Vaccine 35 (2017) 2252–2259

Contents lists available at ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

Review

Innovations in cold chain equipment for immunization supply chains ☆

Joanie Robertson [a,*], Lauren Franzel [b], Denis Maire [c]

[a] PATH, 2201 Westlake Avenue, Suite 200, Seattle, WA 98121, USA
[b] Gavi, The Vaccine Alliance, Chemin des Mines 2, Geneva 1202, Switzerland
[c] World Health Organization, Avenue Appia 20, Geneva 1211, Switzerland

A R T I C L E I N F O

Article history:
Received 30 April 2016
Received in revised form 22 October 2016
Accepted 5 November 2016

Keywords:
Vaccine
Cold chain equipment
Prequalification
Specifications
Market demand
WHO PQS

A B S T R A C T

Background: Since 2010, numerous new technologies have entered the immunization cold chain equipment market. The World Health Organization (WHO) Immunization Devices Programme—Performance, Quality and Safety (PQS)—has played a key role in bringing these to market. In this article, the authors explore the emergence of new cold chain equipment technologies from 2004 to 2016 and the role of PQS in this evolution.

Methods: This review focuses on three major vaccine cold chain technology innovations—solar direct-drive refrigerators, long-term passive cold boxes, and equipment with user-independent freeze prevention. For the review, we used online data from WHO PQS, a literature search, and unpublished research reports.

Results: Timelines with key milestones in the emergence of the three focus technologies show delays of between one and three years between earliest field trials and publication of WHO specifications; procurement builds after the WHO prequalification of initial devices.

Discussion: The timelines show the role of PQS as both gatekeeper and enabler for cold chain equipment technologies. The use of target product profiles by PQS has increased its ability to signal preferred attributes and to engage with manufacturers during the product-development stage. Procurement data show how demand for solar direct-drive refrigerators increased over time. Gavi, the Vaccine Alliance, is employing demand-generation strategies to try to drive procurement of technologies with favorable technical attributes.

Conclusions:

- PQS plays an important role in early product development.
- Target product profiles have proven to be a successful way to communicate desired attributes and focus developer research.
- Field evaluations provide PQS with invaluable data to help refine specifications in line with actual performance in immunization settings.
- Establishing more systematic post-market surveillance systems for cold chain equipment after large-scale deployment could have positive effects.
- Efforts to communicate to countries and other immunization stakeholders about new technologies is needed to accelerate their uptake.

Contents

Abbreviations: CCE, cold chain equipment; EPI, Expanded Programme on Immunization; PIS, Product Information Sheets; PQS, Performance, Quality and Safety department of World Health Organization; SDD, solar direct-drive; TPP, target product profile; UIFP, user-independent freeze prevention; UNICEF, United Nations Children's Fund; WHO, World Health Organization.

☆ Open Access provided for this article by the Gates Foundation.

* Corresponding author.
E-mail addresses: jrobertson@path.org (J. Robertson), lfranzel@gavi.org (L. Franzel), mairedwho.int (D. Maire).

http://dx.doi.org/10.1016/j.vaccine.2016.11.094
0264-410X/

1. Background

1.1. Overview of cold chain equipment

Cold chain equipment (CCE) used for storing and transporting vaccines can be categorized into active refrigeration systems and passive cooling devices. Active systems include mains refrigerators and off-grid refrigerators. Mains refrigerators are cooled by compressors that are powered by the electric grid. Off-grid refrigerators include two main subsets: absorption refrigerators powered by the burning of liquid petroleum gas or kerosene, and solar powered refrigerators, which use electric compressors that may be driven either from batteries that have stored the power generated by solar panels (solar battery-powered), or directly from the solar panels themselves (solar direct-drive or SDD). Passive cooling devices include cold boxes and vaccine carriers. Cold boxes are larger devices (6–25 L capacity), generally transported by motor vehicles, while vaccine carriers are smaller (0.5–3.5 L capacity), and generally carried by hand or on bicycles or motorbikes. They are called passive because there is no active refrigeration mechanism—the cooling is provided by coolant packs containing phase-change material (traditionally plain water) frozen into solid form. In order to avoid freeze damage to vaccines in conventional passive cooling devices, an extra step of 'conditioning' is required, taking coolant packs out of the freezer long enough so that they begin melting before placing them in the device [1].

1.2. Evolution of cold chain equipment

When EPI cold chains were established in the 1970s, absorption refrigerators were the only option for sites with no grid electricity [2]. A number of these devices were prequalified and included in the WHO Product Information Sheets (PIS, the prequalification system that preceded PQS). By the early 1980s, a number of solar battery-powered refrigerators were being evaluated in small-scale pilot studies in developing country EPIs [3]. Batteries were used in order to even out the availability of power to the refrigerators—without them the power would only be available when the sun was shining, while refrigerators need to remain cold throughout the night and during periods of clouds and precipitation as well.

The performance issues that emerged for these early off-grid technologies in field deployment inspired technology innovation. Absorption devices, especially kerosene, require constant adjustment to keep the temperature in the correct range; without adjustment, they carry a high risk of freezing. Both gas and kerosene devices require frequent maintenance and both require an operational supply chain for the fuel, which, even when it reaches its destination, is subject to diversion for other purposes [4]. WHO addressed the need for constant user-adjustment in the rewriting of specifications for absorption devices at the time of the transition from PIS to PQS in 2008. Manufacturers of absorption equipment were given two years to comply; as of March 2016, however, no absorption devices have successfully demonstrated compliance with the new specifications, and as a result, no absorption devices are currently prequalified by WHO [5].

Meanwhile, traditional solar battery-powered refrigerators were also presenting challenges. The batteries often required regular maintenance and had a lifespan far shorter than the refrigerator and solar panels, shortened further by absence of required maintenance. Solar energy proved susceptible to theft, either by outright removal of the panels, or by rerouting of the electricity from the battery system, which compromised the performance of the refrigerator [6]. SDD refrigerators were developed in response to the challenges presented by the batteries. SDD refrigerators are powered directly from the energy generated by solar panels. This required innovations in design to ensure that the refrigerators would be able to maintain their cold temperatures even overnight and during cloudy weather.

Passive cooling devices are undergoing their own evolution. Cold boxes and vaccine carriers have always been used to provide cooling during transport of vaccines from one point to another in the cold chain, including during immunization outreach. The "cold life" of these technologies is defined by WHO PQS as the period of time after coolant packs are added to the device and the container lid is closed until the temperature of the warmest point in the vaccine storage compartment first reaches +10 °C, at a constant ambient temperature of +43 °C [7]. Of course, the actual cold life depends on the ambient temperature, but it is always limited when the ambient temperatures are above freezing, and in general, until this decade, the best-performing cold boxes had cold lives of approximately 2–6 days (17–50 h for vaccine carriers). So these cold boxes could only be used for several days at most without organizing a system of ice replacement. As better insulation technologies began to emerge, including vacuum panels and high thermal resistance gels, extending cold life became possible and