Managing the Information and Analytical Data System on Interaction Between Corium and Structural Materials of a Power Reactor

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Short Report

Keywords: information and analytical system, experimental data, data classification

Posted Date: June 29th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1763378/v1

Abstract

This paper presents the results on designing of an information and analytical data system that characterizes the interaction between melt of the core of a nuclear reactor and structural materials of the corium retention devices (melt traps), which were resulted from physical modeling the processes of a severe accident at the stands of Institute of Atomic Energy Branch of the Republican State Enterprise “National Nuclear Center of the Republic of Kazakhstan”.

1 Introduction

Experimental work on physical modeling of severe accidents is conducted in many research centers around the world. As an example, such large projects for the study of severe accidents as PHEBUS (France), CORA (Germany), CODEX (Hungary), FARO, KROTOS, RASPLAV (Russia), MACE, WETCOR, SWISS, etc. [1]. An analysis of the scientific results obtained in similar projects [2-14] showed that the range of parameters obtained on the test benches ANGARA, EAGLE, VCG-135 at the IAE Branch RSE NNC RK is much wider obtained at any individual facility in other countries [1]. Activity in the IAE Branch RSE NNC RK under international projects COTELS, INVECOR, CORMIT, Fukushima Debris, IVR-AM to study the processes when developing severe accidents with core melting of a nuclear reactor and melt retention in the reactor pressure vessel, allowed obtaining a set of unique experimental data that scientific community concern that involved in safety of nuclear installation operation [15]. In Kazakhstan, such work is not conducted, except for the NNC, due to the specifics of the research area, high cost and complexity of experiments.

The IAE Branch RSE NNC RK has gained experience of almost 30 years of cooperation with Japanese scientific organizations and such companies as JAEA, Toshiba Corp., Marubeni US Ltd., NUPEC, JAPC in the field of research of NPP safety systems, within which a large amount of experimental data and results obtained by simulation of the processes occurring when postulated developing of severe accidents at nuclear reactors have been obtained. Experimental substantiation of ideas and technical solutions underlying the functioning of existing and future passive safety systems of NPP with LWR reactor is carried out using unique test-benches ANGARA, VCG-135 belonging to of the IAE Branch RSE NNC RK [16]. The NNC’s test-benches make it possible to implement physical simulation of the processes typical of the final stage of a water-cooled reactor accident, in particular, interaction between reactor core melt (corium) and:

- coolant (water),

- concrete (traps, load-bearing concrete structures of the reactor);

- candidate materials for protection of traps;

- steel (bottoms of pressure vessels of reactor).

In this case, such parameters as the composition of the melt, the residual energy release of the melt during the retention process, the method of cooling the melt trap, and so on, vary.

Most of the information is heterogeneous, but it has a number of common features that determine the possibility of systematizing and generalizing the results of individual experiments and their series. The most preferable for carrying out a comprehensive analysis of data from experiments conducted on test benches is the generalization of data according to the main criteria in the form of an information and analytical system (IAS).

2 Experimental Data

The designed IAS is designed to consolidate, systematize, increase the efficiency of processing and analysis of experimental data obtained at the Angara, VCG-135 test-benches of the IAE Branch RSE NNC RK and intended to study the processes accompanying severe accidents at nuclear reactors.

ANGARA Test-Bench. The main area of work is an experimental study of the processes typical for the final stage of a water-cooled reactor accident associated with the loss of coolant (LOCA accident), namely an interaction between corium melt and water, concrete, materials of the power vessel of a reactor while simulating decay heat in the melt.

VCG -135 Test-Bench. High-temperature material research are conducted using this test-bench with small-sized samples with their rapid heating to a high (about 3000 °C) temperature, followed by cooling due to heat leakage into a water-cooled inductor with the generator turned off.

The main areas of research are:

- research of interaction of corium components with each other during heating up to the melting point;

- research of the effectiveness of protective coatings for graphite crucibles based on Zr, Nb, Ta carbides; and etc.;

- determination of the temperature of phase transitions in corium of various compositions;

- research of high-temperature interactions between corium and structural materials;

- determination of electrophysical properties of corium;

- obtaining compact corium ingots of a set composition;

- applying of a protective coating based on zirconium carbide on inner wall of graphite crucibles and on outer surface of graphite parts.

3 General Data Structure

Structural order of formation and systematization of primary experimental data within the IAS is presented in Figure 1.

The IAS includes three main blocks:

- experimental test-benches;

- modeling;

- analytics.

The “Test-Benches” block contains information about ANGARA and VCG-135 test-benches in text and graphic formats. The sections also include an installation description, containing information about period of experimental installation operation, manufacturer, design and engineering documentation for the main units and systems of the installations. Information in subsections is stored in text and graphic formats with a possibility of displaying in PDF.

The second block consists information about experiments on simulation of in-vessel (IVR-AM, INVECOR Projects) and out-of-vessel (Fukushima Debris, COTELS, CORMIT, CORMIT-Ph2 Projects) melt retention, including:

- initial data – set of parameters which are very from series to series of experiments (Figure 2);

- results of direct measurements – such data, registered by information and measurement systems, as temperature, pressure, coolant flow for cooling systems and electrical characteristics of test-bench (Figure 3);

- results of material research - data on high-temperature interaction between model corium and materials of the reactor vessel, melt receiver (MR), materials of protective coatings of the MR, spacer grids, absorber rods, coolant, etc. The interaction between corium and structural materials of the reactor is researched by performing a comprehensive analysis, including a visual analysis of the state of components of an experimental assembly, model melt and structural materials (Figure 4).

In the third block, data will be processed for preparing and conducting experiments, as well as during analysis of the results of material research. This block includes functions of calculations, graph plotting, table formation, at the same time, to obtain a certain amount of information on one experiment or to compare the results of several experiments, a protocol is formed in one document, which combines a set of experiment parameters contained in the IAS in the form of graphs, photos, data tables.

4 Ias Design For Data Management

The IAS database is created in the Microsoft SQL Server database management system. This choice is based on ability to work with big data and use with almost any languages.

Application software is created in the Microsoft Visual Studio ASP.NET Core Blazor development environment. Blazor is a framework for building interactive .NET-based web client experiences. Figure 5 shows a prototype of a web application, which displays a hierarchical division of test-benches, installations, projects, series of experiments and experiments, as well as their description and other additional information (photos, drawings, documents).

On the main page of the web application, on the left, the IAS data structure is displayed in the form of a drop-down tree. The first block “Test-Benches” includes lists of installations, projects, series of experiments and experiments. Next, each experiment contains sections: initial data, recorded data and material research data.

The “Initial Data” section contains the initial conditions for experiment, parameters of the main experimental devices (an electric melting furnace and a melt receiver - in large-scale experiments or a crucible and a working chamber - in small-scale experiments), technical characteristics of key measuring instruments (pyrometers, thermocouples, pressure sensors, flow meters, etc.) according to the tasks of the experiment, information on the composition of the model corium and on the structural material that is tested under conditions of high-temperature interaction with corium of a nuclear reactor, their masses, as well as the layout of materials in the melting volume (EMF or crucible), measurers, thermal insulation.

The “Registration Data” section is displayed in the form of graphs (Figure 6). For the convenience of comparing the registration data of two experiments, the workspace is divided into two parts, each of which displays graphs of the data of these experiments.

It is possible to scale the charts with the mouse, and when rolling over a certain point a pop-up tip appears with values of the control points at this place.

The “Materials Research” section includes such sections as “Experimental Assembly”, “Melt” and “Structural material”. These sections contain subsections, their descriptions and photo-materials (Figure 7).

5 Conclusion

Simulation of a severe accident development is the most complex issue, which can be formulated as an issue of non-stationary heat and mass exchange together with chemical reactions in a non-equilibrium system with three aggregate states of matter and changing topology.

The results of studying the interaction between corium and structural materials may be of companies concern that order these works. The IAS, created within the framework of this project, will improve the culture of conducting such experiments and will improve the quality of services provided for experimental simulation.

The project for the IAS data creation will contribute to further development of scientific and technical work in the field of research on nuclear power safety systems. Due to quick access to the necessary

experimental data and structured research results, ability to calculate input parameters using a single mathematical apparatus and a comprehensive analysis of output parameters, speed and volume of processed data will be increased, reliability of compared parameters will be increased, number of errors in planning experiments will be decreased, repeatability of results required for analysis will be increased.

This research was conducted under grant funding from the Ministry of Education and Science of the Republic of Kazakhstan (IRN AP09260704 “Information and analytical system of data, obtained during experimental simulation of severe accidents at a nuclear reactor”, 2021–2023).

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available as they relate to the field of NPP safety systems research. In this case, this is a set of experimental data and research results obtained by modeling the processes of severe accidents at nuclear reactors, these data were obtained within the framework of joint research programs with foreign partners. But datasets are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This research was conducted under grant funding from the Ministry of Education and Science of the Republic of Kazakhstan (IRN AP09260704 “Information and analytical system of data, obtained during experimental simulation of severe accidents at a nuclear reactor”, 2021-2023).

Authors' contributions

All authors wrote the main manuscript text. All authors read and approved the final manuscript.

Acknowledgements

This research was conducted under grant funding from the Ministry of Education and Science of the Republic of Kazakhstan (IRN AP09260704 “Information and analytical system of data, obtained during

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Figures

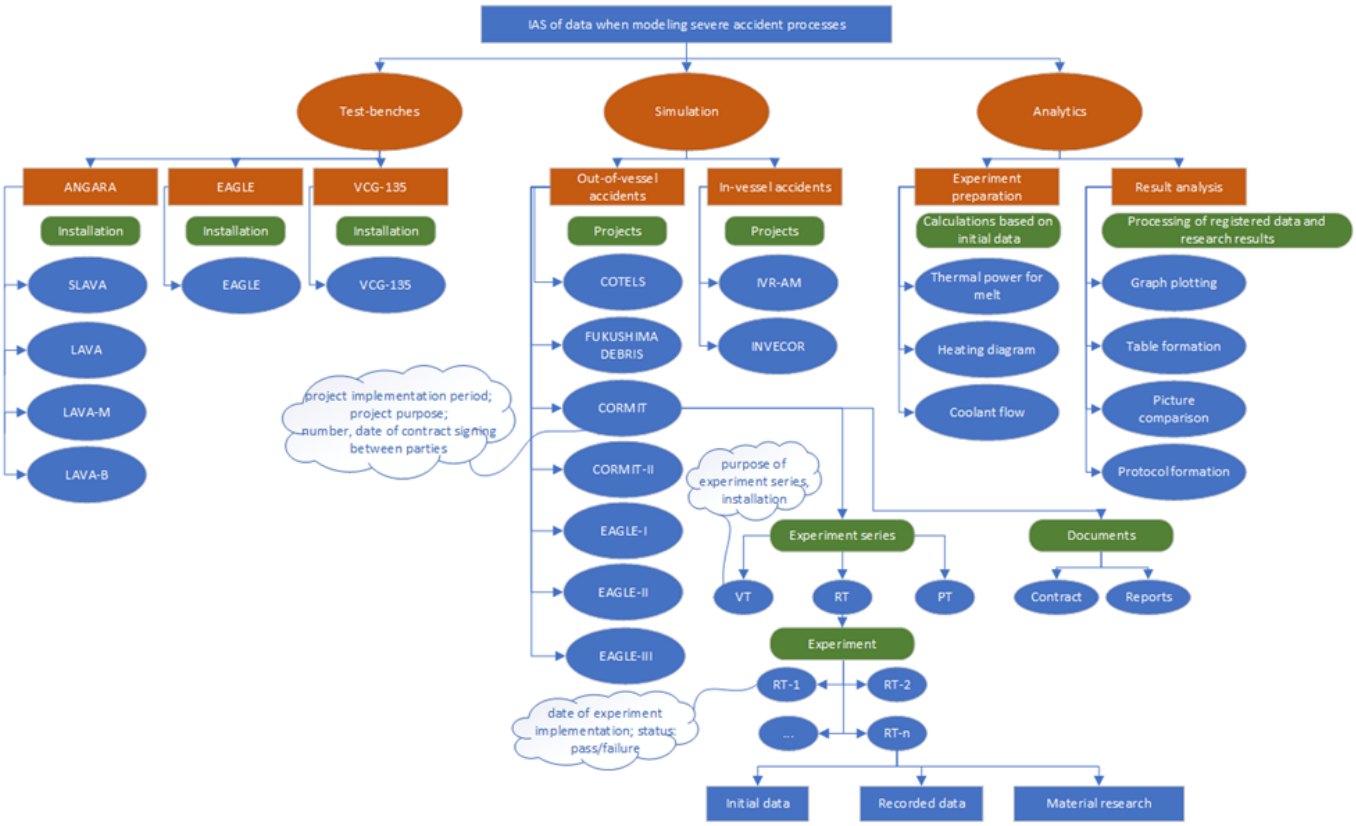

Figure 1

IAS data structure for simulating of severe accident at a nuclear reactor

Figure 2

Structure of initial parameter data

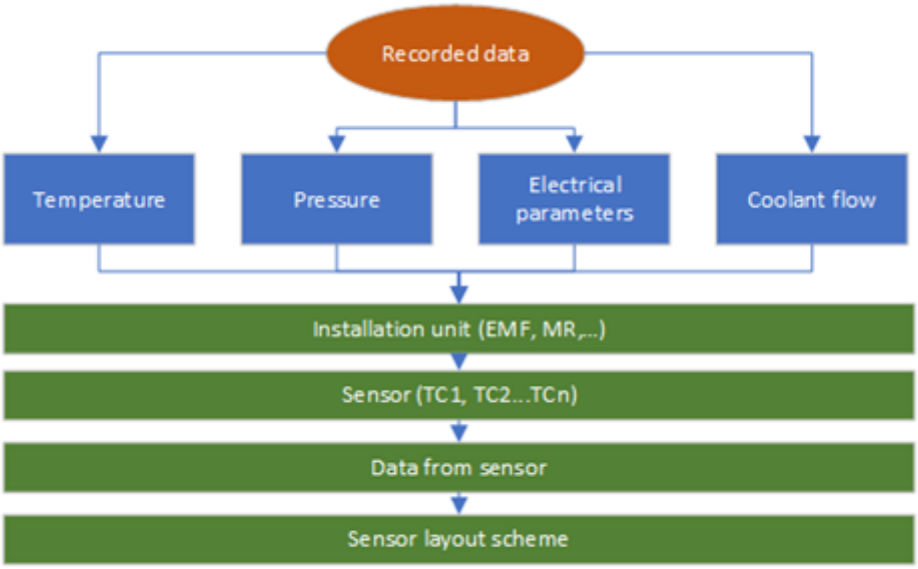

Figure 3

Structure of registered parameter data

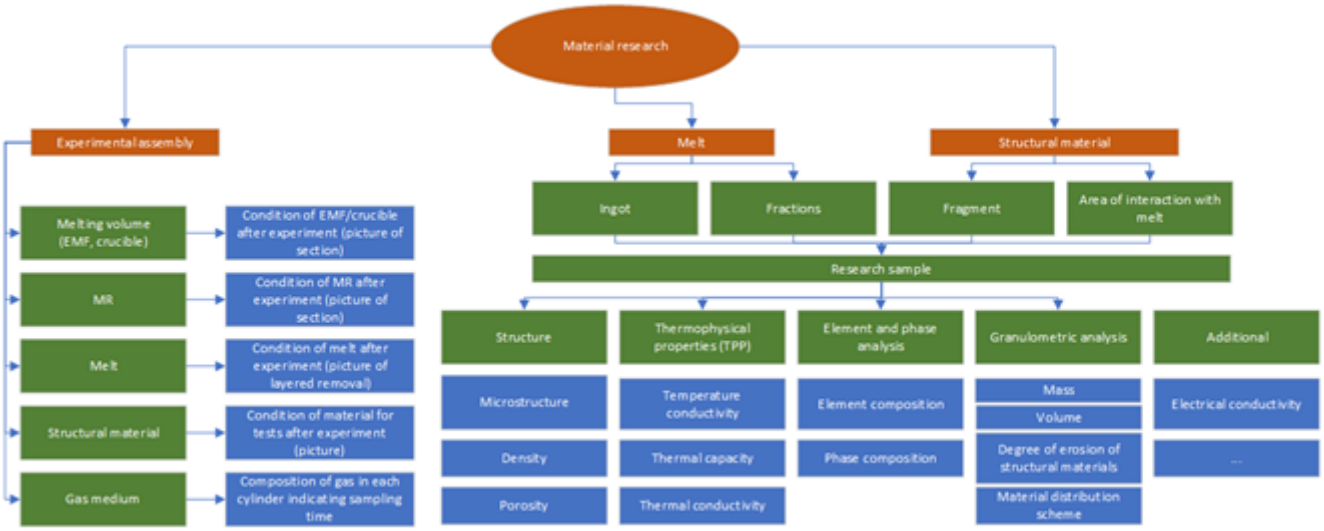

Figure 4

Structure of material research data

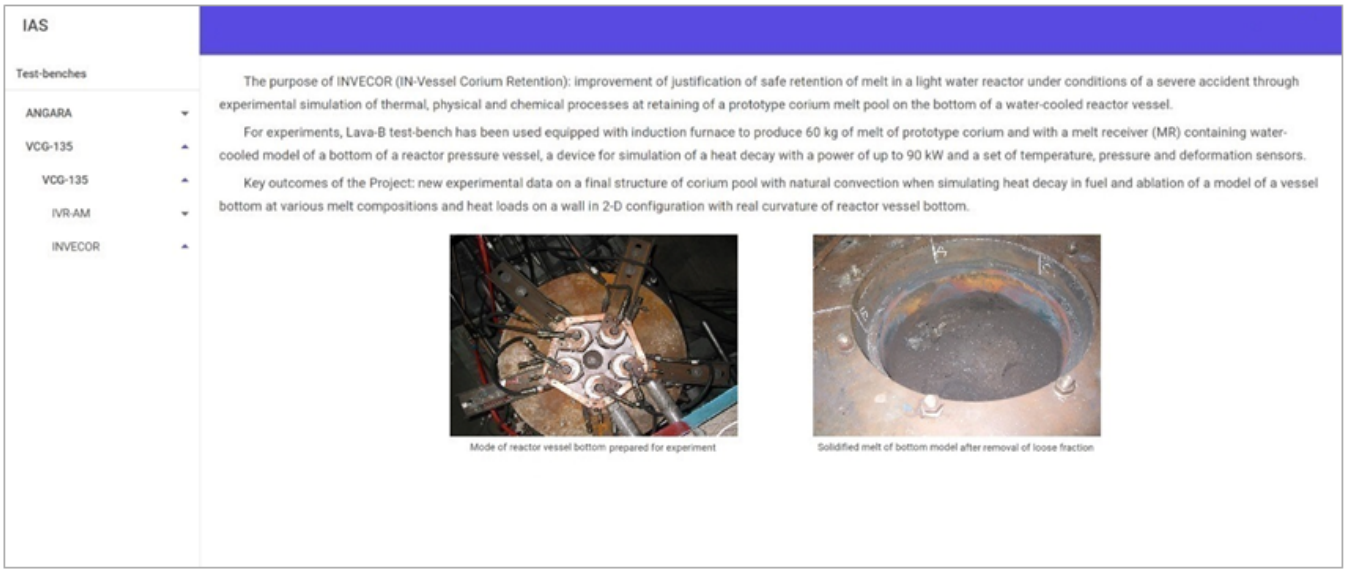

Figure 5

Web application interface prototype

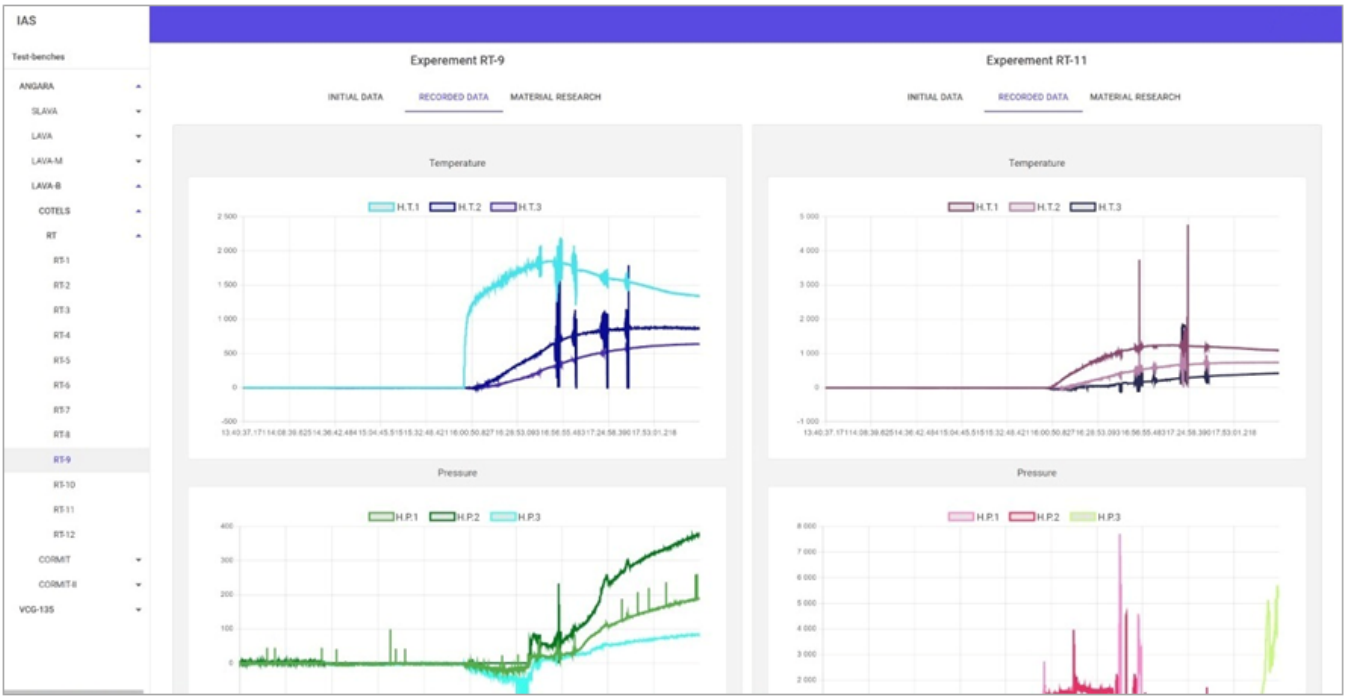

Figure 6

Registration data

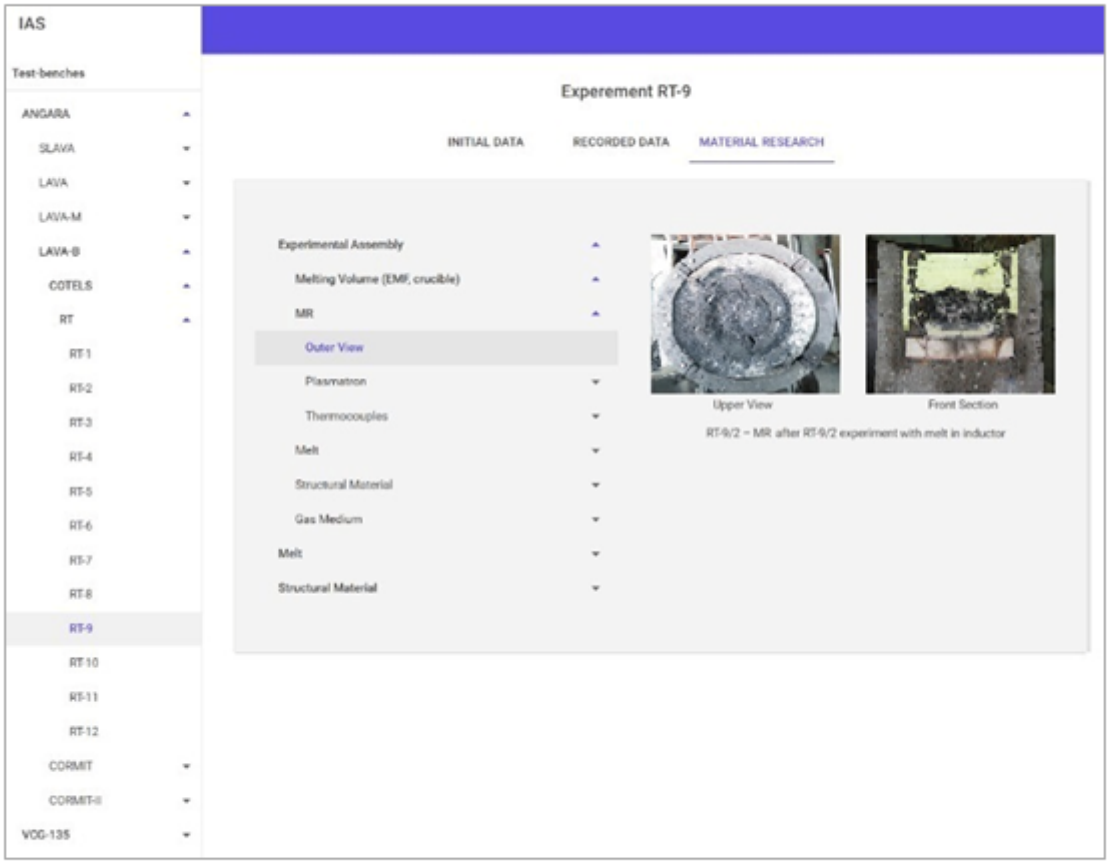

Figure 7

Material Research