Literature review and technology readiness assessment of ultra-high frequency radio frequency identification to Canadian livestock applications

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Abstract

The goal of this document is to perform a literature driven technology readiness assessment of ultra high frequency (UHF) radio frequency identification (RFID) systems for use in Canadian livestock identity and traceability settings.

A comprehensive search and screening of peer reviewed scientific literature is presented. Current standards and processes for RFID animal indicator approval and revocation were assessed for compatibility with currently available UHF RFID systems. The review identified a diverse set of environments where LF, HF and UHF RFID technologies in passive and active designs are deployed in support of individual product identification. These systems support the one time and ongoing identification of products in a variety of supply chain (Shanahan *et al.* 2009; Cao *et al.* 2010) , logistics (Liu *et al.* 2016; Mirzabeiki, Holmström, and Främling 2014) and regulatory compliance (Barge *et al.* 2013) settings. Specifically relevant to livestock application, descriptions of UHF backed traceability systems of a variety of livestock (Lee and Yoe 2007; Mottram 2011), and livestock derived products (Cataldo *et al.* 2016; Eom *et al.* 2014) are presented.

A technology readiness assessment framework (Appendix A) was adopted to support the qualitative assessment of UHF RFID technologies to Canadian livestock applications. This framework was applied to each of the numbered sections of the Canadian Food Inspection Agency document entitled "Animal Indicator Approval and Revocation Framework[1]". In general, technology readiness score was moderate to high, however the process of review identified three main areas where additional work will be required prior to approving the first UHF RFID animal indicators for use in Canadian livestock identity and traceability settings.

A series of recommendations to support the delineation of work required prior to the approval of any first UHF RFID technology backed animal indicator for Canadian livestock application are presented.

Keywords: UHF, RFID, Indicator, Biometrics, Traceability

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1. https://canadaid.ca/wp-content/media_releases/CFIA_ACIA_3412108_v6_animal_indicator_approval_and_revocation_framework.pdf

1 Introduction

Background In spring 2019, the Canadian Cattle Identification Agency published a request for proposals for a pair of activities. A proponent team comprised of researchers and staff from the University of Calgary, The Southern Alberta Institute for Technology and the University of Saskatchewan prepared and submitted a response which was selected as the winning proposal. The stated deliverables were to develop a literature review and an implementation plan for the adoption of ultra high frequency radio frequency identification technologies by the Canadian Cattle Identification Agency for use in continued development and maintenance of the Canadian Livestock Tracking System.

Following discussion with the proponents, Agriculture and Agri-food Canada, the Canadian Cattleman's Association and the Canadian Food Inspection Agency, it was decided in early 2020 to sever the RFP into two separate agreements and begin work on the first activity (literature review) while the CCIA worked to secure project funding under Agriculture and Agri-Food Canada's Industry Association Component of the AgriAssurance Program. This report represents the primary deliverable of this revised engagement.

Context The use of RFID transponders is a well established technical solution to support quick and accurate unique identification of individual animals (Shackell 2008; Shanahan *et al.* 2009). National and international animal and human health standards mandate the prompt reporting of a selection of livestock diseases of importance for economic, animal, and human health reasons. In Canada this set of regulations falls under the Health of Animals Act and Regulations [2].

Disease response activities such as contract tracing, quarantine and testing strategies used to eradicate outbreak, epidemic and pandemic livestock disease events usually require individual animal identification. Surveillance strategies for livestock disease eradication or control programs also utilize individual animal identification. Canada's national animal identification programs are listed among the strengths of our national animal health policy in a recent World Organization for Animal Health report on the performance of Canada's veterinary services industry[3]. While the current standard of RFID transponder deployed to regulated species supports the technical needs of the national animal identification program, the performance specifications of newer standards in the space could improve the utility of the solution both to traceability goals but also to husbandry and other management opportunities (Caja *et al.* 2020; Hammer *et al.* 2016; Kassahun *et al.* 2014).

2. https://laws.justice.gc.ca/PDF/H-3.3.pdf
3. https://www.oie.int/fileadmin/Home/eng/Support_to_OIE_Members/docs/pdf/201804_09_final_OIE_PVS_Evaluation_report_Canada_Eng.pdf

Objectives The specific aim of this review document is to systematically search the body of literature related to applications of ultra high frequency radio frequency identification technologies to livestock settings. These search findings will be used to assess the suitability and maturity of UHF RFID technology for use by the Canadian Cattle Identification Agency as a component solution in the organization's livestock identification and traceability management systems.

2 Materials and Methods

2.1 Literature Search

Search Strategy A systematic search of scientific literature was developed and executed with the support of resources housed the University of Calgary's health Sciences Library[4] using Primo by Ex Libris[5] and the Google Scholar[6] search platforms. Four general search terms were combined in AND/OR Boolean logical strings and applied to 20 University of Calgary library collections. Collections searched are presented as Appendix B.

The terms:

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LIVESTOCK, TRACEABILITY, UHF and RFID
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were combined to return a manageable collection of articles for screening and review.

Search terms included in pesudo-code notation:

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(UHF|Ultra High Frequency AND|OR RFID|Radio Frequency Identification)
AND
(Livestock AND|OR Traceability)
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To work within limitations of the library search tooling this unified search was broken down into four separate searches and results from each were compiled and de-duplicated. These searches were:

1.
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(RFID|Radio Frequency Identification)
AND
(Livestock)
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2.
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(UHF|Ultra High Frequency)
AND
(Livestock)
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4. https://library.ucalgary.ca/hsl
5. https://about.proquest.com/products-services/Ex-Libris-Primo.html
6. https://scholar.google.com

3. (RFID|Radio Frequency Identification)

AND

(Traceability)

4. (UHF|Ultra High Frequency)

AND

(Traceability)

Article Screening Title screening followed by consensus abstract screening by two study staff was performed. Papers were retained if they were peer reviewed and specifically discussed applications of UHF RFID to livestock identification or non livestock traceability settings.

2.2 Technology Assessment Framework

While UHF RFID transponders as indicators in inventory control, and traceability settings are widely used in warehousing, logistics, and other commercial settings, assessment of these technologies for use in livestock settings should be considered from a formal technology readiness assessment perspective. Innovate Canada provides a 9 level technology readiness assessment scale which we present as Appendix A. We will adopt this scale as a means of categorization of the state of readiness of any relevant technical component necessary for successful operation in a national livestock traceability system.

2.3 Assessment Theme selection

Context Deploying any technology at a national scale is something that should involve careful planning and assessment of both the environment(s) that the technology will be deployed in and the existing practices and processes supporting any incumbent technologies in the space.

To ensure full consideration of the body of literature against the likely challenges and perspectives required to appropriately assess UHF technology for roll-out in the Canadian Livestock and Traceability Program, the themes of assessment currently delineated in the Canadian Food Inspection Agency Document entitled "Animal Indicator Approval and Revocation Framework" will be used as the basis of assessment.

These categories of assessment include assessments of electrical, mechanical, performance, material, and retention properties of submitted indicators. We will additionally address UHF technology readiness from the perspective of standardization for the purpose of use in animal identification settings under each of the following themes of assessment.

Electrical Assessment There are stated ISO and/or EPC standards for the testing of the electrical performance of RFID transponders, currently the framework for approval or revocation of approval references standards ISO24631-1 and ISO24631-3 which specifically reference LF RFID transponders. We seek to assess from a technology readiness perspective the presence of approved standards for the electrical assessment of UHF RFID tags for use in livestock applications.

Mechanical Assessment Species specific differences in application force and tensile strength need to be appropriately considered. Caprine and Ovine insertion force testing is in accordance with a referenced standard (BSI PAS66:2014) while bison, bovine, cervid and swine processes are outlined in absence of a ratified international standard. We seek to assess from a technology readiness assessment perspective the presence of approved standards for the mechanical assessment of UHF RFID tags for use in livestock applications. The authors have no reason to believe that UHF specific modifications to this section of the approval and revocation framework will be needed.

Performance Assessment Current performance assessment standards focus on the required magnetic field strength and resultant modulation amplitude of HDX and FDX-B mode tags. Both ratified under ISO 24631-3 section 7.6.4-7.6.7. We seek to assess from a technology readiness perspective the presence of approved standards for the performance assessment of UHF RFID tags for use in livestock application.

Material Assessment In a 2013 revision of the framework for approval or revocation of approval for animal indicators, the main set of materials assessment tests outlined in the Mechanical Assessment section were removed. While we believe retention, tensile strength and tamper evidence tests are suitable to cover the primary material properties assessments of LF RFID buttons at their current stage of maturity, literature backed assessments of influence of material properties on UHF RFID tag Mechanical properties will be sought. This exercise is justified by the different antenna/chip architectures present in UHF to those present in LF technologies.

Retention Assessment Specific characteristics of the Canadian production environment and processes are considered important to the short and long term performance of approved indicators. To this end the protocol for operating a tag retention trial is not drawn from a ratified international standard but rather a well designed effort to ensure that the indicator approval process includes meaningful real world evidence that the tag under consideration will perform appropriately in the diverse set of environmental and operational settings reflected in Canadian livestock production. While it is often nice to point to a well considered international standard of assessment, the authors

believe that if followed to the spirit of the existing Field Trial guidelines protocol, tag approval processes for UHF RFID tags should be appropriate.

Standardization Assessment There are a variety of standards bodies working to draft standards around the deployment of UHF RFID technologies. The International Standards Organization (ISO) has published a selection of standards for passive RFID in LF, HF and UHF frequencies. The Electronic Product Code Global organization (EPC) has also published a selection of standards for UHF RFID technical implementation. Few of these standards (ISO-117894/ISO-117895) deal specifically with the application of RFID technologies to livestock settings.

Adoption of international standards of assessment and performance should be considered where practical to ensure Canadian programs are scrutinized with the same scales as other exporting countries. We will seek literature support for livestock specific standards development undertakings.

2.4 Scope of Review

Livestock identity management and traceability systems are comprised of many components (Lee and Yoe 2007; López *et al.* 2009; Mohammed and Wang 2017). For the purpose of this document we are restricting the scope of exploration of these components to the specific changes or modifications required to any given component needed to support the addition of UHF RFID based animal indicators to the Canadian system.

Specifically we will attempt to identify literature to support the assessment of technology readiness of UHF RFID technology to be integrated into livestock identity and traceability management platforms in general terms. This document will not address traceability system design implications, or implications of adoption of UHF RFID technologies to areas outside of livestock identification for the purpose of national traceability objectives.

3 Results

3.1 Literature Search

As outlined in section 2.1 a composite search strategy was executed across University of Calgary Health Sciences Library Collections and Google Scholar. The article counts for each search theme and peer reviewed totals are presented in table 1. After download peer reviewed articles returned in more than one search were de-duplicated[7]. In addition to the Google Scholar Results, screenable literature was returned by the Primo Ex Libris search software from 20 university catalogues which

are presented as Appendix B.

Table 1. Search Results

Search	Articles	Reviews	Other	Total	Peer Reviewed
Primo 1 RFID AND TRACEABILITY	5612	13	6156	11781	990
Primo 2 RFID AND LIVESTOCK	1888	6	4642	6536	667
Primo 3 UHF AND LIVESTOCK	422	0	581	1003	160
Primo 4 UHF AND TRACEABILITY	675	0	634	1309	359
Scholar (UHF|RFID) AND (LIVESTOCK OR TRACEABILITY)				2960	100[8]

3.2 Article Screening

All articles returned by the collection of search strategies were first title screened to identify papers with direct reference to livestock identity applications of RFID technologies and second abstract screened to confirm relevant content to support our assessments. In total 127 peer reviewed articles were retained for review across our 5 search strategies. Retained citation lists for each search are presented as Appendix D.

3.3 Themes of Assessment

Electrical Assessment The EPC Generation 2 UHF RFID Version 2.0.1 Air Communication protocol is widely accepted as the ratified standard protocol for UHF RFID Communications. While there is a growing body of literature assessing and refining the electrical performance of the EPC Generation 2.0.1 Air Communication protocol (Hartley 2013; Laheurte 2014; Kolarovszki *et al.* 2016). Literature support in the form of protocols for testing, or well designed field study results assessing the electrical assessment of UHF RFID tags in under the humidity and temperature recommendations of Annex D of the Animal Indicator Approval and Revocation Framework were not found. Discussions with senior members of the Southern Alberta Institute of Technology RFID Applications Development Laboratory support this finding, however this organization has recently procured a testing rig for UHF RFID equipment that will allow them to support the development of such protocols and standards once it is brought on line later in 2021.

The current protocol for testing of LF RFID tags requires a range of humidities and temperatures and less than 30dBuV/m of electromagnetic noise, but does not require tags to be affixed to livestock

7. A total of 71 documents were returned by more than one search
8. Scholar results limited to top 100 for initial boolean search strategy

tissue while undergoing these performance assessments.

As UHF RFID may be more impacted by the close proximity of tissue than LF RFID, it may be worth considering the strategic deployment of electromagnetic phantom technologies, or more complex interference designs in the electrical assessment components of any proposed or revised testing standards for livestock applications.

Adrion *et al.* (2017) proposed a preliminary protocol for test bench assessment of the relative importance of pig and cattle ear tissue on the received signal strength indicator (RSSI). While the authors point to variable influences of ear tissue of pigs and cattle, and across tag designs, three of four tags considered in the study had good performance even in light of this. The study raises and dismisses the idea that targeted de-tuning may improve reads when tags are in contact with ear tissue, but points to broad bandwidth and omni-directionally readable designs as being important considerations for tag manufacturers. In this study a range of 24 reads per repetition was used from 0.4m - 3.85m in 0.15m increments. Pig ear tissue posed the largest impacts to RSSI and read distance. Findings in cow ear tissue were less varied and impacts of tissue on read performance were smaller. In the papers across transponder summary, pig and cattle ear tag read range for front and back of ear placements was > 1.3m in all settings, ranging up to 2.3m in the least impacted setting.

This paper could serve as an important foundational piece of work in the extension of ISO Standard 24641-1 and 24631-3 to specifically reference the assessment and evaluation of RFID transponders compliant with ISO-11784 and ISO-11785. The paragraph on Standardization Assessment in this section outlines how the International Standards Organization and the International Committee on Animal Recording are working to update these standards to include new technologies.

> Technology readiness level 7: Prototype ready for demonstration in an appropriate operational environment. Prototype at planned operational level and is ready for demonstration in an operational environment. Activities include prototype field testing.

Performance Assessment Similar to the electrical assessment findings, there is a growing body of scientific work looking at the performance of transponders conforming with the EPC Generation 2 UHF RFID Version 2.0.1 Air Communication protocol outside of the livestock sector. There is a small but growing body of literature assessing the performance of UHF RFID transponders packaged for animal traceability applications (Adrion *et al.* 2017; Barge *et al.* 2013).

Most of these studies focus on the change in operating frequency characteristics, read range performance or other technical measures of performance associated with packing the transponder

in a fashion suited for application to livestock or their environment for use in traceability.

Work underway by the International Standards Organization and the International Committee on Animal Recording referenced the standardization assessment of this section has the potential to modify the process of assessment of the performance specific technology readiness assessment.

> Technology readiness level 7: Prototype ready for demonstration in an appropriate operational environment. Prototype at planned operational level and is ready for demonstration in an operational environment. Activities include prototype field testing.

Material Assessment We were unable to specifically identify literature related to the materials assessment of UHF RFID livestock tags, however there is a decent body of literature assessing the durability of non-livestock UHF RFID transponders. The International Electrotechnical Commission standard IEC 60529, degrees of Ingress Protection ratings are defined degrees of environmental protection. IP ratings are commonly presented in non-livestock RFID Transponders particularly the Read on Metal ROM tags. Cross validating known IP ratings with the materials assessment processes currently outlined for LF RFID tags may be a worthwhile exercise in standards adoption.

Independent of the adoption of existing materials assessment approaches from other settings, the packaging of RFID electronics in a format suited for use in animal indicators is a task that is well tested in the current standard. While insertion force for Caprine and Ovine species falls under a current standard, the balance of species insertion, tensile strength and tamper evidence protocols are not specific to LF or other technologies and should be well suited to assessing UHF RFID technology carrying indicators.

> Technology readiness level 7: Prototype ready for demonstration in an appropriate operational environment. Prototype at planned operational level and is ready for demonstration in an operational environment. Activities include prototype field testing.

Retention Assessment There is a small body of literature on the field testing and assessment of UHF RFID technology (Pugh 2013). However, we were unable to identify specific literature containing protocols for the field testing of UHF RFID animal indicators. Similar to section 3.3, the protocol for retention assessment does not have elements specifically limiting the test to LF RFID equipment. Replacing the readers used to readers conforming with the EPC Generation 2 UHF RFID Version 2.0.1 Air Communication protocol should be the only step required to ensure a suitable protocol for field testing and retention assessment of UHF RFID animal indicators.

> Technology readiness level 8: The technology is completed and qualified through tests and demonstrations. The technology has been proven to work in its final form and

under expected conditions. Activities include developmental testing and evaluation of whether it will meet operational requirements in new environments and under the conditions present in the Canadian livestock production sector.

Standardization Assessment The International Standards Organization in conjunction with the International Committee on Animal Recording has established a Working Group (Work Group 3, Sub Committee 19, of Technical Committee 23 on Agricultural Electronics). The purpose of this working group is to detail the conditions under which integration of additional technologies to the existing ISO Animal Identification Standards ISO-11784 & ISO-11785, ISO-14223-1..3, and ISO26431-1..7, would be possible. The completion of this work would lay the groundwork for ISO or a sponsored party to produce and ratify an amendment to ISO-11784 or ISO-11785 to include livestock numbering standards for applications in national animal identity and traceability management platforms for UHF backed animal indicators.

Technology readiness Level NA: The standards themselves are not a technology. However their development and adoption allow for the repeatable and transparent assessment of the technology that is UHF RFID in applications of animal identity management and traceability.

4 Discussion

4.1 Technology readiness assessment

Across the main themes of the current Animal Indicator Approval and Revocation Framework, UHF Technology displays a moderate level of technology readiness under Innovation Canada's Technology Readiness Scale (Appendix A). While the technology is tested, deployed and in production in many non-livestock settings (Badia-Melis, Mishra, and Ruiz-García 2015) and outside of direct individual animal identification through animal indicator use, is widely used in animal product traceability (Cataldo *et al.* 2016; Bai *et al.* 2017; Eom *et al.* 2014). There are research gaps that would need to be filled prior to assigning it a high level of technology readiness.

The primary nature of the remaining work to bring UHF RFID technology to the highest level of readiness, is adoption of new standards of assessment and or revision of the current standards of testing, approval and revocation of indicators. From there, field testing of manufacturer submitted indicators and an appropriate level of end user technology adoption would be the last barriers to deployment.

Focusing on one specific component of the Animal Indicator Approval and Revocation Framework, the Material Assessment section may need extension to include additional assessments of

durability. This recommendation is raised based solely on the difference in the antenna design and coupling between LF and UHF tags. LF tags use a spooled copper wire which is carried on a rigid plastic substrate, where UHF tags often use larger copper or aluminum foil antennae which could be more susceptible to damage from flexing or vibration than their LF counterparts. It would not be unreasonable to suggest that much like these assessments were phased out of the LF protocol after a reasonable level of performance became routine, such amendments could be made in the future of UHF assessment.

4.2 The current state of UHF RFID Technologies

The Scottish EID organization (Moxey 2011) and the Irish Department of Agriculture Fisheries and Food (Mc Carthy *et al.* 2011) has literature outlining their considerations of UHF RFID technology as an addition to their primarily LF RFID platform. Themes include the evolution and advance in UHF RFID performance in environments common to livestock production, range and speed improvements compared to LF counterparts, and the economists argument to set performance goals rather than technical standards to adhere to. They conclude that appropriate field testing, and real world evaluation are two main components in developing a true assessment of a technology's performance in a novel setting, and they point to examples of just this work getting underway internationally. In Southern Alberta, the Picture Bute Feeder Cooperative has been trialing UHF RFID management tags for the past 6 months and expect to have ten-thousand tags applied, by the end of the first quarter of 2021. Early assessment is that the tags are performing well for their feedlot induction and shipping gate based read settings.

Over the past 10 years a large up tick in the volume of research and policy development work around applications of UHF RFID technology to traceability, logistics, and asset management has occurred. This increase in investment and the associated improvements in performance and reliability are indicators that UHF RFID technology has been maturing and by these assessments concerns other than integration challenges and standards development are less likely to derail an adoption plan. While there are challenges in any new technology integration, wholesale changes in the assessment of the suitability of UHF RFID technology to identification and traceability settings are unlikely.

4.3 Technology change in animal identity management

This exploration of the suitability of UHF RFID backed animal indicators does not represent the first technology change in indicators since the inception of the CCIA in 1998. Bar code and LF HDX or FDX-B tags have serviced the goals of the industry well and only now as technology matures do

opportunities to base the program on a solution with more desirable performance characteristics manifest. Just as UHF RFID solutions seem to be poised to be next, alternative indicator or non-indicator identity management technologies are being tested and in time have the potential to bring new levels of identity assurance to Canadian systems.

While outside of the scope of this document, it is noteworthy that secondary discussion in many of the arcicles reiewed in this document included discussion of biometeric identification (Ludu and Plastow 2013; Sun, Zhao, and Yang 2013), computer vision (Achour *et al.* 2020; Velez *et al.* 2013; Xu *et al.* 2020), active sensing (Kolarovszki *et al.* 2016; Lu and Liou 2017) or alternative communications protocol backed tags (Ruiz-Garcia *et al.* 2009) in addition to passive UHF RFID tags.

The authors of this document feel that it would be prudent to ensure that efforts to extend or edit the processes used to support the current system take care to consider how or if these emerging solutions could fit in future versions of the tools used to support national animal identification and traceability goals.

5 Conclusion

This review was unable to identify a suitable body of scientific evidence to support a strong recommendation for or against the adoption of UHF RFID technologies for use in livestock identification settings in the Canadian Livestock Traceability System(s). This review was successful in quantifying the body of work required for such an adoption, should stakeholders decide that the suite of properties UHF presents is compelling enough to justify such an exercise.

From a technology readiness assessment perspective UHF RFID is showing a level of readiness that is encouraging. However a few key gaps in technology or process remain.

Process and Policy: The ISO will need to finalize and ratify a set of ISO numbering standards to support the use of EPC Gen 2 UHF RFID tags in livestock applications, the CFIA will need to update the Animal indicator approval and revocation framework to include appropriate extention of the processes outlined to include UHF specific assessments, and the CCIA will need to extend the current Canadian Livestock Traceabiity System process set to support the new UHF numbering scheme.

Technical/Engineering: Manufacturers will need to produce (and submit for assessment), UHF RFID tags that meet the new ISO numbering standard, and successfully satisfy the requirements of the CFIA Animal Indicator Approval and Revocation Framework. The CCIA will need to update the Canadian Livestock Traceability Data System(s) to support the assignment and collection of UHF

backed indicator data for tag assignment, birthdate verification, feedlot move-in, import/export and tag retirement events.

The authors conclude that prior to further development of implementation plans or execution of cost benefit analyses, that there are a series of important milestones which need to be met. These milestones are presented below as a list of recommendations which the CCIA and it's collective group of stakeholders would want to discuss and debate individually.

5.1 Recommendations

- Recommend that CCIA support ISO and ICAR in the establishment of a UHF specific set of extensions to ISO-11784 and ISO-11785
- Recommend that CCIA work with CFIA to extend the Animal Indicator Approval and Revocation Framework to include appropriate testing of EPC Generation 2 UHF RFID Version 2.0.1 Air Communications Protocol conforming animal indicators
- Recommend that CCIA undertake an assessment of the technical and procedural change required to the CLTS and it's component systems to support UHF RFID technologies
- Recommend that CCIA engage tag manufacturers to assess the availability of UHF RFID animal indicators that meet or exceed the testing standards outlined in the Animal Indicator Approval and Revocation Framework
- Recommend that in absence of manufacturer driven UHF tag technology submissions, an appropriately designed set of field trials to assess the performance of commercially available UHF RFID tag options is commissioned
- Recommend that where possible CCIA publicly publish the results of their field trials and tag approval exercises to support other countries in their assessment of the technologies supporting national traceability platforms

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Appendices

A Innovation Canada Technology Readiness Levels

These are the 9 technology readiness levels, with 1 being the least ready and 9 being already used in real-life conditions. See Innovation Canada for more information.

Level 1: Basic principles of concept are observed and reported. Scientific research begins to be translated into applied research and development. Activities might include paper studies of a technology's basic properties.

Level 2: Technology concept and/or application formulated. Invention begins. Once basic principles are observed, practical applications can be invented. Activities are limited to analytic studies.

Level 3: Analytical and experimental critical function and/or proof of concept. Active research and development is initiated. This includes analytical studies and/or laboratory studies. Activities might include components that are not yet integrated or representative.

Level 4: Component and/or validation in a laboratory environment. Basic technological components are integrated to establish that they will work together. Activities include integration of "ad hoc" hardware in the laboratory.

Level 5: Component and/or validation in a simulated environment. The basic technological components are integrated for testing in a simulated environment. Activities include laboratory integration of components.

Level 6: System/subsystem model or prototype demonstration in a simulated environment. A model or prototype that represents a near desired configuration. Activities include testing in a simulated operational environment or laboratory.

Level 7: Prototype ready for demonstration in an appropriate operational environment. Prototype at planned operational level and is ready for demonstration in an operational environment. Activities include prototype field testing.

Level 8: Actual technology completed and qualified through tests and demonstrations. Technology has been proven to work in its final form and under expected conditions. Activities include developmental testing and evaluation of whether it will meet operational requirements.

Level 9: Actual technology proven through successful deployment in an operational setting. Actual application of the technology in its final form and under real-life conditions, such as those encountered in operational tests and evaluations. Activities include using the innovation under operational conditions.

B Library Collections

List of library collections returning results for all study search strings.

1. Gale General OneFile
2. Business Premium Collection
3. Factiva
4. Alma Unassigned Holdings
5. Newspaper Source
6. Gale Academic OneFile
7. Gale OneFile: Military and Intelligence
8. Scopus
9. Hellenic Academic Libraries Link
10. IngentaConnect
11. Web of Science
12. Gale OneFile: Entrepreneurship
13. Gale OneFile: Hospitality and Tourism
14. ProQuest Dissertations & Theses Global
15. Directory of Open Access Journals
16. Academic Search Complete
17. Gale OneFile: Nursing and Allied Health
18. Business Source Complete
19. Gale OneFile: Psychology
20. PubMed Central

C Raw Search Results

A public Mendeley.com Reference sharing group with all returned results from each of the five searches has been created to facilitate sharing of content. A free https://mendeley.com user account may be required to visit the group and browse citations.

The group can be found at https://www.mendeley.com/community/uhf-rfid-literature-search/.

D Screened Search Results

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