IAEA TECDOC SERIES

IAEA-TECDOC-2012

Muon Imaging

Present Status and Emerging Applications

IAEA
International Atomic Energy Agency

CONTENTS

4. INDUSTRIAL APPLICATIONS

Industry is one of the fundamental pillars of economic activity worldwide. The industrial sector processes raw materials to manufacture finished goods ready for consumption by the end user or by other industries. The implementation of the manufacturing processes requires the deployment of large production plants with specialized equipment and personnel. Companies working in the direct transformation of raw materials such as minerals, petroleum, rubber, etc, usually need to produce chemical reactions involving extreme temperature and pressure conditions. The equipment used to transport the raw materials, to host the reaction, to supply energy, and to remove the products, usually operates under these hostile conditions making difficult both the monitoring of the process and maintenance of the equipment.

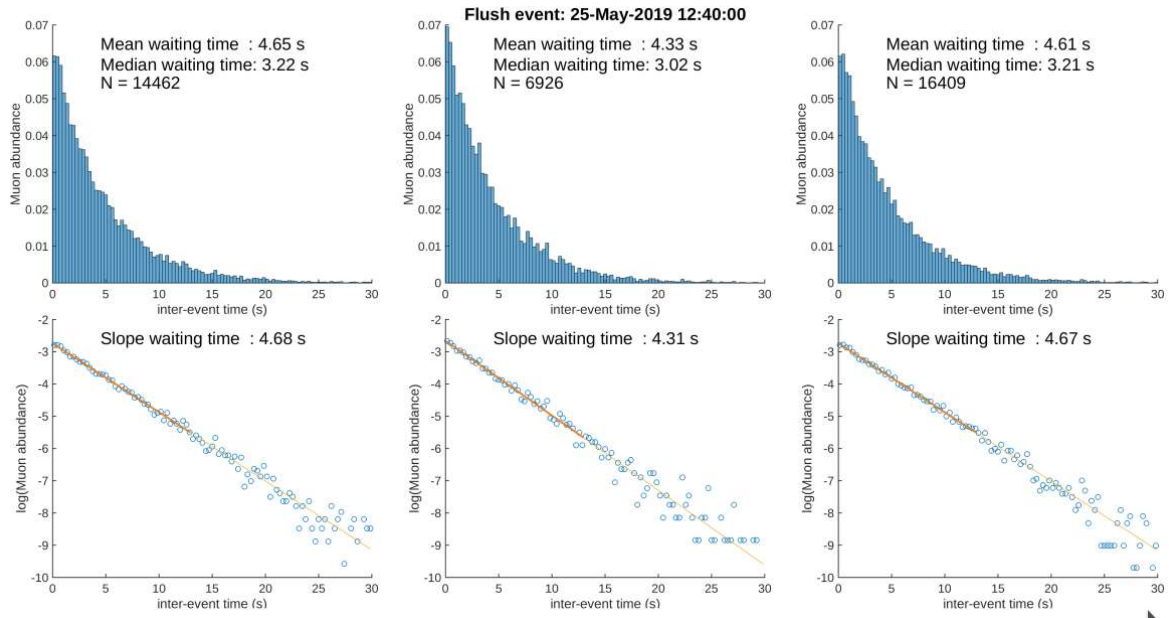
The processes implemented in industrial plants present a large heterogeneity, although many elements and features of these production infrastructures are common. These facilities often include equipment devoted to containing chemical reactions such as vessels, cauldrons, blast furnaces, etc, and auxiliary components to bring or remove materials, such as pipes, ducts, chimneys, and torches. The dimensions of these structures range from a few cm to several m, while most of their components are made of metals such as steel, Pb, and others, and also carbon-based such as refractory in the case of the walls of cauldrons, blast furnaces, and similar equipment.

A large fraction of the operation costs in many of these plants is directly related to the inefficiencies of the production procedures and the maintenance of the equipment. The former can present many different forms according to the specifics of each procedure, although it is frequently a consequence of incomplete knowledge about the processes. The latter is needed because of the gradual deterioration of the equipment due to exposure to environmental agents such as humidity, extreme temperatures and pressures.

Many companies implement strategies to mitigate these effects based on the careful monitoring of the processes and the equipment. Several NDT techniques are employed to perform this monitoring. There is a plethora of different technologies such as ultrasounds, X-rays, thermography, etc., that can serve this purpose (see Section 3.2). All of them present limitations in the achieved resolution, capability to penetrate the material, or exposure time. In many cases, the techniques are complementary and can be combined to improve the results. Many of these techniques require stopping production during ‘technical stops’ for maintenance. Depending on the kind of factory, these stops can last from a few hours to several days. The cost of stopping production can represent a large fraction of the total maintenance spending.

Muon imaging emerges in this context as a suitable NDT technique that offers large penetration power and the possibility to operate without stopping production since no artificial source of radiation nor physical contact with the equipment are needed. Due to the variety of different situations and problems in the industry, the needs and requirements are strongly dependent on the application.

In the following Sections several paradigmatic cases are shown to illustrate the potential of muon imaging in industrial contexts. The examples are grouped into two blocks attending to the kind of technique being applied: MST or muography.



(a) (b) (c)

FIG. 30. Inter-event distance for different states of the NE cycle. (a) and (c) correspond to the NE operation in standard conditions. (b) presents a reduction of the inter-event distance indicating an increase of the muon flux and a change in the standard conditions. Such a method correlated with atmospheric parameter corrections may be developed to reach the few percent sensitivity level relevant for industrial requirements (courtesy of J. Marteau, Institut de physique des deux infinis).

International Atomic Energy Agency
Vienna

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[Posible Spam] FW: Technical Document on Muon Radiography

5 messages

FOULON, Francois <F.Foulon@iaea.org> Mon, Apr 20, 2020 at 9:28 AM
To: Andrea Giammanco <andrea.giammanco@cern.ch>, Lee Thompson <l.thompson@sheffield.ac.uk>, "ralf.kaiser@glasgow.ac.uk" <ralf.kaiser@glasgow.ac.uk>, Lorenzo Bonechi <lorenzo.bonechi@fi.infn.it>, PROCUREUR Sébastien <sebastien.procureur@cea.fr>, Oleg <oleg.kamaev@cnl.ca>, "checchia <paolo.checchia@pd.infn.it> (paolo.checchia@pd.infn.it)" <paolo.checchia@pd.infn.it>, Pablo Martinez <parbol@ifca.unican.es>, "Martinez Ruiz Del Arbol, Pablo" <pablo.martinez@unican.es>, "konstantin.borozdin" <konstantin.borozdin@decisionsciencescorp.com>, Michael Tytgat <michael.tytgat@ugent.be>

Dear Colleagues,

I hope that my email finds all of you well and healthy in this difficult situation with the COVID19. We are all impacted by this unusual situation and way of organizing our work and activities.

Thus it is very understandable that the development of the TecDoc on Muon radiography is delayed.

At this stage the first draft of two sections have been established : **Industrial Applications** and **Nuclear Safeguards (Spent Fuel)**.

Here below is the table summarizing the content and contributors to this TecDoc on Muon radiography (Mines and Glaciers are still not fully “secured”).

I suggest to target to have all contributions (first draft) by the 8th of May.

Could you **please confirm** by return email, in the table below, what is **the status of the section you are in charge and the expected date for finalization of the first draft**.

We noticed that Konstantin moved to another position and we do not have his actual email address. If some of you have it, hopefully Oleg, this will be helpful.

Provisional Sections/activity	**Leading contributor** / Contributors	**Status**
Introduction (incl. terminology, overview of methods)	**Andrea** / Lorenzo	
Civil Engineering	**Lee** / Chris, Ralf, Sebastien, Germano	
Industrial Applications	**Pablo** / Carlos, Jacques	**Draft finalized, version 2**
Nuclear Waste Characterisation	**Ralf** /Anna	
Mines	**David – Amnon ? /** Doug ? additional	
Volcanology - Natural Disaster Prevention	**Lorenzo** / Jacques, Domenico Lo Presti, Valeri Tioukov (about Stromboli), Giovanni Macedonio ?, Tanaka ?	**One individual contribution form Domenico Lo Presti sent to Lorenzo**
Glaciers	**Andrea or David – Amnon ?** Ryuichi Nishiyama r-nishi@eri.u-tokyo.ac.jp	
Archaeology	**Sebastien** / Lorenzo , Jacques	
Security applications (Borders and Facilities)	**Konstantin** / Oleg	
Nuclear Safeguards (Spent Fuel)	**Paolo** / Darius, Konstantin, Yang, Katharina	**Draft finalized, version 1**
Nuclear Material Control	**Oleg** / Konstantin	
Education	**Ralf (potential Sebastien ?)** / Konstantin, Michael, Oleg, Andrea, Lee	
Summary & Outlook (to contain other applications)	Ralf, Konstantin, Michael, Oleg, Andrea (leader to be defined later on)	
Overall editing	Ralf, Konstantin, Michael, Oleg, Andrea	

Thanks for your cooperation, stay healthy and best regards.

Francois

Andrea Giammanco <Andrea.Giammanco@cern.ch> Mon, Apr 20, 2020 at 9:43 AM
To: "FOULON, Francois" <F.Foulon@iaea.org>, Lee Thompson <l.thompson@sheffield.ac.uk>, "ralf.kaiser@glasgow.ac.uk" <ralf.kaiser@glasgow.ac.uk>, lorenzo bonechi <lorenzo.bonechi@fi.infn.it>, "sebastien.procureur@cea.fr" <sebastien.procureur@cea.fr>, Oleg <oleg.kamaev@cnl.ca>, paolo checchia <paolo.checchia@pd.infn.it>, Pablo Martinez <parbol@ifca.unican.es>, "Martinez Ruiz Del Arbol, Pablo" <pablo.martinez@unican.es>, "konstantin.borozdin" <konstantin.borozdin@decisionsciencescorp.com>, "michael.tytgat@ugent.be" <michael.tytgat@ugent.be>

Dear Francois, all,
the status from my side (Introduction): I am almost done with a first draft, but:

- for the moment I am recycling some illustrative figures by Lorenzo, originally used in the review that we coauthored with Raffaello D'Alessandro; if we understand correctly, it is not sufficient for a TecDoc to provide reference and reprinting permission from the editor, but we have to modify them, is that correct?

- I'd like to have some time to iterate on the text with Lorenzo and Raffaello, before circulating;

- I received a couple of nice paragraphs written by Jacques Marteau, originally intended to be included in "Industrial applications" but Pablo suggested to move them to the introduction because of their generality; I have to adapt them a bit though.

But all in all I think that 8th of May is an easy target for finalising the Introduction.

Best,
Andrea

Andrea Giammanco
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Phone: +32 10 473221 (UCLouvain), +32 493 581662 (mobile)

From: FOULON, Francois [F.Foulon@iaea.org]
Sent: 20 April 2020 09:28
To: Andrea Giammanco; Lee Thompson; ralf.kaiser@glasgow.ac.uk; lorenzo bonechi; sebastien.procureur@cea.fr; Oleg; paolo checchia; Pablo Martinez; Martinez Ruiz Del Arbol, Pablo; konstantin.borozdin; michael.tytgat@ugent.be
Subject: FW: Technical Document on Muon Radiography

[Quoted text hidden]

FOULON, Francois <F.Foulon@iaea.org> Mon, Apr 20, 2020 at 11:14 AM
To: Andrea Giammanco <andrea.giammanco@cern.ch>, Lee Thompson <l.thompson@sheffield.ac.uk>, "ralf.kaiser@glasgow.ac.uk" <ralf.kaiser@glasgow.ac.uk>, lorenzo bonechi <lorenzo.bonechi@fi.infn.it>, "sebastien.procureur@cea.fr" <sebastien.procureur@cea.fr>, Oleg <oleg.kamaev@cnl.ca>, paolo checchia <paolo.checchia@pd.infn.it>, Pablo Martinez <parbol@ifca.unican.es>, "Martinez Ruiz Del Arbol, Pablo" <pablo.martinez@unican.es>, "konstantin.borozdin" <konstantin.borozdin@decisionsciencescorp.com>, Michael Tytgat <michael.tytgat@ugent.be>

Dear Andrea,

Thanks for the update and good news regarding the overall progresses.

Regarding the figures, there are two approaches, use existing figures and getting the reprinting permission hopefully at no cost, or making new figures not to have any copyright issue.

If you have reprinting permission at not cost already then, 1st option is fine. If not second option is the easiest.

Thanks to all contributors and best regards

Francois

[Quoted text hidden]
[Quoted text hidden]

Kamaev, Oleg <oleg.kamaev@cnl.ca>
To: "FOULON, Francois" <F.Foulon@iaea.org>, Andrea Giammanco <andrea.giammanco@cern.ch>, Lee Thompson <l.thompson@sheffield.ac.uk>, "ralf.kaiser@glasgow.ac.uk" <ralf.kai <lorenzo.bonechi@fi.infn.it>, PROCUREUR Sébastien <sebastien.procureur@cea.fr>, "checchia <paolo.checchia@pd.infn.it> (paolo.checchia@pd.infn.it)" <paolo.checchia@pd.infn.it>, "Martinez Ruiz Del Arbol, Pablo" <pablo.martinez@unican.es>, Konstantin Borozdin <sandia.rcenter@gmail.com>

UNRESTRICTED / ILLIMITÉE

Dear Francois,

For Section 9, I have a preliminary draft with some input/suggestions from Chris Morris (LANL). I'll check with Konstantin and in any case should be able to provide August 10.

Regards,

Oleg

From: FOULON, Francois [mailto:F.Foulon@iaea.org]
Sent: Saturday, July 18, 2020 7:23 AM
To: Andrea Giammanco <andrea.giammanco@cern.ch>; Lee Thompson <l.thompson@sheffield.ac.uk>; ralf.kaiser@glasgow.ac.uk; Lorenzo Bonechi <lorenzo.bor Sébastien <sebastien.procureur@cea.fr>; Kamaev, Oleg <oleg.kamaev@cnl.ca>; checchia <paolo.checchia@pd.infn.it> (paolo.checchia@pd.infn.it) <paolo.checcl <parbol@ifca.unican.es>; Martinez Ruiz Del Arbol, Pablo <pablo.martinez@unican.es>; Konstantin Borozdin <sandia.rcenter@gmail.com>
Subject: [External] Technical Document on Muon Radiography

Dear All,

I updated the documents available in the shared folder as well as the table below (feel free to update the list of contributors).

I suggest to change the order of the sections to focus at first to applications not related to nuclear industry or material (end users less familiar with nuclear techniqu this approach.

Provisional Sections/activity	**Leading contributor** / Contributors
0. Foreword	
1. Introduction (incl. terminology, overview of methods)	**Andrea** / Lorenzo
2. Civil Engineering and Underground Applications	**Lee** / Chris, Ralf, Sebastien, Germano, David, Amnon, Jacques
3. Industrial Applications	**Pablo** / Carlos, Jacques
4. Geophysical Surveys and Natural Disasters Prevention_18-07-2020	**Lorenzo** / Jacques, Domenico Lo Presti, Valeri Tioukov (about Stromboli), Giovanni
5. Archaeology	**Sebastien** / Lorenzo , Jacques
6. Security applications (Borders and Facilities)	**Konstantin** / Oleg
7. Nuclear Waste Characterisation	**Ralf** /Anna
8. Nuclear Safeguards (Spent Fuel)	**Paolo** / Darius, Konstantin, Yang, Katharina
9. Nuclear Material Control	**Oleg** / Konstantin
10. Education ?	**Ralf (potential Sebastien ?)** / Konstantin, Michael, Oleg, Andrea, Lee
Summary & Outlook (to contain other applications)	Ralf, Konstantin, Michael, Oleg, Andrea (leader to be defined later on)
Overall editing	Ralf, Konstantin, Michael, Oleg, Andrea

For Sections 6,7,9 could you please confirm when the first draft can be provided, if possible by the 10th of August.

In parallel NSIL Team Assistant will combine the sections 0 to 5 in a single document.

We will still have to decide if a specific section should be dedicated to Education, any suggestion ?

Thanks for your cooperation and best regards.

Francois

Konstantin Borozdin <sandia.rcenter@gmail.com> Sun, Jul 26, 2020 at 9:59 AM
To: "FOULON, Francois" <F.Foulon@iaea.org>
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Dear Francois and Everyone,
We had a telecon with Oleg on Sections 6 and 9 last week. I sent my draft of Section 6 to Oleg and expect to get his draft of Section 9 within the next few days. We would like to get an input from Chris Morris as well.
We will then discuss the drafts and should be ready to send it to you before August 10. I apologize to everyone for falling behind, there have been many things happening this year, not the least of them a global pandemic, which is still ravaging the US and disrupts things that we considered to be 'normal'. In any case, I just wanted to share our status and confirm that I should be able to send you a draft of Section 6 with all contributions and also contribute to Oleg's Section 9.
Thank you,
Konstantin
[Quoted text hidden]