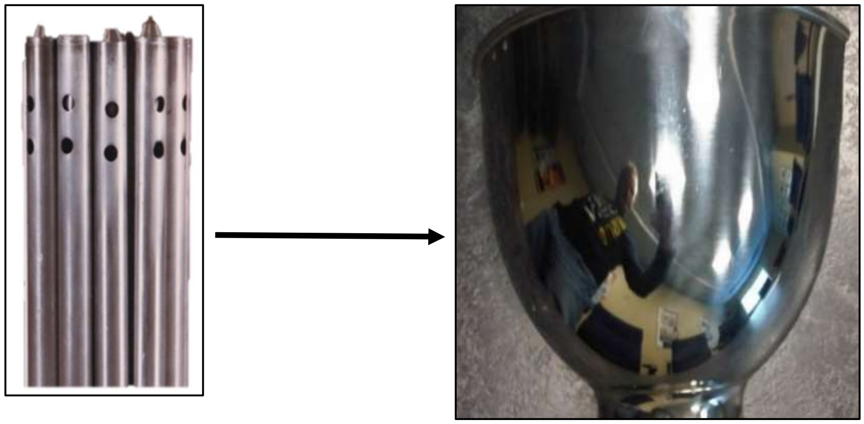

Fig. 1, a) highly radioactive Cobalt-60 irradiator [7], b) radioactive mixing bowl with Cobalt-60 from a steel plant smelting

INTRODUCTION

There are actually more than 1,000 radioactive isotope, however, of all the reported major steel plant smelting incidents involving a highly radioactive gauge, to date, there have only been three isotopes reported: Americium-241, Cesium-137 and Cobalt-60 (see Fig. 2 for the Gamma Ray spectra taken by an inorganic scintillator). In addition to these three isotopes, it is important to take note that the isotope Iridium-192 is of major concern to the steel industry. Iridium-192 is also a major concern, because of the sheer number of gauges currently being used in every country around the globe which are manufactured with extremely high concentrations of radioactive material in a small recyclable metallic case.

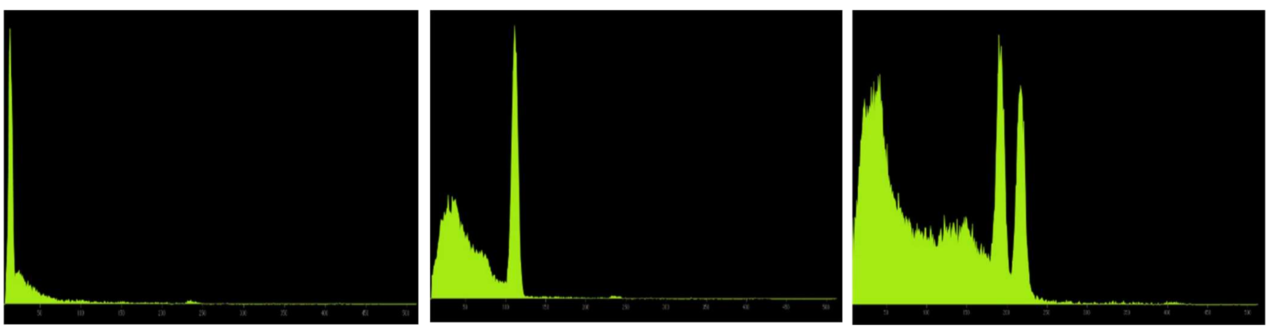

Fig. 2, Spectra examples: a) Americium-241, b) Cesium-137, c) Cobalt-60

In the event of a radioactive gauge smelting, it is imperative for steel making personnel to know as soon as possible which isotope has been smelted. Knowing the isotope at the earliest possible moment will determine what is happening to the radioactive material during the smelting process and where it will end up in the melting operation. There have been many studies conducted on exactly where specific isotopes will end up in the melting process after it has been subjected to high furnace temperatures (Fig. 3, [7]). For example, Cobalt-60 primarily stays in the steel (Fig. 3) with a very small fraction of the initial concentrations ending up in the slag and dust. In the case of Cesium-137, the vast majority (Fig. 3, [7]) will end up in the flue dust and exhaust fumes (Fig. 3, [7]), while minute amounts are found in the slag and steel. Whereas, with Americium-241, the majority will end up in the slag with minute concentrations found in the steel, flue dust and exhaust fumes.

There must be specific handling procedures for different isotopes in order to properly handle the smelting of these radioactive gauges. Failing to follow the correct procedure for each specific type of isotope can result in unnecessary radiation exposure to personnel, increased product and plant contamination and exhaust gas emissions. When the safety shield of a radioactive gauge is melted, exposing the radioactive material to the high temperature of the furnace, is a critical event - it is at this point, or soon after, that melt shop personnel must be informed that a smelting has taken place. Clear and precise automated step-by-step instructions for the smelted isotope are needed by the furnace operator and other associated personnel in order to eliminate the guess work associated with handling the events which follow a radioactive source smelting.

Further to knowing where and how the radioactive material is travelling from the furnace through the off-gas system as the radioactive gauge is being smelted, is knowing in live-time the Exposure/Dose levels in order to protect personnel from radiation exposure. The accumulated radiation Exposure/Dose for one isotope may pose a serious risk to humans while another isotope would have much less consequence (for example, Americium poses a more serious health risk when ingested than, Cesium).

Element	Name	Distribution factor			Isotope characteristics		
		Metal	Slag	Fume (Dust)		Half life Years	Energy keV
Mn	Manganese	**1**	0.1	0.05	^{54}Mn	0.855	
Fe	Iron	**1**	0.1	0.05	^{55}Fe	2.68	
Co	Cobalt	**1**	0.01	0.005	^{60}Co	5.27	1250γ
Ni	Nickel	**1**	0.01	0.001	^{63}Ni	125	β
Sr	Strontium	0.1	**1**	0.1	^{90}Sr	2.81	540β
Cs	Cesium	0.001	**0.1-0.5**	**0.5-1**	^{137}Cs	30	662γ
Ir	Iridium	1	0.01	0.001	^{192}Ir	0.2	561γ
Ra	Radium	0.1	**1**	0.1	^{226}Ra	1620	800γ
Th	Thorium	0.1	**1**	0.01	^{232}Th	$1.4*10^{10}$	55γ
Am	Americium	0.1	**1**	0.001	^{241}Am	432	60γ

Table 3.8 Partitioning in steelmaking (%)

Elements	Metal product	Dust	Slag	Volatile
H	5-15	0	0	85-95
C	27-100	0	0	0-73
Na, K	0	40-60	40-60	0
P	9-48	2-4	50-87	0
S	6-25	1-5	74-89	0
Cl, I	0	0-50	0-50	0-100
Ca, Sc, Sr, Y, Zr, Nb, Ba, Ce, Pm, Sm, Eu, Gd, Tb, Tm, Ta, Ra, Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es	0	2.5-7.5	92.5-97.5	0
Cr	40-97	1-3	0-59	0
Mn	2-24	3-4	72-95	0
Fe	95.5-98.5	0.5-1.5	1-3	0
Co, Ni, Mo, Tc, Ru, Sn, W, Ir	98.5-99.5	0.5-1.5	0	0
Zn	0-20	80-100	0	0
As	50-90	10-50	0	0
Se, Te, Os, Tl, Pb, Bi, Po	2.5-7.5	92.5-97.5	0	0
Ag	75-99	1-25	0	0
Cd	0	100	0	0
Sb	75-99	1-20	0-5	0
Cs	0	95-100	0-5	0

Fig. 3. partitioning factors of isotopes in steel, slag, flue dust and exhaust [7]

There are other important factors to consider in real-time, when a radioactive gauge is been smelted, such as when does is it time to shutdown the melting operation, what is the shutdown procedure and does the melting operation have to be shutdown at all. It is important to note; there will also be situations where a smelted radioactive gauge will result in a specific activity level below the allowable release limits. An example of this situation is where a smelted Cobalt-60 source of 295μCi (10.9MBq) in a furnace of 120 tons (1.2e+8 grams) would result in a specific activity of 0.1 Bq/g (2.7pCi/g) in the steel which is at the IAEA recommended clearance levels for reuse (Fig. 4, [8]).

TABLE I.4. SUMMARY OF RESULTS OF STUDIES ON CLEARANCE LEVELS FOR REUSE

Radio-nuclide	Bq/g		Bq/cm^2				
	IAEA[a] [4]	NUREG[a] [34]	IAEA[b] [4]	IAEA[c] [4]	CEC[d] [11]	Haristoy et al. [33]	NUREG[b] [34]
H-3		1×10^{5}				1×10^{6}	3×10^{3}
C-14		4×10^{3}				2×10^{4}	1×10^{2}
Na-22		5×10^{-1}				2×10^{-1}	2×10^{-1}
Na-24		3×10^{-1}				2×10^{-16}	1×10^{-1}
P-32		2×10^{2}				4×10^{3}	2×10^{1}
S-35		2×10^{4}				2×10^{4}	4×10^{2}
Cl-36		1×10^{3}				2×10^{3}	6×10^{1}
Ca-45		2×10^{3}				8×10^{3}	6×10^{1}
Cr-51		3×10^{1}				2×10^{3}	1×10^{1}
Mn-54	4×10^{0}	1×10^{0}	4×10^{-1}	4×10^{1}	2×10^{0}	8×10^{0}	6×10^{-1}
Fe-55	9×10^{3}	2×10^{3}	9×10^{1}	5×10^{3}	4×10^{2}	4×10^{3}	8×10^{1}
Fe-59		1×10^{0}				4×10^{1}	4×10^{-1}
Co-57		1×10^{1}				7×10^{1}	3×10^{0}
Co-58		1×10^{0}				4×10^{1}	5×10^{-1}
Co-60	1×10^{0}	4×10^{-1}	1×10^{-1}	1×10^{1}	5×10^{-1}	2×10^{0}	2×10^{-1}
Ni-63	2×10^{4}	1×10^{4}	3×10^{3}	1×10^{4}	5×10^{2}	3×10^{4}	3×10^{2}
Zn-65	6×10^{0}	2×10^{0}	6×10^{-1}	5×10^{1}		1×10^{1}	7×10^{-1}
Sr-89		3×10^{2}				9×10^{2}	2×10^{1}
Sr-90	7×10^{1}	8×10^{1}	1×10^{1}	4×10^{1}	2×10^{0}	2×10^{2}	1×10^{0}
Y-90		1×10^{2}				7×10^{5}	1×10^{1}
Nb-94	2×10^{0}	7×10^{-1}	2×10^{-1}	2×10^{1}		2×10^{0}	3×10^{-1}
Tc-99m		1×10^{1}				∞	4×10^{0}
Tc-99	9×10^{3}	2×10^{3}	1×10^{3}	5×10^{3}		6×10^{2}	5×10^{1}
Ru-106		5×10^{0}				3×10^{1}	2×10^{0}
Ag-110m		4×10^{-1}				3×10^{0}	2×10^{-3}
Cd-109		2×10^{2}				1×10^{2}	8×10^{0}
In-111		4×10^{0}				1×10^{6}	1×10^{0}
I-123						3×10^{20}	
I-125		8×10^{1}				7×10^{2}	3×10^{0}
I-129		3×10^{1}				1×10^{2}	7×10^{-1}
I-131		3×10^{0}				3×10^{3}	1×10^{0}
Sb-124		6×10^{-1}				1×10^{1}	2×10^{-1}

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Fig. 4. summary of results of studies on clearance levels for reuse

It is well worth mentioning in this paper that, historically, many steel making plants install a single PVT (PolyVinyl Toluene) based radiation detector panel on or near a flue dust screw conveyor, thereby alerting personnel to an increase in the measured radiation level from the dust. PVT based systems cannot identify isotopes, the can only detect increases in the total measured radiation level. As a result of this limitation, they are prone to false-positive alarms caused by radiation not associated with a smelting. False-positive alarms are misleading and can potentially result in an unnecessary shutdown of the melting operation. There are many variables and unknowns when measuring ambient background radiation levels, such as, changing weather conditions, Thorium and Uranium progenies (Thoron and Radon) [9] in the K061 flue dust and external radiation shots from radiographers doing X-Raying inspection on pipe welds, causing elevated radiation levels resulting in false-positive alarms. Radiation monitoring at the furnace and off-gas system is considered a critical stage in the manufacturing process. Conventional PVT based radiation detection systems cannot provide the critical information required for decision-making or the consequences of making costly mistakes.

The crystal based RMEWS utilizes Photo-Peak recognition providing isotopic identification - a significant improvement over conventional PVT scintillator detection systems which virtually eliminates false-positive alarm conditions.

RadMelt EARLY WARNING SYSTEM (RMEWS) OVERVIEW

There are three primary objectives of the RMEWS; firstly, to realize a radioactive source smelting, secondly, to provide live-time monitoring and, thirdly, to help facilitate the furnace and associated equipment shutdown.

The RMEWS includes multiple crystal-based detector panels strategically located in the melt shop furnace and pulpit area, along the off-gas dust collection system and on the exhaust fume stack. Each detector panel has been specifically designed to identify isotopes, in live-time elevated radiation levels, and at the earliest possible moment, while simultaneously assessing the radiation Exposure/Dose levels. The RMEWS technology has been field tested for reliability and sustainability in the rough and hazardous environment associated with steel making operations with excellent results. Over a two-year period, the Beta test site where the RMEWS is installed, there was a zero false-positive alarm rate and one radiation warning alert to an unusual increase in one the detectors measured radiation levels. In order for the RMEWS to produce an actual rad melt alarm condition, a specific sequence of events must occur, otherwise, it is considered a warning alert. Both the true rad melt alarm and warning alerts can easily be accessed by authorized personnel using the RMEWS software application tools.

The RMEWS utilizes a number of interactive alarm configuration tools centered around a library which includes a series of isotopes that have historically made up greater than 99% of all radioactive gauge smeltings in steel making facilities around the Globe. Each applicable Isotope has its own developed step-by-step alarm procedure included in the RMEWS procedural data base. Depending on the identified isotope(s), (there could be more than one at the time of a smelting) there will be a specific step-by-step procedure developed for each facility with input from the manufacturer, a qualified radiation safety specialist and steel plant personnel associated with steel making operations (Fig. 5). In order to ensure the step-by-step procedures will work properly, plant operational personnel can be instructed in the procedures required in a classroom environment. From a practical standpoint, their input and acceptance of the automated RMEWS procedures, will ensure that the system satisfies the plants' operational logistical requirements. Once the RMEWS step-by-step procedures have been configured, they can be incorporated into the RMEWS software application as required. Isotopes react differently to the high temperatures of the furnace, they could alloy with the steel, be captured in the slag, or vaporize into the off-gas dust collection system and exhaust fume stack.

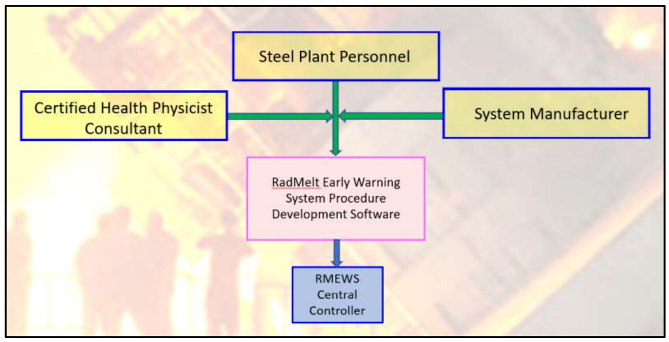


Fig. 5, team required to formulate a step-by-step RMEWS RadMelt plan

The RMEWS system will store pure raw data before, during and after the smelting of a radioactive source allowing the user to replay the entire event as it unfolded at a time-selected-at-a-glance view and/or selected and controlled replay speed. Specific details of the measured radiation levels can be extrapolated from the stored raw data for further analyses. This data is extremely important for a number of reasons, it will capture the entire event for future scientific analyses, it will provide real-life training for steel plant personnel, it will provide critical data when making a report of the event, and it will serve as concrete evidence should there be a need for investigation. The other benefit of the RMEWS data is to guide the radiation cleanup company to the areas where decontamination will be required. Having this pure raw data will give the cleanup critical information about the source smelting and what isotope and Exposure/Dose rate they will be facing prior to entering the site. Providing this information may also help to minimize plant decontamination downtime.

RadMelt EARLY WARNING SYSTEM (RMEWS) TECHNOLOGY

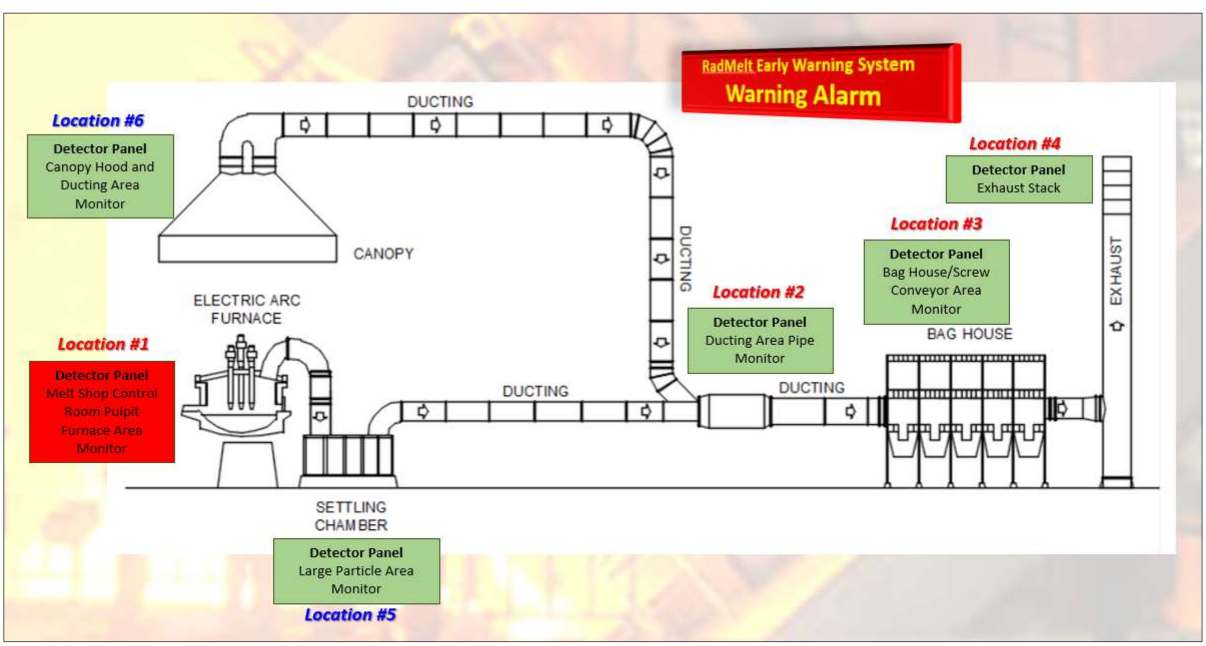


Fig. 6 Example of a RMEWS Layout

A comprehensive RMEWS system layout includes a series of detector panels (minimum 5 detectors in 4 locations) strategically located near plant equipment associated with a EAF melting operation (see Fig. 6). These detector panels will be incorporated into the plants TCP/IP network, communicating with a dedicated central detector controller located in an area where personnel will be present during scanning periods. Each detector will operate as a standalone unit sampling the ambient background radiation time stamping and storing each data sample in the event of a data transfer interruption with the RRMEWS central controller. Once the TCP/IP communications have been re-established with the central controller the stored data from each detector panel will be extracted, reanalyzed and archived accordingly. The RMEWS GUI interface (Fig. 7 and Fig. 8) will provide live-time detector operational information allowing personnel to view the system performance at a glance. Only authorized personnel with have password registration, allowing them to make changes and adjustments to the system configuration and step-by-step procedures.

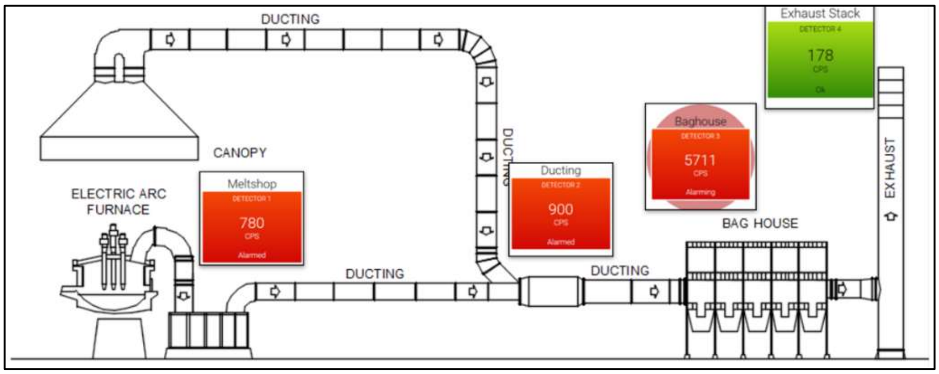


Fig. 7, typical RMEWS GUI interface (showing 4 detector locations)

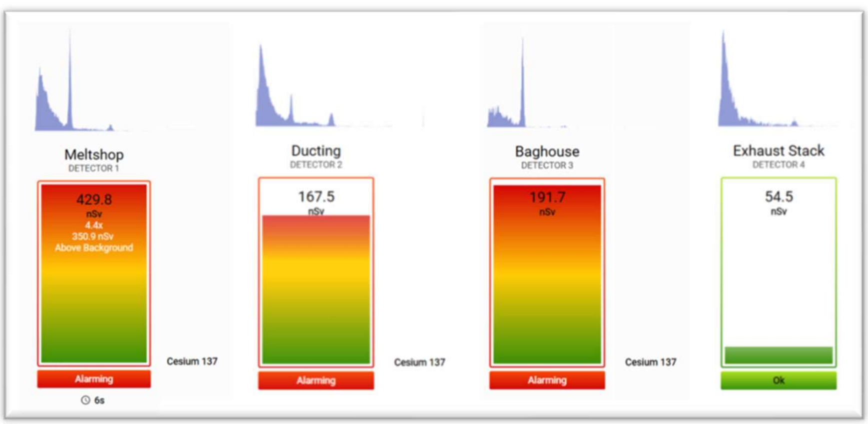


Fig. 8, RMEWS GUI live-time interface (showing 1 detector panel in 4 locations)

The RMEWS incorporates large Sodium Iodide Thallium Doped crystals (NaI(Tl)) specially selected and tested for high spectral resolution. The crystals are securely protected inside a hermetically sealed low-density case mounted inside an IP65 housing. To ensure the best possible spectral response, the crystals are continuously energetically stabilized without the use of an external radiation check source, allowing them to operate independently of personnel interaction. The RMEWS continuously performs various automated system health checks with alerts in the event there is a change in the normal systems operation. The crystals utilize internal temperature monitoring, to ensure the signal output maintains stability during temperature changes and will provide an early warning alert in the event of elevated temperatures which may damage the detector panels. It is important to note; the detector panels will be located at a safe a secure distance from any steel making component which has excessive temperatures.

The RMEWS central controller will also communicate with the steel plants PLC control system via TCP/IP (Fig. 9), where it will continuously transfer a data string with each detector panels' operational information. The plants PLC programmers can parse this data string and incorporate interactive functions in the PLC network as required at selected locations throughout the plant network. During normal operational mode the RMEWS passively operates, with no interference or interruption to any of the plant's operations. Once there is a situation which needs to be addressed, the RMEWS system will immediately notify local personnel with audio and visual alarms and the PLC plant control system via the data string, which in turn will trigger the appropriate alerts and step-by-step procedures for plant personnel to follow.

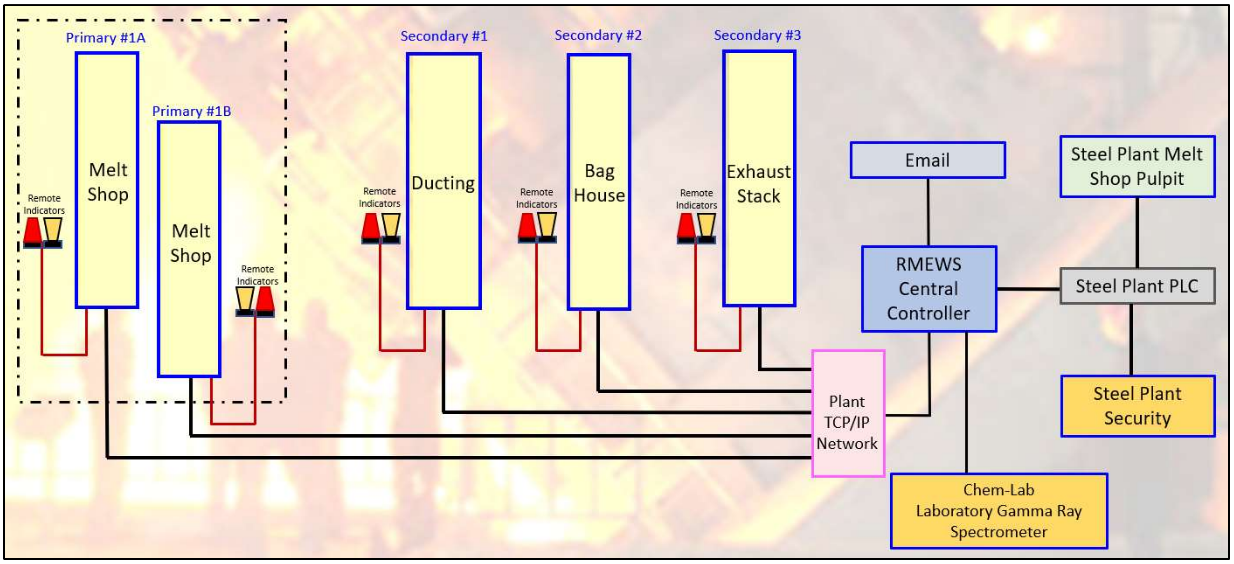
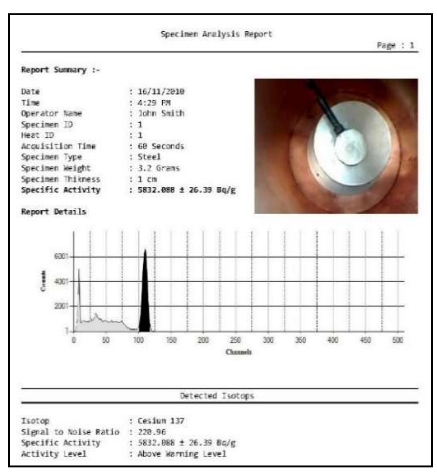


Fig. 9, RMEWS interconnection layout

Since every steel plant has a unique mode of operation, The RMEWS step-by-step rad melt procedures will be incorporated during system commissioning. If , at any time, the steel plant operations or regulation requirements change, updating and changing these password protected procedures can easily be performed by approved personnel.

The RMEWS will have a password protected test mode for running simulations of various isotopic smeltings to assist with training of plant personnel. Individual(s) responsible for running the simulation can select a specific Isotope and the Exposure/Dose level allowing a wide range of smelting condition and step-by-step RMEWS procedures. This classroom simulation allows personnel to view and become familiar with the procedures and events as they unfold after a smelting. Personnel familiar with these procedures will be made aware of the fact that the RMEWS can minimize radiation exposure to personnel and further plant contamination and assist with a controlled plant shutdown.

The RMEWS, also includes a sensitive and accurate laboratory Gamma Ray spectrometer (Fig. 10) for the Chem-Lab. The RMEWS central controller provides a scaled signal-to-noise ratio response level which notifies the melter to take a specific activity measurement of a sample from the heat and/or slag to establish the radioactive concentration level. There could be a situation where a gauge smelting takes place and the radiological level is below the free-for-release criteria as outlined in the IAEA TECHDOC 855 [8].



Specimen Analysis Report

Page : 1

Report Summary :-

Date	: 16/11/2010
Time	: 4:29 PM
Operator Name	: John Smith
Specimen ID	: 1
Heat ID	: 1
Acquisition Time	: 60 Seconds
Specimen Type	: Steel
Specimen Weight	: 3.2 Grams
Specimen Thikness	: 1 cm
Specific Activity	**: 5832.088 ± 26.39 Bq/g**

Report Details

Detected Isotops

Isotop	: Cesium 137
Signal to Noise Ratio	: 220.96
Specific Activity	: 5832.088 ± 26.39 Bq/g
Activity Level	: Above Warning Level

Fig. 10, example of a Chem-Lab laboratory Gamma Ray spectrometer and its report

The RMEWS will also have a sensitive and versatile handheld portable Gamma Ray Spectrometer with Neutron detection capability (Fig. 11) for doing follow up inspections and pinpointing the magnitude of the contamination after the RMEWS has alarmed. The unit will also provide live-time Exposure/Dose rate levels to personnel conducting the spot checks to ensure safety.

Fig. 11, example of a handheld portable Gamma Ray spectrometer

CONCLUSIONS

1. There have been a significant number of radioactive gauges smelted over the past 30 plus years. The vast majority of these melting facilities were monitoring with multiple large volume radiation detection systems at the time of the smelting. Unfortunately, It is impossible to achieve 100% protection against a radioactive source been smelted in an arc furnace, no matter how many radiation detection systems are installed to scan the raw material before being smelted.
2. Historically, melting facilities could only have a written RMEWS Rad Melt plan. This was a major step in trying to address the issues of attempting to protect personnel and plant from exposure to radiation exposure and contamination. These written Rad Melt procedures are focused on Exposure/Dose rates. This is not enough information for a melter to properly assess and address a radioactive source smelting. Additionally, these procedures depend heavily on a series of manual steps, multiple personnel and radiation scanning equipment, resulting in excessive time delays.
3. It is critical to identify the isotope being smelted be as quickly as possible. Without knowing the isotope, procedures following a smelting are based on guess work. Guess work decisions can endanger personnel and result in costly mistakes.
4. Having an automated RMEWS spectral analyses system provides critical information about the radioactive source smelting in live-time. Smelting a radioactive source may not mean that the entire melting operation has to be halted instantly with a melt shop decontamination to follow.
5. The RMEWS can provide reasonable simulations of an actual radioactive gauge smelting for training purposes. These simulations will clearly demonstrate the formulated live-time step-by-step scenarios to plant personnel which were programmed in the RMEWS system by qualified plant personnel and radiation specialists.
6. Raw data collected during an actual radioactive gauge smelting incident will be captured in memory for the purpose replaying a real-life smelting incident in its entirety as it unfolded. This replay data will serve multiple purposes such as personal training, scientific research, detailed reporting of the incident for improvements in the RMEWS plan and litigation if required.
7. The RMEWS live-time updating and tracking of the radiation levels will help plant personnel execute a proper shutdown of the melting operation and help to alleviate radioactive material cleanup, thereby minimizing cleanup costs and downtime.

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