THE GLOBAL SHIFT TO HYDROGEN AND LESSONS FROM OUTSIDE INDUSTRY

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ABSTRACT

The recognition of hydrogen as a technically viable combustion fuel and as an alternative to more carbon intensive technologies for all forms of industrial applications has resulted in significant global interest leading to both public and private investment. As with most shifts in technology, public acceptance and its safe production and handling will be key to its growth as a widespread energy vector. Specific properties of hydrogen that may prompt concern from the public and that need to be considered in terms of its use and safe handling include the following:

- Hydrogen, in its natural state, is a colourless, odourless, and tasteless gas that is combustible with very low ignition energy, burns nearly invisibly, and is explosive at a very wide range of concentrations with an oxidate.
- Hydrogen as any other gas except oxygen is an asphyxiant in a confined space.
- Hydrogen is an extremely small molecule and interacts with many materials which, over time, can alter the physical properties and can lead to embrittlement and failure. Additionally, due to the small molecular size its permeation and diffusion characteristics make it more difficult to contain compared to other gases.

As hydrogen production, use, and storage increases, these properties will come under greater scrutiny and may raise questions surrounding the cost/benefit of the technology. Understanding how the public sees this technology in relation to their safety and daily lives is important in hydrogen's adoption as a low carbon alternative. A review of deployable experience relevant to the handling of hydrogen in other industries will help us to understand the technology and experience necessary for ensuring the success of the scaling up of a hydrogen economy. The social considerations of the impacts should also be examined to consider acceptance of the technology as it moves into the mainstream.

1.0 NOMENCLATURE

CANDU	Canada Deuterium Uranium (Canadian pressurized heavy-water reactor design)
CNSC	Canadian Nuclear Safety Commission
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide Equivalent
CSA	Canadian Standards Association
COG	CANDU Owner's Group
DGR	Deep Geological Repository
DRI	Direct Reduced Iron
EHSP	European Hydrogen Safety Panel
GHG	Greenhouse Gas
GH2	Hydrogen (gas)
GWP	Global Warming Potential
HIAD	Hydrogen Incident and Accident Database
IAEA	International Atomic Energy Agency
IESO	Independent Electrical System Operator
INPO	Institute of Nuclear Power Operators
kt	Kilotonnes
LH2	Hydrogen (liquid)
Mt	Million tonnes
NFPA	National Fire Protection Association
NSCA	Nuclear Safety and Control Act
OPG	Ontario Power Generation
OSW	Offshore Wind
PAR	Passive Autocatalytic Recombiner
Paris Agreement	The Paris Agreement sets out a global framework to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C
REGDOC	CNSC Regulatory Document
SMR	Small Modular Reactor
TPD	tonnes per day
QA	Quality Assurance
WANO	World Association of Nuclear Operators

2.0 INTRODUCTION

As countries around the world make strong commitments to reduce greenhouse gas emissions in response to the Paris Agreement, it has become clear that many countries have identified hydrogen as one of the key implementation tools to decarbonize their economies. There is a specific focus for low carbon hydrogen to help address hard to abate sectors such as heavy industry and transportation. This paper focuses on markets in Canada, but the trends are generally true internationally based on the common objectives.

Canada has planned that the strategy to meet climate objectives includes hydrogen making up 30% of end-use energy use by 2050 [1]. With this significant revolution in energy use it is expected that the public will begin interacting with the new energy vector in many new ways, including the use of hydrogen refuelling stations for commercial and passenger vehicles, production and storage integrated throughout communities, distributed networks of hydrogen transmission through pipeline and road transport, and in-home use for building and residential heating.

The public is increasingly interacting with hydrogen projects and has a general lack of knowledge and understanding of the risks, as well as possibly harbouring pre-existing negative connotations with hydrogen. As projects progress there will be a focus on hydrogen safety, community consultation, education, and training required to facilitate the transition to a more intensive hydrogen economy.

Operational experience from existing industrial applications will form a strong basis for understanding how to effectively communicate with the public and deploy proven safety and quality techniques to ensure a smooth transition to an energy medium different than what the public is familiar with.

3.0 CURRENT INDUSTRIAL USAGE

Hydrogen production and usage is not a new concept, as it has been utilized in industrial processes for over 100 years with ammonia production using the Haber-Bosch process being a key industrial hydrogen user since the process was established in 1913 [2]. The Oil and Gas industry is another key industrial user, utilizing hydrogen for processing high energy / low value long-chain hydrocarbons into smaller chain hydrocarbons (hydrocracking) as well as reducing the sulfur content and other impurities in fuels (hydrotreating) [3].

The hydrogen economy sees global demand for hydrogen (as of 2021) of approximately 94 million tonnes (Mt) per year [4]. Of that global demand, approximately 40 Mt per year comes from refining, and a further approximately 54 Mt per year from chemical processes consisting of mainly ammonia and methanol production [4]. The current hydrogen demand from other applications such as those that will be required for the full-scale transition to a large hydrogen economy by offsetting current fossil fuel uses (e.g., transportation), while increasing substantially each year, still represents demand in the "thousands of tonnes", only a small fraction of the overall current demand [4] .

When factoring in the current use cases for hydrogen and considering the public interaction with these existing projects, to-date there has been comparatively minimal involvement of the public in densely populated areas with such projects, and likely minimal awareness of hydrogen's applications and properties. Large producers and users currently operate in large and often remote industrial areas where the public has not had a need to take special interest to date. As the hydrogen use enters the daily routines of the public, or projects emerge that are directly adjacent to or within populated areas and neighbourhoods, there may be a shift to increased public awareness, public involvement, and inevitably public concern and potential opposition.

4.0 CHANGING INTERACTION WITH THE PUBLIC

The following sections briefly identify some key drivers behind the potential increasing public interaction with hydrogen as the hydrogen economy scales up.

A key change that is common to all areas below will be the widespread need for training first responders (fire departments) and technicians servicing the expanding and changing network of production, storage, distribution, and use. This increased visibility and interaction will put pressure on industry participants and regulators to address the public concerns that may arise.

H_2 Opportunity

	2030	2050
% of Delivered Energy	6%	30%
Hydrogen Demand	4 Mt-H_2	20 Mt-H_2
GHG Emissions Abated	up to 45 Mt-CO_2e	up to 190 Mt-CO_2e

Figure 1. Indication of the magnitude of scale-up expected in Canada between 2030 and 2050 [1]

4.1 Production

As discussed earlier, the current main producers and users of hydrogen generally remain in centralized locations surrounding industrial areas or areas generally having low population density. As the hydrogen economy transitions to having an increased reliance on renewables-based and other low carbon hydrogen production methods, a transition to a different profile of production locations is likely to occur.

In addition to upscaling in pre-established industrial regions, generation dedicated for new applications may emerge that are no longer co-located with operations in areas with low population density.

As one example, the Independent Electrical Supply Operator (IESO) who is responsible for managing the electrical power grid in Ontario, Canada, is planning for 15,000 MW of electrical production using hydrogen as an offset for natural gas electricity generation [5]. This document plans the electrical supply mix through to 2050 to meet climate commitments. The intent is for the hydrogen to be produced from renewable or low-carbon energy inputs and the source of that hydrogen production will be from both small-scale distributed production networks and large-scale commercial production centers. This alone would represent a step change in low carbon hydrogen production on the scale of several orders of magnitude to achieve the required quantities even without factoring the additional production required for other end use applications such as for transportation and heavy industry.

Another example local to Ontario, Canada, is that ArcelorMittal has announced plans to transition steel making operations in Hamilton, Ontario, away from coal blast furnaces to Direct Reduced Iron (DRI) using electric arc furnaces. This is a transition that would create a demand of several hundred tonnes per day (tpd) of low carbon hydrogen [6]. This additional hydrogen demand could amount to an electrical demand for production of the hydrogen supply of approximately 15,000 MW installed electrical generation capacity.

Many entities are seeking on-site production in smaller scale fit-for-purpose projects for production and consumption on-site (e.g., public transportation hubs such as rail yards and terminals, large distribution centers/warehouses, etc.). On-site production will also be a focus for key shipping terminals, where energy inputs can be generated from large offshore wind (OSW) farms for production, storage, and dispensing to the shipping industry either as hydrogen or an easily transportable hydrogen derivative such as anhydrous ammonia.

Sub-station scale electrolysis facilities may be distributed at strategic locations to utilize low-cost surplus baseload generation during favourable grid conditions, which would also drive the production closer to and within larger communities. In general, a trend may occur whereby new hydrogen usages drive a more decentralized and distributed production network closer to communities and into regions that traditionally may have been unaware of hydrogen as an energy vector or the implications of its use.

4.2 Distribution & Storage

As with production, trends surrounding storage and distribution are expected to be similar whereby hydrogen distribution and storage infrastructure will become necessary in more densely populated areas. From a storage standpoint, each production location will likely include storage inventory in pressurized tanks. This includes infrastructure sites such as existing traditional vehicle fuelling stations where people may be quite familiar with gasoline pumps and propane storage tanks, but the concept of hydrogen storage may elicit new concerns. This could also be true of facilities looking to produce and use hydrogen on-site such as bus terminals and distribution centers, which would introduce the concept of the associated new potential hazards with personnel and the host communities.

Small to medium scale distributed storage networks will be important for a hydrogen economy, however, there is also a specific need for large scale hydrogen storage. This can potentially be achieved utilizing unique geological features that would enable underground storage in impermeable cavernous structures. While this practice is currently well established and essential in support of the natural gas markets in Ontario, the unique properties of hydrogen and the relative lack of public awareness surrounding hydrogen safety may lead to concern over public and environmental safety associated with this application.

Served by the large-scale storage infrastructure, one of the most pervasive changes that is possible as the hydrogen economy develops is the potential for piping infrastructure to transmit hydrogen either in existing natural gas infrastructure (in pure or blended form), or in dedicated new pipeline infrastructure. As domestic/building heating is one the major contributors to greenhouse gas (GHG) emissions representing 13% of Canada's GHG emissions profile due to the usage of natural gas, it is a key target area of carbon reduction plans [1]. Depending on climatic conditions for the region and underlying economics, hydrogen is being targeted as a "straightforward" direct replacement for natural gas. Of course, this would require hydrogen gas being introduced through pipeline directly into the homes of natural gas appliance users. This is a direct and prolific interaction that may drive concern and require significant public engagement and communication on safety and regulations to support such a step change.

One final aspect associated with distribution will be the need to address potential hydrogen leakage from pipeline infrastructure as studies indicate fugitive hydrogen emissions are an indirect greenhouse gas that results in a Global Warming Potential (GWP) index of (on average) approximately 11. This means 1 kg of H_2 is equivalent to 11 kg of atmospheric CO_2 (CO_2eq), contributing to climate change if not properly mitigated and controlled [7]. However, several studies have arrived at different values for GWP and more research in this field is required.

4.3 Refuelling Stations

Naturally, point-of-use public interaction will require a campaign of public awareness and public consent. As refuelling networks for heavy commercial freight and passenger vehicles expand, so will the public interest in the safety and environmental implications. Speaking specifically about Canada, there is currently a modest retail hydrogen refuelling infrastructure in only very few areas. However, among other noteworthy initiatives, plans have been announced to deploy refuelling infrastructure along the 401 (Windsor-Quebec City corridor) through parts of Ontario and Quebec, the busiest highway in North America and the corridor along which more than 50% of the population of Canada resides.

In addition to refuelling for transportation in vehicles owned and operated by the general public, it has been discussed above that jurisdictions are exploring opportunities for hydrogen refuelling applications for public transportation (bus terminals, rail yards, etc.) and warehouse/distribution fleet vehicles. These applications will also require user interaction with hydrogen refuelling equipment which will necessitate training requirements and public awareness and support campaigns.

5 DEPLOYABLE COMMUNITY / SOCIAL CONSENT EXPERIENCE

Like most new infrastructure, particularly ones containing new or unfamiliar technology like hydrogen or nuclear Small Modular Reactors (SMRs), one often faces public opposition. Such opposition is not unreasonable, and in most cases should be anticipated. Failure to address such opposition at the outset often results in project delays or in some cases outright project rejection. Project rejection in this case is not caused by regulatory delays or regulatory rejection, rather, public-driven opposition delays and even public-driven rejection. Such was the case for Ontario Power Generation's (OPG) low-level radioactive waste repository at the Bruce nuclear site in 2019, or Toronto's municipal solid waste proposal for Kirkland Lake's Adams Mine in 2004. In both cases the project proponent received regulatory approval but failed to proceed because of public opposition.

The Problem stems from a failure to consider the conditions necessary for social consent at the outset even as early as the conceptual design phase. Social consent does not require that the public necessarily wants the project to be executed or that they are happy about it. It is recognition from the public stakeholders that the project is the solution to an important larger issue, which in the case of low carbon hydrogen, is about reducing carbon emissions. Consent from even the most ardent opposition means that although they might not agree with the project they at least will not stand in its way.

The Solution lies in achieving social consent from the public. This entails strategic planning prior to any project announcement. A successful planning phase often includes the following five steps:

<u>What problem is the project addressing?</u> This requires much clarity on the project proponent's part. The hydrogen technology the project aspires to implement is intended to solve social challenges regarding carbon emissions. To be successful the project proponent must be specific about the project's intention, why it is important, and ensure there is clarity such that the stakeholder recognizes the problem as a social challenge that is theirs to contribute toward resolving. Specifically, it is important to articulate in lay terms how the solution reduces emissions and why this is important for everyone. This could include a description of benefits.

<u>Does the affected public see the problem the same as the project</u>? Be sure to validate with a cross section of the public stakeholders if and how they see the problem that the project is attempting to address. It is equally important to ascertain if affected public stakeholders agree that the problem is worthy of solving with the same urgency as seen by the project. Many projects [such as OPG's low-level radioactive waste Deep Geological Repository (DGR)] were confronted with a public that did not understand or agree with the urgency of the problem let alone the solution itself.

Are the affected Indigenous groups and stakeholders adequately identified? Before the project is announced, it is always valuable to map out who will be affected and how. More important, this should include a list of publicly affected interests that may arise from the implementation of the project. The more the interests, principles, values, and aspirations are understood, the better the outcomes. Two outcomes are possible from a strong upfront understanding of the stakeholders in the planning phase:

1. The project design and execution plan can be amended beforehand to better align with these interests and concerns, and
2. A more effective Indigenous and stakeholder engagement plan could be developed.

Can the project build and sustain public trust? The key to successful engagement and winning social consent rests on the project's ability to build and sustain trust with the publicly affected stakeholders and Indigenous groups. Trust is built upon open two-way dialogue. The project's ability not only to listen, but to demonstrate genuine care about the Indigenous and stakeholder interests and a willingness to act to mitigate negative effects from the project, are all important.

What is the plan? The project's plan for engagement is a statement of the project's commitment to the public regarding how it will look, listen, and learn about the aspirations and challenges related to the project. The most effective plans are those that are developed in collaboration with the community and affected stakeholders.

The value of the above five steps is two-fold:

1. It helps to clarify choices for the project proponent and the public based upon mutually developed information and facts, and
2. It lays a platform for dialogue that enhances the chance of achieving social consent.

These principles identified above have been applied successfully in industries facing many similar hurdles in obtaining public consent for important infrastructure projects such as the nuclear industry, and these lessons can be carried forward as a pathway to success.

6 DEPLOYABLE SAFETY EXPERIENCE FROM THE NUCLEAR INDUSTRY

To make the transition to an economy more reliant on hydrogen as an end-use energy vector, lessons can be learned from existing industrial experience with hydrogen use, and more broadly, can be learned from the experience of highly regulated industries where public and environmental safety, social consenting, and demonstrated reliability are central themes and pathways to successful projects.

The nuclear industry (specifically the Canadian nuclear industry) is the focus of this discussion and offers a unique perspective that is applicable in many aspects of the challenges faced in a transition to a hydrogen economy. The nuclear industry is highly regulated, considers safety to be paramount in all decision making, operates within a strict Codes, Standards, and Requirements architecture, and has been interacting with the concerned public to communicate key messages and gain social consent for major infrastructure initiatives for several decades. Further, the nuclear industry has a history of experience with hydrogen in operations.

The following section discusses some key aspects of the regulator in the Canadian nuclear industry. While this paper is not suggesting or recommending such a regulatory framework is appropriate for the deployment of a hydrogen economy, there are important takeaways and successful traits to be observed from within this structure.

The Canadian Nuclear Safety Commission (CNSC) is the regulator for Canada's nuclear industry. The CNSC operates under the authority of the Nuclear Safety and Control Act (NSCA) to regulate the use of nuclear energy and materials to protect health, safety, security, and the environment [8]. Through the CNSC the industry is mandated to adhere to a set of prescribed requirements as outlined by CNSC Regulatory Documents (REGDOCs). Further, an established set of Codes, Standards, and Quality

Assurance (QA) requirements are prescribed from the initial project proposal through all licensing phases including siting, design, construction, commissioning, operations, decommissioning, and waste management. Throughout the licensing process the CNSC conducts public hearings and inquiries to ensure the applicant can demonstrate that all processes have been adhered to and that the appropriate level of Indigenous consultation and public engagement has been obtained. CSA N286-12 (R2017) *Management System Requirements for Nuclear Facilities* is a document which outlines the responsibilities of top management having overall accountability for the nuclear facility, and includes a strong emphasis on "Nuclear Safety Culture." With this philosophy, safety is the utmost priority and overrides all other values and priorities. Such a system focused on safety *culture*, when properly implemented, will result in a strong safety mentality and commitment that will pervade the industry at all levels and ensure multiple barriers are in place to prevent a safety event from occurring.

The nuclear industry adheres to a hierarchy of policies, procedures, codes and standards that govern all aspects of each project lifecycle stage. Such a system that focuses on a top-down safety culture and well-defined and structured quality systems ensures very predictable outcomes. A dedicated oversight body ensuring implementation of a well unified and prescribed set of requirements are success lessons that can be learned from the nuclear industry.

Another aspect of the nuclear industry that can be applied to an expanding hydrogen economy is the emphasis on training and qualifications. Nuclear professionals are highly trained and there are strict requirements that must be met, recorded, and held as quality records to maintain qualifications to perform work. This is true for plant personnel (operations and maintenance) as well as design teams (knowledge workers). Codes and standards for the design, operation and maintenance of hydrogen systems are available and effective but it is essential for the safety of the public, workers, and environment to ensure consistent adherence to this governance – that is to say, it is essential to have robust systems in place and enforced to ensure hydrogen energy workers "do the right things right".

Collaboration is a noteworthy element of the nuclear industry that can be leveraged as a successful model. The nuclear industry has several pathways for deep meaningful sharing of information related to safety events that have occurred as well as other more general learning opportunities. Industry tools are available and meant to ensure any relevant operational experience is shared among operators and industry participants to prevent recurrence of these events. For instance, the International Atomic Energy Agency (IAEA), CANDU Owner's Group (COG), Institute of Nuclear Power Operators (INPO), and the World Association of Nuclear Operators (WANO), are bodies that provide governance, oversight, collaboration, and control with the purpose of enhancing safety in the industry. Interestingly, these groups generally formed in response to nuclear safety events that occurred in the industry with a vision to ensure the events are not repeated. Notably, the nuclear safety events that served as the catalyst for these organizations have typically involved hydrogen (either as near miss or explosion events) as a contributor to the nuclear safety event significance. Each organization maintains databases of events that are catalogued that can be leveraged to ensure safety in design, operations, and maintenance. This approach is already analogous to hydrogen incident databases that are intended to serve a similar purpose in the hydrogen industry, for example the European Hydrogen Safety Panel (EHSP) Hydrogen Incidents and Accidents Database (HIAD) [9].

While the nuclear industry has used hydrogen in station systems such as generator casing cooling systems and in the annulus around pressure tubes in Canadian CANDU reactor designs, this is not the most significant contribution the nuclear industry has made to hydrogen safety.

In contrast to the scaling challenges associated with implementation of a hydrogen economy, the nuclear industry has faced a challenge in ensuring mitigation measures are in place to control the *unwanted* production of hydrogen in a nuclear reactor under certain conditions (either through radiolysis or other processes such as high temperature oxidation of zirconium). In a nuclear radiological event, hydrogen is typically an unwanted byproduct of the harsh environmental conditions. Under these conditions, hydrogen gas can accumulate in the reactor containment buildings or adjacent structures. If left unmitigated this can lead to a large explosion that can compromise the integrity of the containment structure or adjacent buildings and contribute to difficulties in emergency response and/or potentially uncontrolled releases of radiation to the public and environment in the worst case. Notably, Three Mile Island (TMI) Unit 2 nearly experienced a hydrogen explosion, and both the Chernobyl and Fukushima nuclear events were affected by large hydrogen explosions.

In response to the risk of dangerous unintended hydrogen accumulation the nuclear industry developed mitigation technology in the form of Passive Autocatalytic Recombiners (PARs) which in the absence of additional intervention will convert concentrations of atmospheric hydrogen into heat and water vapour in the presence of a catalyst. Research has been conducted to model the optimal quantity and location of these safety devices, and this could be strategically deployed in high value targets such as production facilities and pipeline compression stations. This would simultaneously be a safety implementation to protect against dangerous a potentially explosive accumulation of hydrogen gas as well as an environmental safety measure to mitigate potential fugitive emissions in distribution locations that are most susceptible to significant leakage.

The nuclear industry has also spearheaded materials science research into the effects of hydrogen diffusion into metals and embrittlement in the harsh high temperature high radiation environments in nuclear reactors. CANDU reactors can suffer hydrogen ingress forming brittle hydrides on the reactor pressure tubes which can lead to fracture [9]. The importance of understanding and mitigating the effects has been the topic of much research in the industry which is informative for the deployment of a hydrogen economy utilizing existing pipeline infrastructure.

The experience from the nuclear industry is an appropriate reference point to ensure safety and quality and help mitigate public concern by demonstrating appropriate measures are in place to ensure the safety of the public and environment.

7 CONCLUSIONS

It is evident that the deployment of a hydrogen economy will result in new and plentiful opportunities for interaction with the public. A scaling of the hydrogen economy will see new use cases driving significant changes to the infrastructure profile of the current hydrogen economy, likely pushing it into much closer contact with the public. This is likely to happen through any of the following but not limited to: distributed production networks, hydrogen equipment requiring more public interaction, prevalence of hydrogen refuelling stations, and large-scale storage projects. All these factors will drive production, distribution, storage, and usage closer to and/or within communities. This will inevitably come with challenges in obtaining social consent and ensuring important projects are implemented. Society will see large projects seek regulatory approvals and these projects risk opposition from those who may not fundamentally oppose the implementation of the hydrogen economy but firmly believe that it is well justified that it should not be implemented in their immediate communities.

The transferable tools from a broad base of industry experience are available for interaction with the public using a highly effective and successful approach yielding favourable social consent outcomes. A model is available for what a robust and well-regulated industry can look like when experience is sought from the nuclear industry, among other industrial players that may have not been directly addressed. Decades of experience in the production, storage, distribution, and use of hydrogen products are available from several industries that can be codified into an approach that is demonstratable as safe to a regulatory authority and ultimately the public. Specialized tools that have been developed out of necessity can be deployed as required to mitigate any residual safety or environmental concerns. To succeed in the deployment of a hydrogen economy and to succeed in society's collective objective to mitigate CO_2 emissions, professionals must draw on all avenues of experience to ensure that this important initiative is implemented while meeting all public and environmental safety requirements.

8 REFERENCES

1. Natural Resources Canada, Hydrogen Strategy for Canada, Seizing the Opportunities for Hydrogen, A Call to Action, December 2020.
2. Oliver J. Lee, Scientific Events – The Haber Process, *Science*, **57**, No. 1471, 1928, pp. 292.
3. James G. Speight, in The Refinery of the Future, 2011, William Andrew Applied Science Publishers.
4. International Energy Agency (IEA), Report: Global Hydrogen Review, September 2022.
5. Independent Electrical System Operator (IESO), Pathways to Decarbonization, December 15, 2022.
6. ArcelorMittal Press Release, October 2022, ArcelorMittal breaks ground on first transformational low-carbon emissions steelmaking project, Accessed 08Feb2023, <https://corporate.arcelormittal.com/media/press-releases/arcelormittal-breaks-ground-on-first-transformational-low-carbon-emissions-steelmaking-project>.
7. Nicola Warwick, Paul Griffiths, James Keeble, Alexander Archibald, John Pyle, Atmospheric implications of increased Hydrogen use, University of Cambridge and NCAS and Keith Shine, University of Reading, April 2022.
8. Canadian Nuclear Safety Commission, https://nuclearsafety.gc.ca/eng/, Accessed 27Mar2023
9. Melideo, D., Weidner Ronnefeld, E., Dolci, F. and Moretto, P., HIAD - Hydrogen Incident and Accident Database, In: 53rd ESReDA Seminar, 14-15 November 2017, Ispra, 53rd ESReDA Seminar, 2017, p. 326-336, JRC108666.
10. Douglas Rodgers, Malcolm Griffiths, Grant Bickel, Andrew Buyers, Christopher Coleman, Heidi Nordin, and Sterling St Lawrence, Performance of Pressure Tubes in CANDU reactors, Canadian Nuclear Laboratories, 08June2016