



VETERINARY COLD CHAIN MANUAL

Ensuring effective vaccines

VETERINARY COLD CHAIN MANUAL

Ensuring effective vaccines

Mary Young, Rosa Costa, Gabriel Shirima, Quintino Lobo, Karim Tounkara,
Penny Farrell and Robyn Alders

The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. ACIAR operates as part of Australia's international development cooperation program, with a mission to achieve more productive and sustainable agricultural systems, for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

Where trade names are used this constitutes neither endorsement of nor discrimination against any product by the Centre.

ACIAR MONOGRAPH SERIES

This series contains the results of original research supported by ACIAR, or material deemed relevant to ACIAR's research and development objectives. The series is distributed internationally, with an emphasis on developing countries.

© Australian Centre for International Agricultural Research (ACIAR) 2015

This work is copyright. Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced by any process without prior written permission from ACIAR, GPO Box 1571, Canberra ACT 2601, Australia, aciar@aciar.gov.au

Young, M., Costa, R., Shirima, G., Lobo, Q., Tounkara, K., Farrell, P. and Alders, R. (2015). Veterinary Cold Chain Manual: ensuring effective vaccines. ACIAR Monograph No. 165a. Australian Centre for International Agricultural Research: Canberra. 90 pp.

ACIAR Monograph No. 165a

ACIAR Monographs – ISSN 1031-8194 (print), ISSN 1447-090X (online)

ISBN 978 1 925133 78 3 (print)

ISBN 978 1 925133 79 0 (online)

Editorial production and design by Louise Grayson.

Front photograph by Louise Grayson

Foreword

Livestock are vital to the livelihoods of the world's rural poor, and vaccines are a key component of livestock disease prevention and control worldwide. Vaccines have a major role in protecting animal health and public health, reducing animal suffering, enabling efficient production of food animals, and greatly reducing the need for antibiotics to treat food and companion animals. However, these important benefits can be seriously compromised by poor vaccine storage and handling.

Investments by ACIAR in the development and use of new technologies and interventions for the control of animal disease in Asia and Africa have contributed to food and nutrition security, food safety and ecologically sustainable livestock production. This manual contributes significantly to this work through enhancing local capacity to store and handle vaccines effectively, leading to better nutritional, livelihood and environmental outcomes for those living in poverty.

The information presented in this manual will help laboratory technicians, scientists, extension officers, policymakers and private vaccine distributors to improve their understanding of the principles of effective storage and handling of vaccines. Veterinary vaccines, when used in accordance with the label instructions, and in accordance with documented best practice guidelines, are safe and efficacious. Their effectiveness requires proper storage and handling as detailed in this manual, which has been developed from the experience of scientists, field workers and farmers working in Africa on Newcastle disease control programs.



Nick Austin
Chief Executive Officer

Contents

FOREWORD	3
ABOUT THE AUTHORS	6
ACKNOWLEDGEMENTS	7
ABBREVIATIONS	8
GLOSSARY	9
GENERAL INTRODUCTION	13
How to use this manual	13
1. Vaccines	14
1.1 Introduction	14
1.2 Vaccine types	15
1.3 Vaccine sensitivity	15
1.4 Thermotolerant vaccines	16
1.5 Correct conditions for storing diluents	17
1.6 Vaccine expiry date	17
2. The cold chain	19
2.1 What is the cold chain?	19
2.2 Components of the cold chain	20
2.3 Cold chain failure	20
3. Cold chain equipment	21
3.1 Refrigerators	21
3.2 Voltage stabilisers	27
3.3 Portable insulated containers (cold boxes, vaccine carriers and coolers)	27
3.4 Icepacks	29
4. How to use cold chain equipment	33
4.1 Where to put your refrigerator	33
4.2 Modifying a domestic refrigerator for vaccine storage	33
4.3 Packing a vaccine refrigerator	35
4.4 How to keep cold boxes, vaccine carriers and coolers in good condition	36
4.5 Packing a portable cold box or cooler	38
4.6 Conditioning icepacks	39

EFFECTIVE COLD CHAIN

5.	Cold chain monitoring	41
5.1	Introduction	41
5.2	Equipment	41
5.3	Measuring and recording temperatures	43
5.4	Monitoring the vaccine refrigerator	44
5.5	Monitoring a cold box or cooler used for temporary storage of vaccine	45
5.6	Using a data logger	45
6.	Cold chain maintenance	49
6.1	Introduction	49
6.2	Maintaining the vaccine refrigerator	49
6.3	Cold boxes, coolers and vaccine carriers	51
6.4	Monitoring equipment	51
6.5	Logbooks	53
6.6	Vaccine storage self-audit	53
7.	Cold chain risk management	55
7.1	Cold chain failure	55
7.2	Factors	55
7.3	Actions to take in the event of a cold chain breach	58
8.	How to assess and map the cold chain	59
8.1	Conducting a cold chain assessment	59
8.2	How to map the cold chain	64
9.	Annexes	68
Annex 1	Vaccines and liquid nitrogen	69
Annex 2	Vaccine storage information	70
Annex 3	Refrigerator selection	74
Annex 4	Mapping the refrigerator used for vaccine storage	77
Annex 5	Protecting cold chain equipment	78
Annex 6	Refrigerator warning signs	80
Annex 7	Vaccine storage self-audit	81
Annex 8	Generators	85
Annex 9	Cold chain equipment suppliers	86
10.	References and resources	88

About the Authors

Author	Description	Contact details
Mary Young	A veterinary pathologist with many years' experience in control of Newcastle disease in village poultry using thermotolerant I-2 Newcastle disease vaccine, and a lengthy professional interest in cold chain management.	KYEEMA Foundation, GPO Box 3023, Brisbane, Queensland 4001, Australia maryy@kyeemafoundation.org
Rosa Costa	A veterinary pathologist and head of the National Veterinary Research Institute in Mozambique for many years; lecturer at the Veterinary Faculty of the Eduardo Mondlane University, Mozambique. Involved with the control of Newcastle disease in village poultry using the thermotolerant I-2 Newcastle disease vaccine.	KYEEMA Foundation, PO Box 1168, Maputo, Mozambique rosac@kyeemafoundation.org
Gabriel Shirima	A veterinary bacteriologist and vaccinologist, working in the field of bacterial zoonoses for decades. Has provided consultancy services, including vaccine cold chain management in Tanzania.	Tanzania Veterinary Laboratory Agency, PO Box 9254, Dar es Salaam, Tanzania gmshirima@gmail.com gmalekia@yahoo.com
Quintino Lobo	A veterinarian with an MSc in agriculture development and 15 years working in vaccine production.	Instituto de Investigação Agraria de Moçambique, Direcção de Ciências Animais, PO Box 1922, Maputo, Mozambique quintinolobo@yahoo.com.br
Karim Tounkara	Director of the African Union Pan African Veterinary Vaccine Centre (retired).	AU-PANVAC, PO Box 1746, Debre Zeit, Ethiopia
Penny Farrell	A veterinarian committed to improving the quality of the lives of people in low- and middle-income settings, and the welfare of their animals.	pennycf@gmail.com
Robyn Alders	An Associate Professor at the Faculty of Veterinary Science within the University of Sydney and a village poultry specialist with the International Rural Poultry Centre (IRPC) of the KYEEMA Foundation.	Faculty of Veterinary Science and Charles Perkins Centre, University of Sydney, NSW 2006, Australia KYEEMA Foundation, GPO Box 3023, Brisbane, Queensland 4001, Australia robyn.alders@sydney.edu.au robyna@kyeemafoundation.org

Acknowledgements

We gratefully acknowledge the assistance and guidance of all who have been directly involved in our work and the many others who provided information and comment during the development of this manual.

The project cold chain manual prepared by Assoc. Prof. Robyn Alders and Dr Josefina Coucelo during the Reduction and Control of Newcastle Disease in Angola component of the *Projecto de apoio pela Uniao Europeia ao sector pecuario familiar no sud de Angola (PAPEFSA)* provided the framework of the current manual.

Ms Sarah Muegge kindly provided information for Case Study 3.

Figure 2 is adapted from Controlling Newcastle disease in village chickens: a laboratory manual, and Figure 6 is from Controlling Newcastle disease in village chickens: a field manual. Both figures are the work of Mr Razac Chame.

Figures 3, 4 and 7 are the work of Mr Grant Quine, whose assistance we gratefully acknowledge.

The support of ACIAR through the project ‘Strengthening food and nutrition security through family poultry and crop integration in Eastern and Southern Africa’ made the development of this manual possible. This project was implemented by the University of Sydney in collaboration with the Tanzania Veterinary Laboratory Agency, the Zambian Department of Veterinary Services, the KYEEMA Foundation and the Royal Veterinary College, London.

During the preparation of this manual, the authors drew on information contained in the National Vaccine Storage Guidelines ‘Strive for Five’ of the Department of Health and Ageing, Australian Government, and experience gained during collaboration with staff and consultants working with USAID|DELIVER, Indonesia.

Abbreviations

ATS	Automatic transfer switch
°C	degrees Celsius (Centigrade)
cm	centimetre
FEFO	First in and first out
FMD	Foot and mouth disease
I-2	Thermotolerant, avirulent strain of Newcastle disease virus, used as a live vaccine
mm	millimetre
ND	Newcastle disease
NGO	Non-governmental organisation
PQS	Performance, Quality and Safety
rDNA	Recombinant DNA
SOP	Standard Operating Procedure
WHO	World Health Organization

Glossary

Ambient temperature	The temperature of the environment surrounding the cold chain equipment. This temperature may fluctuate during the day.
Cold box	A thermally insulated, solid-walled, insulated container with a tight-fitting lid, used for collection and transport of vaccine. Icepacks are placed within the box to maintain vaccine within the recommended temperature range during transportation, short-period storage (from 24 to 96 hours) and during refrigerator maintenance or emergencies. (See also vaccine carrier.)
Cold chain	The system that is used to ensure that vaccines and other biological products that need special handling are kept within the safe temperature range of +2 °C to +8 °C.
Cold chain breach	A break in the cold chain caused by vaccine storage temperatures outside the recommended range of +2 °C to +8 °C; may also be referred to as an adverse vaccine storage event. (Short periods at up to +12 °C, lasting no longer than 15 minutes when stocktaking or restocking, are not considered a breach in the cold chain.)
Cold chain validation	The testing of cold chain equipment and procedures to ensure that vaccine stays within the recommended range for a specified period of time. It is important to test vaccine storage or transport containers under the environmental temperature changes likely to be experienced while vaccine is in transit.
Cold life	The time that a specialised vaccine carrier, cold box or cooler packed with the appropriate number of conditioned, frozen water-packs will keep vaccine within the recommended temperature range. Cold life is measured from the moment when the container lid is closed until the temperature of the warmest point in the vaccine storage compartment first reaches +10 °C. WHO recommends that testing is carried out at a constant ambient temperature of +43 °C to simulate transport of vaccine in hot environments and vehicles.
Cold mass	The term used to describe the presence of items in a refrigerator (e.g. cooled water bottles) that help to maintain stable cold temperatures. These items of additional thermal mass are of particular use if, for example, the power fails or the door has been left open.
Cold room	A temperature-controlled storage room used to store large amounts of vaccine for an extended period of time. The inner temperature is maintained between +2 °C and +8 °C.
Conditioning	A procedure used to ensure that frozen icepacks used in a cooler or vaccine carrier are at 0 °C, thus minimising the risk of vaccine freezing.

Cooler	A solid-walled, insulated container that is used with ice or icepacks to keep food and drinks cold for short periods. May also be used to keep vaccines and diluents within the recommended temperature range during transport and for short periods if validated.
Cooling plate	A component of a mechanical refrigeration system (also known as a plate evaporator, load heat exchanger or cold plate) usually located on the back wall, inside the refrigerator.
Data logger	A piece of electronic equipment used to record data such as temperature or humidity at intervals set using a computer and software. The data logger will continue to record and store information until it is stopped. The information can then be downloaded, displayed and analysed.
Expiry date	The date by which vaccine must be used, if it is stored in accordance with the manufacturer's recommendations. The expiry date should be printed on all vaccine vials, bottles or containers and packets during manufacture. If there has been a cold chain breach, the vaccine may be damaged and its potency will be reduced, even before the expiry date shown on the vial or packet.
Freeze-dried vaccine	A vaccine preserved by rapid freezing and drying in a high vacuum.
Freezing	Exposure of liquid vaccine to temperatures at or below 0 °C. Vaccines may not appear frozen but may have been damaged at these temperatures.
Gel-packs	Commercial coolant products and other non-ice coolants containing chemicals that depress the melting point and ensure the coolant remains colder than 0 °C for longer, in comparison to water-filled icepacks. This may pose a risk of freezing vaccines, especially if the gel-packs are allowed to come into direct contact with the vaccine stock.
Holdover time	The time taken for the internal temperature of the warmest part of a refrigerator to reach +10 °C during a power failure, assuming that the refrigerator is functioning well. The term also applies to the time taken for the internal temperature in the warmest part of a vaccine carrier packed with the recommended number of conditioned icepacks to reach +10 °C. Holdover time depends on the ambient temperature, the frequency of opening the door or lid, the quantity of vaccines, the number and condition of frozen icepacks, and the presence of cold mass items.
Ice or water pack	A flat, rectangular plastic container that is seven-eighths filled with water, frozen, and used in vaccine carriers, cold boxes or coolers to keep vaccines at the recommended temperatures. An icepack may have a removable lid for filling, or be pre-filled and sealed. Icepacks that are filled with tap water and then frozen are the safest type for maintaining the recommended vaccine storage temperature of +2 °C to +8 °C, inside a cold box. The number of icepacks required for safe vaccine transport varies. Direct contact between icepacks and vaccine must be avoided.

EFFECTIVE COLD CHAIN

Immunogenicity	The ability of a substance to provoke an immune response or the degree to which it provokes a response.
Inactivated vaccine	Vaccine in which the infectious components have been destroyed by chemical or physical treatment. The immunogenicity of the viral coat or bacterial outer membrane proteins is not affected. Inactivated vaccines do not multiply in the host and are usually administered in multiple doses to induce a full immunological response.
Live vaccine	Vaccine prepared from live isolates of a disease-causing agent. The agent has either been selected for low virulence or has been modified for reduced virulence. Most live vaccines should be stored at +2 °C to +8 °C and must not be frozen unless the instruction sheet specifically indicates that the vaccine concerned will tolerate freezing.
Oil emulsion vaccine	An emulsion is a dispersion of a liquid (the dispersed phase) in a second liquid (the continuous phase) with which the first one is not miscible. In vaccine formulations, these phases are water (antigenic media) and oil. In order to stabilise the emulsions, surfactants are added. Oil-emulsion vaccines should not be frozen.
Potency	The strength of a vaccine or product. For a vaccine it is the capacity to induce an immune response.
Slush test	A method used to confirm the accuracy of a thermometer. In the event of a suspected/reported cold chain breach, it is of great importance to check the accuracy of temperature recording systems.
Standard operating procedure (SOP)	The step-by-step written instructions that describe how to perform a specific function in a procedure. The SOP should be concise, to the point, and able to be understood by the person who is performing the procedure.
Temperature recovery	The ability of a refrigerator to return to its set temperature after being exposed to elevated temperatures (e.g. after opening the door to remove vaccine).
Thermolabile	Rapidly loses its immunogenic value/potency if its ambient temperature rises above +8 °C.
Thermostat	A device that regulates the temperature in a refrigerator.
Thermotolerance	The ability of vaccine and the parent virus to retain a level of infectivity (immunogenicity) after exposure to heat, i.e. the delayed heat degradation of the virus at temperatures above +8 °C (in relation to thermolabile strains). It is defined by the length of time the vaccine will retain its required immunogenicity at a particular temperature.

Thermostable	A term sometimes used to describe vaccines that are able to retain a level of immunogenicity after exposure to heat. In our experience, the use of the term creates the expectation that the vaccine is 'stable' under all conditions and so requires less attention to handling. This has resulted in many problems and so 'thermotolerant' is preferred by the authors of this manual. In addition, some 'thermostable' vaccines lose their 'thermostability' on reconstitution when the 'thermostability' is due to the freeze-drying protocol rather than a characteristic of the particular vaccine strain.
Vaccination	Inoculation of healthy animals with a vaccine in order to stimulate a protective immune response. Vaccination protects against the clinical signs of disease but does not prevent infection.
Vaccine	A preparation containing (part or whole) mild, weakened, dead (inactivated) or genetically altered strain(s) of disease-causing agent(s) that, when inoculated into an individual stimulates an immune response and helps to provide protection from disease. Vaccines may be live or dead (inactivated). (See also live vaccine, inactivated vaccine.)
Vaccine carrier	A portable container used for the transport of vaccines by an individual from one point to another, and to maintain the temperature of the vaccine within acceptable limits during the transport and vaccination activity, typically from a few hours to a whole day.
Vaccine stability tests	Tests that provide evidence of how the quality of a vaccine varies with time under different environmental conditions. Data generated from such tests allows storage conditions and shelf life of the vaccine to be established. Tests should cover those features that may change during storage and are likely to influence the quality, safety and/or efficacy of the product. The length of the studies and the type of conditions should be sufficient to cover storage, transport and subsequent use of the vaccine.
Vaccine storage capacity	The actual volume of a refrigerator, cold box or vaccine carrier that is available for the storage of vaccines. The capacity may be stated by the equipment manufacturer or established by physical measurement. The volume suitable for storing vaccine will be less than the actual internal capacity of the equipment.
Validation	Testing, performed under controlled conditions, that demonstrates a procedure consistently producing a result that meets predetermined acceptance criteria. The test protocol and results must be documented.

General introduction

Good-quality vaccines are essential for the maintenance of animal health. They are an important means of control for many animal diseases, and crucial components of many national disease-control or eradication programs; however, these important activities can be seriously compromised by poor vaccine storage and handling.

Vaccines are supplied with specific instructions such as dose rate, storage and administration procedures, any side effects that may potentially occur, withdrawal periods, and the expiry date of the product. These instructions are very important and must be understood and followed to ensure that the product does what it is supposed to do.

This manual deals with a very important part of the instructions: how to store and transport vaccines appropriately. This is achieved through paying particular attention to the cold chain, i.e. the system used to ensure that vaccines and other biological products are stored and handled at appropriate temperatures. The manual is intended for laboratory technicians and scientists, extension officers, policy makers and private vaccine distributors who wish to ensure the appropriate storage and transport of animal vaccines. The information presented in this manual will help you to improve your understanding of the principles of effective storage and handling of vaccines, and to apply these principles in your workplace.

How to use this manual

The manual has eight sections:

1. Vaccines
2. The cold chain
3. Cold chain equipment
4. How to use cold chain equipment
5. Cold chain monitoring
6. Cold chain maintenance
7. Cold chain risk management
8. How to assess and map the cold chain

Useful reference material, including information on selecting a refrigerator for vaccine storage, is presented in the Annexes. Terms used throughout this manual are defined in the Glossary.

1. Vaccines

1.1 Introduction

A vaccine is any preparation intended to produce immunity to a disease by stimulating the production of antibodies (WHO 2013b). There are different types of vaccines (see section 1.2), but all vaccines have one thing in common. They are delicate biological substances that can become less effective or be destroyed if they are:

- frozen¹;
- allowed to get too hot; and/or
- exposed to direct sunlight or fluorescent light.

If vaccines are exposed to such conditions, they may lose their potency, i.e. the capacity to induce an immune response in the vaccinated animal.

Potency is the strength of the vaccine or product.

For a vaccine it means that it is able to induce an immune response.

Once potency is lost, it cannot be restored. The damaged vaccines must be discarded, leading to wastage and inadequate stocks. This can be very costly in money and time.

As animal health professionals we must ensure that we handle and store vaccines properly. Using a vaccine that has been stored and handled inappropriately is risky. The animals may not develop adequate immunity and hence will not be protected from the disease. Imagine having to inform owners that their animals may have received an ineffective vaccine and will require revaccination!

¹ In this manual 'frozen' is used to describe the situation where liquid vaccines experience temperatures at or below 0 °C. Vaccines may not appear frozen but may have been damaged at these low temperatures. Most live vaccines should be stored at +2 °C to +8 °C and should not be frozen unless the instruction sheet specifically indicates that the vaccine concerned will tolerate freezing.

1.2 Vaccine types

There are two basic types of vaccines: live and inactivated ('killed').

Live vaccines are prepared from avirulent or low-virulence isolates of a disease-causing agent. These isolates of disease-causing agents may have been additionally weakened (attenuated), usually by repeated culturing in the laboratory or deletion of virulence-related genes from a microorganism. High immunogenicity and low virulence can also be produced by the insertion into a non-virulent vector microorganism of genes that code for specific immunising antigens from a disease-causing microorganism. The resulting vaccine organism retains the ability to replicate (grow) and produce immunity, but usually does not cause illness.

'Killed' vaccines are prepared from cultures of microorganisms that have been inactivated by chemical or other means – inactivated toxins or subunits (antigenic parts of microorganisms) that have been extracted from cultures or that have been produced through rDNA procedures. Inactivated vaccines cannot replicate and cannot cause disease from infection, even in an immunodeficient animal, provided the vaccine has been correctly inactivated. The entire dose of antigen is administered in the injection.

Both live and inactivated vaccines may be formulated with adjuvants designed to enhance their efficacy. Vaccine antigens may also be produced by genetic engineering technology. These products are sometimes referred to as recombinant vaccines.

1.3 Vaccine sensitivity

All vaccines are sensitive to heat to some extent, but some are more sensitive than others. If a vaccine is damaged by heat and loses some of its potency, the damage is permanent and the lost potency can never be restored. Each time heat damage occurs the loss of potency accumulates, and eventually, if the cold chain problem is not rectified, all potency will be lost and the vaccine becomes useless.

All vaccines are damaged if they reach temperatures greater than +8 °C, whether they are exposed to a high temperature for a short time (e.g. as a result of keeping them in a closed vehicle in the sun) or to a small elevation of temperature over a long period (e.g. as a result of the frequent opening of the door of a refrigerator).

Please note: All freeze-dried vaccines become much more heat-sensitive after they have been reconstituted. Therefore, it is even more important that they are not exposed to heat after reconstitution.

Some vaccines are also sensitive to freezing. For these vaccines, freezing or exposure to temperatures below 0 °C can also cause loss of potency, and again the vaccine will become useless. For vaccines that are freeze-sensitive, the loss of potency following freezing is immediate, and these damaged vaccines must not be administered.

Keeping vaccines at the right temperature is not an easy task, but the consequences of not doing so can be dangerous. For example, inactivated fowl cholera vaccine that has been damaged by becoming frozen may induce endotoxic shock in birds due to the lysing of bacterial cell walls by ice formed during freezing (Ahlers et al. 2009).

A few vaccines must be stored frozen at –20 °C and others at less than –100 °C in liquid nitrogen. Guidelines for storing vaccines in liquid nitrogen are given in Annex 1.

Some vaccines are sensitive to ultraviolet light, and exposure will cause loss of potency. Therefore, they must always be protected against sunlight or fluorescent (neon) light. These vaccines are usually supplied in vials made from dark-brown glass, which gives them some protection against light damage. Care must still be taken to keep them covered and protected from strong light at all times. As a general rule, it is good practice to protect all vaccines from UV light.

Inactivated vaccines should all be treated as sensitive to both excessive heat and freezing. They should be stored in a refrigerator at +2 °C to +8 °C. Exposure to temperatures outside this range may result in decreased vaccine potency.

Annex 2 gives a summary of vaccine storage information for vaccines in common use in Africa and Asia.

1.4 Thermotolerant vaccines

There is increasing interest in the development of vaccines that can tolerate adverse storage conditions. The availability of such vaccines would simplify storage and delivery, reduce wastage and improve accessibility.

In this manual thermotolerance is defined as the ability of vaccine and the parent virus to retain a level of infectivity (immunogenicity) after exposure to heat, i.e. the delayed heat degradation of the virus at temperatures above +8 °C. It is defined by the length of time the vaccine will retain an effective titre sufficient to induce a protective immune response at a particular temperature.²

² The terms 'heat resistant', 'delayed heat degradation' and 'thermostable' may also be encountered. In our experience, the use of the terms 'heat resistant' and 'thermostable' creates unrealistic expectations of a vaccine's properties. (This is why the term 'thermotolerant' is used.)

1.5 Correct conditions for storing diluents

Some vaccines come in the form of a powder or 'tablet' and must be dissolved (reconstituted) before they are used. In most cases the manufacturer will supply a special diluent for this purpose.

It is best to use the diluent supplied by the manufacturer with the vaccine. It is formulated for the needs of that specific vaccine, in terms of volume, pH and chemical properties. When a diluent is not provided, always follow the manufacturer's recommendations.

In general, diluents are less sensitive to storage temperatures than vaccines and may be stored outside the cold chain. Always ensure that vaccines and diluents are at the same temperature when mixed, otherwise thermal shock may occur, i.e. the death of some or all the essential live organisms in the vaccine. Most vaccines are kept in the refrigerator; therefore, keep diluents in the refrigerator for at least 24 hours before use.

Store the diluents and droppers with the vaccines in the vaccine carrier during transportation. Diluents should not come into direct contact with icepacks.

1.6 Vaccine expiry date

Only vaccine stocks that are fit for use should be kept in the vaccine cold chain. Any expired vials or heat-damaged vials should not be kept in the cold room, refrigerator or freezer, as they may be confused with good-quality vaccines. If unusable vaccines need to be kept for a period before disposal, e.g. until accounting or auditing procedures have been completed, such vials should be kept outside the cold chain, separated from all usable stocks and carefully labelled to avoid mistaken use.

When using thermotolerant vaccines, the date recorded on the vial usually refers to the expiry date when stored between +2 °C and +8 °C. The date the vial is removed from the conventional cold chain should be recorded and the expiry date altered according to the manner under which the vaccine is stored.

Key points

- Once vaccine potency is lost, it cannot be restored. Vaccines that have lost their potency due to heat or freezing will not stimulate an effective immune response.
- Never use damaged vaccines, as it gives a false sense of security to the beneficiaries and also affects the credibility of the vaccination program. As a result of the administration of damaged vaccines, outbreaks of vaccine-preventable diseases could occur.
- Always read the product label and instruction leaflet for information on the best storage temperature for that particular product.

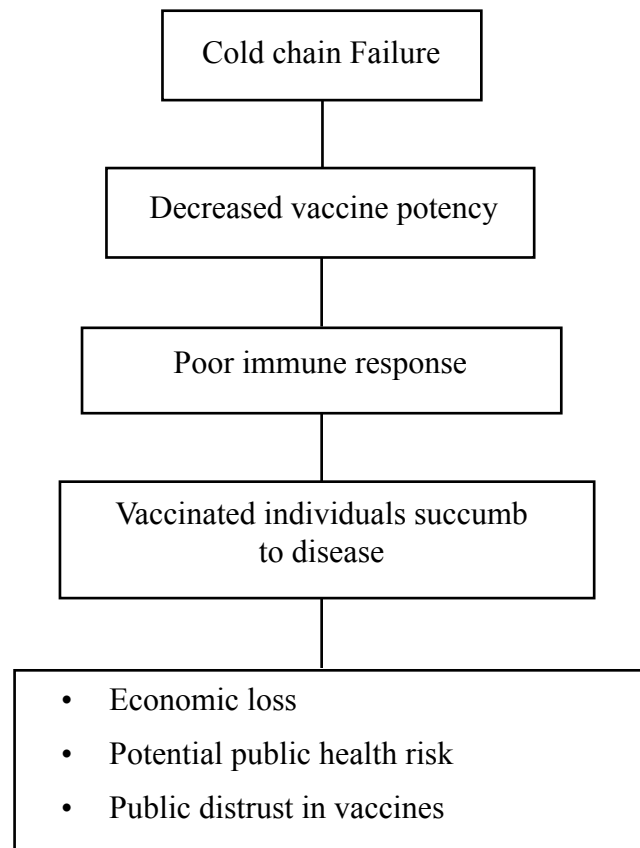


Figure 1 The consequences of cold chain failure

2. The cold chain

2.1 What is the cold chain?

To ensure that vaccines do not lose their potency, a system called the cold chain is used. The system is called the cold chain because, just like a real chain, it is composed of a number of links that connect with one another to form a chain.

The 'cold chain' is the system that is used to ensure that vaccines and other biological products that need special handling are kept within the safe temperature range of +2 °C to +8 °C.

The cold chain begins from the time the vaccine is manufactured, continues through transport to national, provincial or regional vaccine distribution centres, then to the district, and ends when the vaccine is administered.

Figure 2 shows the links of a typical cold chain for I-2 Newcastle disease vaccine in Mozambique. Vaccine is manufactured at the Animal Science Directorate in Maputo, Mozambique (the building) and is transported to provincial or district vaccine stores by road, where it is stored until it is sent to the field and used by community vaccinators.

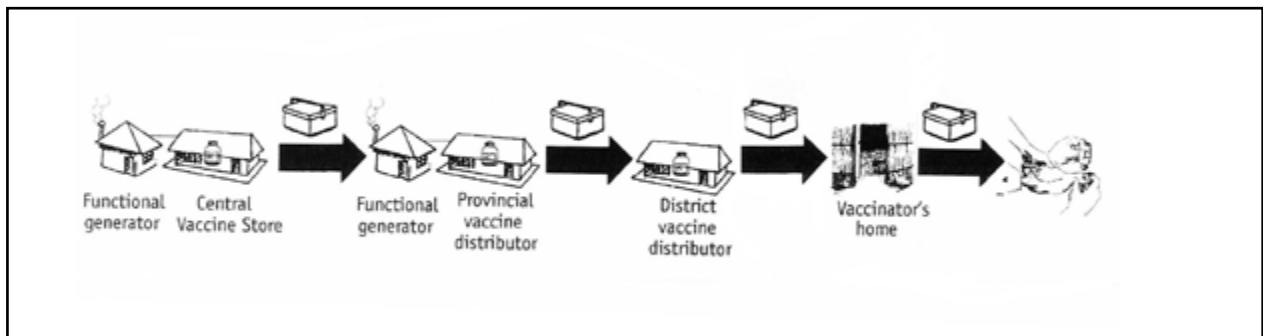


Figure 2 The cold chain

2.2 Components of the cold chain

Each link of the cold chain shown in Figure 2 comprises three key components:

- Equipment: to store and transport vaccine;
- Personnel: to manage vaccine storage and distribution; and
- Procedures: to ensure that vaccines are stored and transported at appropriate temperatures.

These three components must be present at all points of the cold chain to ensure that the vaccine is stored, packed for distribution and transported appropriately, and that any breakdowns in equipment or procedures are identified and rectified.

2.3 Cold chain failure

It is important to understand that a failure or break in one link of the cold chain will affect the potency of the product. Good handling after that failure or break will not restore the potency of the product. In addition, repeated cold chain failure will have an additive (negative) effect on the potency of the product.

It is tempting to focus on the final leg of the cold chain – the critical period of time between delivery to the veterinary pharmacy or extension office and administration to the animal.

It is during this time that temperature-sensitive vaccines are most vulnerable to cold chain breaks; however, the reality is that cold chain breaks can and do happen at any time and are surprisingly common in both human and animal health services.

A break in the cold chain is indicated if the temperature in the refrigerator rises above +8 °C or falls below +2 °C. This is called a cold chain breach.

(Short periods at up to +12 °C, lasting no longer than 15 minutes when stocktaking or restocking a refrigerator, are not considered a breach in the cold chain.)

Key points

- The cold chain is a system of storing and transporting the vaccines at recommended temperatures from the point of manufacture to the point of use.
- It is crucial to maintain an efficient cold chain from the point of manufacture to the use of the vaccines in the field.
- The physical appearance of the vaccines may remain unchanged even after they are damaged. The loss of potency due to either exposure to heat or cold is permanent and cannot be regained.

3. Cold chain equipment

This section describes the equipment that is commonly used to store vaccines. This includes refrigerators, and vaccine carriers, cold boxes or cooler boxes and icepacks used in the temporary storage or transport of the products.

Cold rooms are used to store vaccines in many national and provincial government livestock offices but are not discussed in detail in this manual. General advice and guidance on using a cold room for safe vaccine storage can be found in the User’s handbook for vaccine cold rooms and freezer rooms (WHO 2002).

Ideally, refrigerated vehicles should be used to transport vaccine from the manufacturer or importer to distributors, but vehicles are also beyond the scope of this manual. Important features of such vehicles are discussed in Section E002.5 ‘Buyers’ guide to refrigerated vehicles’ of the PQS Devices Catalogue (WHO 2013a).

3.1 Refrigerators

Safe vaccine storage depends on continuous refrigeration, and this requires a reliable source of power. Refrigerators can operate on mains electricity, electricity produced by a generator, renewable energy (e.g. solar electricity), bottled gas or kerosene. Where mains electricity is absent, or is available for less than eight hours per day, solar, gas and kerosene are currently the only alternatives. The flowchart shown in Annex 3 gives guidance on choosing a refrigerator for vaccine storage and selecting a suitable energy source. This manual will concentrate on electrical refrigerators.

Both front-opening (upright) and top-opening (chest-type) refrigerators are available.

Table 1 Comparison of front- and top-opening refrigerators

	Front opening	Top opening
Temperature stability	Unstable temperature. When the refrigerator door is opened, cold air flows down and out of the refrigerator.	More stable temperature. When the refrigerator lid is opened, less cold air escapes from the refrigerator.
Holdover time	Temperature goes up relatively faster during power outages.	Temperature stays stable for a longer time during power outages.
Vaccine placement	Vaccine placement is easier, as vaccine can be clearly seen from the front.	Vaccine placement is more difficult, as vaccines are stacked.

All refrigerators used to store vaccines should be reliable, regularly maintained and serviced, and monitored each day. They should be clearly labelled [‘Vaccines Only’] and should not be used to store items other than vaccines.

3.1.1 Vaccine refrigerators

The best refrigerator for storing vaccines is a purpose-built vaccine refrigerator. These are designed and built for vaccine storage and have the following features:

- Stable, uniform and controlled cabinet temperature, unaffected by ambient temperature.
- Good temperature recovery after the lid or door is closed.
- Nearly all of the internal space can be used for storing vaccine.
- Most have standard alarm and safety features alert.

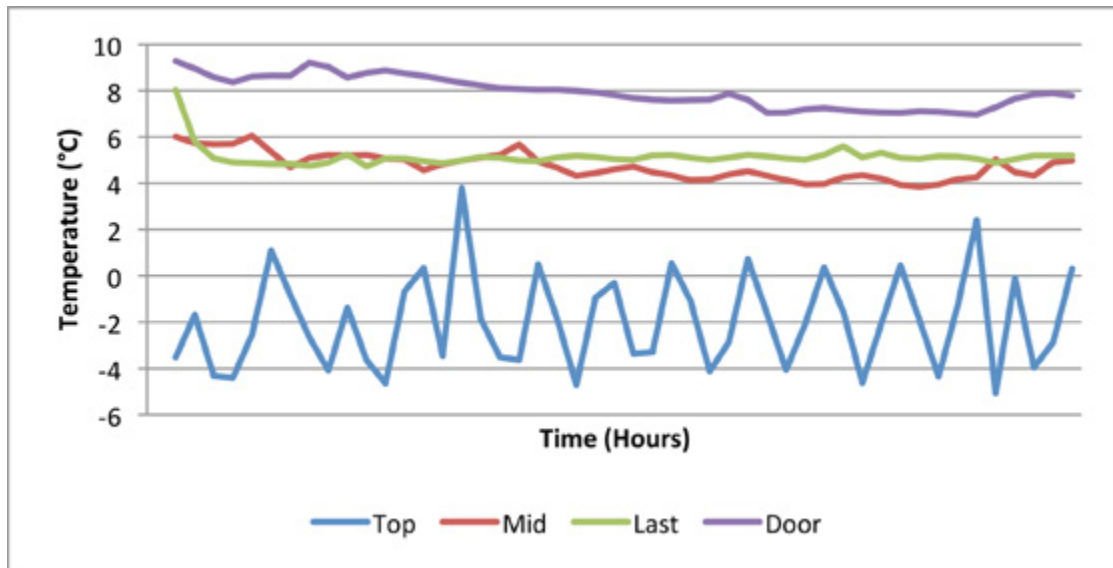
3.1.2 Domestic refrigerators

There are a number of advantages to using domestic refrigerators: they are readily available; no foreign currency is required for the purchase; and spare parts are more likely to be available so repair and maintenance are usually easier.

Unfortunately, there are also many disadvantages: domestic refrigerators are usually poorly insulated and are not designed to maintain the temperatures recommended for vaccine storage; the cabinet of the refrigerator has a number of zones, each with a different temperature to meet the varying storage requirements of different foods; and temperatures often fall below freezing in areas close to the freezing compartment.

Case Study 1

Refrigerator temperature zones



A data logger was programmed to read at 30-minute intervals and placed on the top shelf (near the freezer), the middle shelf, the lowest shelf, and on a shelf in the door of a two-door, frost-free, 446-litre domestic refrigerator. The data logger was left for 24 hours in each position.

The graph clearly shows that only the middle and last shelves of this refrigerator are suitable for vaccine storage. The temperatures recorded on the top shelf and door shelves are outside the safe temperature range for vaccine storage.

Although domestic refrigerators can maintain a cabinet temperature of +2 °C to +8 °C during normal operation, the temperature increases when the electricity fails and may exceed +10 °C in only 4 hours. This is the holdover time of the refrigerator. Domestic refrigerators also have a limited capacity to store vaccines and freeze icepacks. These refrigerators are not generally recommended for vaccine storage.

Holdover time is the time in hours during which all points in the vaccine compartment of a vaccine refrigerator remain below +10 °C after the power supply has been disconnected.

Other disadvantages of using a domestic refrigerator are:

- Thermostats are generally slow to react and have a wide temperature tolerance.
- It is difficult to accurately set the temperature.
- No air is circulated in the refrigerator when the compressor is off.
- The defrost function can cause temperature fluctuations.

There are several types of domestic refrigerators on the market. A domestic refrigerator and freezer combination unit is acceptable, but the refrigerator and freezer compartments must have separate external doors. Such a refrigerator requires modification to store vaccines (see section 4.2).

Domestic frost-free refrigerators

‘Frost-free’ refers to the freezer compartment of the refrigerator, where food is supposed to stay relatively free from frost.³ When the compressor is on, a fan blows the cool air from the freezer to the refrigerator. Therefore, the air being circulated to the refrigerator may be below 0 °C and may damage vaccines placed near the vents. Figure 3 shows two types of domestic frost-free refrigerators.

Multi-air-flow refrigerators have several cold-air outlets on the back wall. These are frost-free and are designed to ensure even temperatures throughout the refrigerator cabinet; however, the refrigerator compartment is cooled with sub-zero air ducted down from the freezer compartment, and if vaccine is placed in this airstream it may freeze.

Manual- and cyclic-defrost refrigerators

In cyclic-defrost refrigerators similar to the one in Figure 4, the ‘cooling plate’ (or evaporator) is most commonly found as an exposed vertical plate at the back of the refrigerator. While the compressor is running, the area near the evaporator can be very cold, whereas other areas are much warmer. Manual- and cyclic-defrost refrigerators are not recommended for vaccine storage because of the significant temperature variations and the risk of vaccines freezing. Domestic refrigerators that require defrosting are not recommended.

³ A coating of small ice crystals.

EFFECTIVE COLD CHAIN

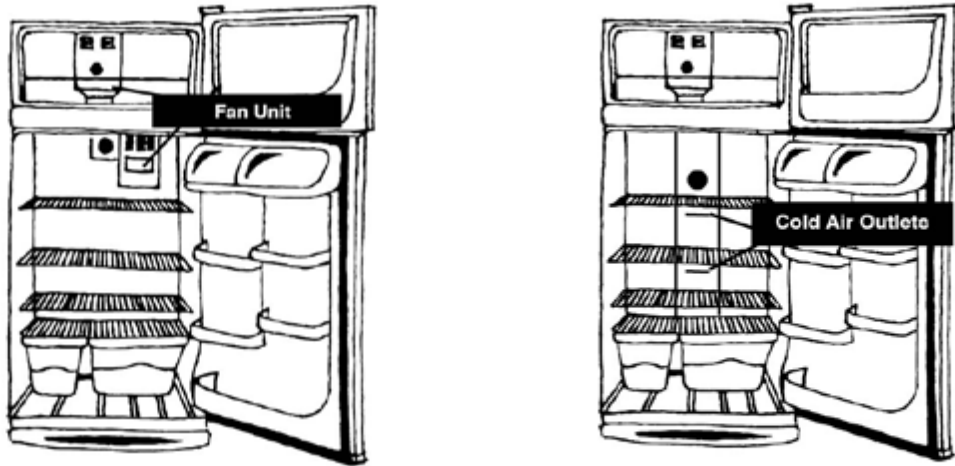


Figure 3 Domestic frost-free refrigerators

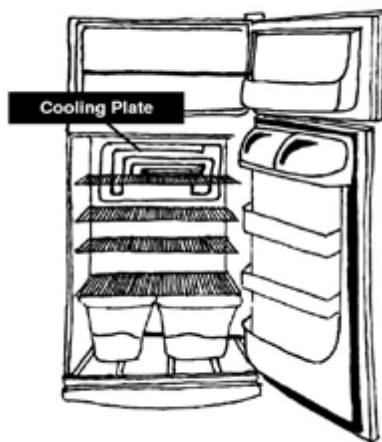


Figure 4 Manual- or cyclic-defrost refrigerator

Dormitory-style (bar-style) refrigerators

These are small combination refrigerator and freezer units with one external door and an evaporator plate usually located in an ice-maker compartment within the refrigerator. The temperature inside the refrigerator is generally unstable, susceptible to ambient temperatures, and there is a risk of freezing vaccines. These refrigerators should not be used for vaccine storage.

Multi-mode refrigerators

Multi-mode domestic refrigerators are available in a number of countries. These are chest freezers with a variable thermostat, allowing the unit to be used as a refrigerator (minimum temperature 0 °C), chiller (−2 °C to +2 °C) or freezer (−2 °C to −18 °C). Before these are used to store vaccines, the staff should ‘get to know’ the refrigerator by recording temperatures in its different parts, particularly near the walls and on the floor. The holdover time of the refrigerator should also be determined. Vaccines should be packed in baskets suspended in the refrigerator.

Drinks refrigerators (with see-through glass doors)

These refrigerators are designed to operate at 0 °C to +5 °C according to food and beverage health standards and are not recommended for vaccine storage. It may be possible to use a drinks refrigerator if the staff ‘get to know’ the refrigerator by recording temperatures in its different parts. Contact the manufacturer to see if the temperature can be adjusted so that the temperature is maintained within the recommended range for vaccine (between +2 °C and +8 °C).

‘Know’ your refrigerator

If it is not possible to purchase a purpose-built vaccine refrigerator, a frost-free domestic refrigerator can be modified to suit vaccine (see section 4.2). In this case it is important to know:

- the various temperature zones within the refrigerator (vaccines can only be stored in certain areas);
- the location of the air vents (vaccines should be kept away from the air vents to avoid potential freezing); and
- how changes in ambient temperature affect internal temperature.

The compartments and shelves in the door of your refrigerator are unsuitable for vaccines. Do not store vaccines in these parts of a refrigerator.

Careful monitoring and knowledge of the refrigerator is essential to minimise risk to the vaccines, so it is important that you ‘know your vaccine refrigerator’ by monitoring and recording temperatures throughout (also called ‘mapping’; see Annex 4) and pack the refrigerator accordingly.

3.2 Voltage stabilisers

Another important element of the cold chain is the voltage stabiliser. Electrical cold chain refrigerators must always be installed and operated with voltage stabilisers. The function of a voltage stabiliser is to monitor fluctuations in the mains voltage and maintain voltage in the required range.

Stabilisers should be installed according to the input voltage available. More information on voltage stabilisers is given in Annex 5.

3.3 Portable insulated containers (cold boxes, vaccine carriers and coolers)

A variety of portable insulated containers are used for short-term storage and transport of vaccines. Vaccine carriers and cold boxes are specifically designed for transporting vaccines. They are insulated containers with tightly fitting lids that, when lined with frozen icepacks, keep vaccines and diluents cold during transportation and/or temporary storage. The cold life of some models is up to 48 hours with the lid closed. Section 004 'Insulated containers' of the PQS Devices Catalogue (WHO 2013a) provides guidance on selecting a cold box or vaccine carrier and gives data sheets for WHO-recommended models.

Cold life is the time that a specialised vaccine carrier, cold box or cooler packed with the appropriate number of conditioned, frozen water-packs will keep vaccines within the recommended temperature range. Cold life is measured from the moment when 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. ⁴

Domestic-style coolers have a limited cold life. They are normally not adequate for the transport of vaccines longer than 3 to 4 hours; however, if they have been tested and shown to be adequate for the relevant environmental conditions and period of use, they may be used (see section 3.4). Cold boxes are frequently known by brand names (such as Esky™, WAECO, CADAC and Coleman™). These are of different volumes (e.g. 5, 8, 20 and 22 litres) and are used with the appropriate number of icepacks. They stay cold for only a short time.

⁴This allows for transport of vaccine in hot environments and in vehicles (WHO 2013a).



Figure 5 Vaccine carriers, cold boxes and coolers

Cold boxes and coolers are also used to store vaccines when the refrigerator is out of order or is being defrosted.

3.4 Icepacks

Icepacks are key components of the cold chain. They are flat, square, plastic bottles that are seven-eighths filled with water and frozen. Icepacks are used to keep vaccines cool inside the vaccine carrier, cooler or cold box. The number of icepacks required to keep a cold box, cooler or vaccine carrier within the safe temperature range varies according to the type of box or cooler (particularly the insulation), the size (volume) of the box, and the amount of vaccine in it.

How to calculate the number of icepacks you will need for your cold box

- Pack the cold box with a ‘mock vaccine load’ to simulate vaccine stock and place a minimum-maximum thermometer or temperature data logger in the centre.
- In the laboratory simulate the journey made by the cold box (in terms of temperature and time).
- Monitor (and record) the temperature for the duration of the simulated journey and vary the number of icepacks until you find the right number for your cold box. The number may change with seasonal temperature variations, so you will need to repeat the experiment during the hottest and coldest times of the year.

Normally, the volume of vaccine transported or stored in a cold box should not exceed one-third of the container’s capacity.

To prepare icepacks for freezing

- Icepacks should be filled up to the maximum level (marked on the top of the icepack).
- The lid or stopper should be tight so that there is no leakage. If there is any leakage, the icepack should be discarded.
- Clean the outer surface of icepacks with a dry cloth before putting them into the deep freezer (temperature range of -15°C to -25°C). Stack icepacks in the freezer on their edges, ensuring that they are 1 to 2 mm apart to allow for air circulation.

Always keep a spare set of icepacks in the freezer.

Remember:

- Check icepacks for leakage before putting them in the freezer. Do not use icepacks that are cracked and are without caps.
- Icepacks need not be refilled every time they are used. The same water can be used repeatedly.

Icepacks should be ‘conditioned’ before using them in a vaccine carrier. Section 4.6 describes the procedure for conditioning icepacks.

For a thermotolerant vaccine such as I-2 ND vaccine, it has been demonstrated that it is possible to use the principles of evaporative cooling to keep vaccine cool for certain periods in the field, predetermined by the manufacturer for key temperature ranges, e.g. between +10 °C and +30 °C and over +30 °C. The vaccine is wrapped in a damp cotton cloth and placed in an open-weave basket to allow free flow of air over the vaccine. It may also be placed in a cool, shady area beside a clay water pot in the vaccinator’s home.



Figure 6 I-2 ND vaccine wrapped in a damp cotton cloth and placed in an open-weave basket to keep it cool in the field.

Case Study 2

Testing options for transport of vaccine by community vaccinators

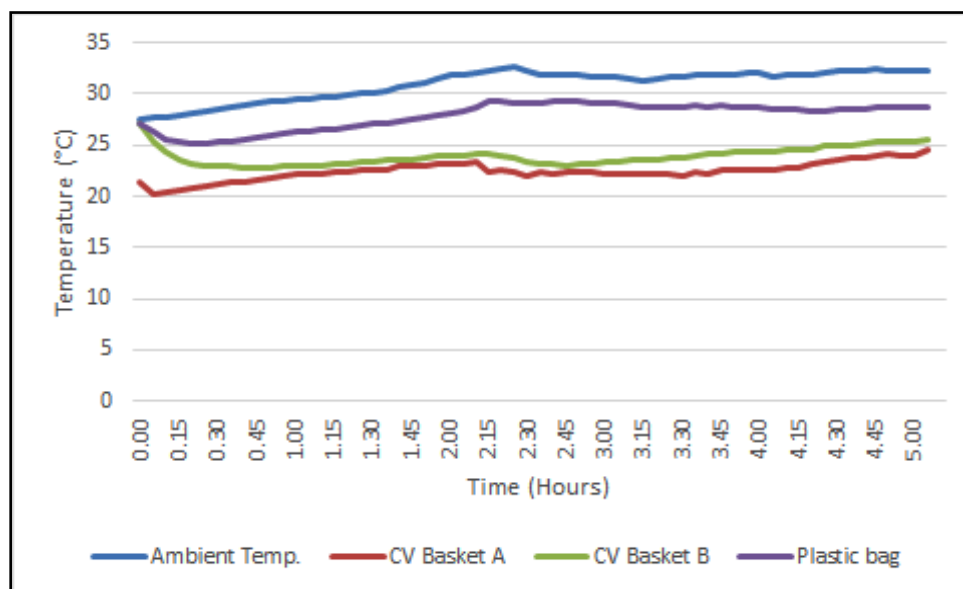
Where coolers and icepacks are not available, it is recommended that community vaccinators use locally made baskets and a wet cotton cloth to store and transport vaccines. In Malawi, data loggers were used to confirm this recommendation.

The ambient temperature and the temperature of a vaccine dropper wrapped in a wet cotton cloth in the locally made open-weave baskets or a black plastic bag were recorded every five minutes. The baskets and bag were placed side by side in a shady place for five hours.

During the test:

- the ambient temperature varied from +27.5 °C to +32.8 °C (average +31 °C);
- the temperature in the baskets varied from +20.3 °C to +24.6 °C (Basket A, average +22.5 °C) and +22.8 °C to +27.0 °C (Basket B, average +23.9 °C); and
- the temperature in the plastic bag varied from +25.1 °C to +29.4 °C (+27.8 °C).

The results clearly demonstrate that covered open-weave baskets with the vaccine wrapped in a damp cloth inside provided the coolest environment.



Key points

- The best refrigerator for vaccine storage is a purpose-built vaccine refrigerator.
- Frost-free domestic refrigerators can be ‘modified’ for safe vaccine storage.
- Manual- or cyclic-defrost refrigerators, bar refrigerators and drinks refrigerators are not recommended for vaccine storage.
- Before using a domestic refrigerator for vaccine storage, map the temperature zones.
- Protect your refrigerator by connecting it to a voltage stabiliser.
- It is important to know the limitations and capacity of your vaccine carriers, cold boxes and coolers.
- Remember that the number of icepacks required to keep a cold box, cooler or vaccine carrier within the safe temperature range varies according to the type of box or cooler (particularly the type and thickness of the insulation), the size (volume) of the box, and the amount of vaccine in it. Therefore, always determine the number of icepacks you need for your cooler, vaccine carrier or cold box (see section 3.4).

4. How to use cold chain equipment

It is important that personnel responsible for vaccine storage know how to use cold chain equipment correctly and pack vaccines appropriately to ensure safe storage and transport.

4.1 Where to put your refrigerator

Good air circulation around the vaccine storage unit is essential for proper heat exchange and cooling. Place the refrigerator in a well-ventilated room and make sure there is space around the sides, top and back. Leave at least 10 cm of space (or as recommended by the manufacturer) between the back of the unit and the wall. If the unit has coils on the back, measure 10 cm from the coils to the wall.

Nothing should block the cover of the motor compartment, which is normally located at the back or the side of the unit.

Refrigerators should be located away from outside walls where the temperature of the wall can vary, depending on the season, and out of direct sunlight. Always place the refrigerator away from any heat source.

Make sure that the refrigerator stands firmly and level, and that the wheels or levelling legs are adjusted so that the bottom of the unit is 2.5 to 5 cm above the floor.

4.2 Modifying a domestic refrigerator for vaccine storage

1. Place water bottles or icepacks in the freezer. Icepacks should be kept in the freezer compartment in a vertical position to avoid leaking, and with a space of at least 2 mm between them.
2. Fill the lower drawers and door with bottles or containers filled with water. If there are any unused shelves, place bottles of water on these as well. Allow a small space between the bottles or containers to facilitate the circulation of air.

These measures will increase the 'cold mass' and assist in stabilising the temperature and reducing the warming period when the refrigerator is opened. They will also help if there are power cuts or refrigerator failures (see Case Study 3).

The term 'cold mass' is used to describe the presence in a refrigerator of items (e.g. cooled water bottles) that will help to maintain cold temperatures if, for example, the power fails or the door has been left open.

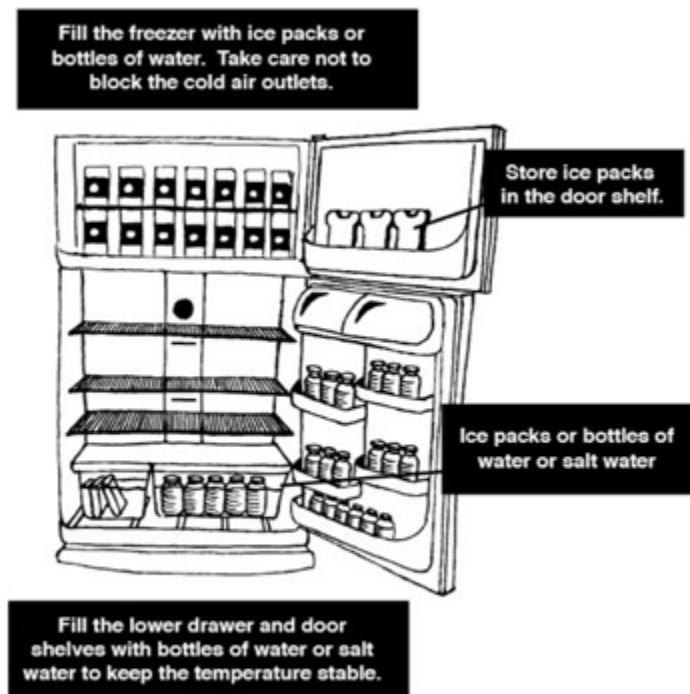


Figure 7 Modification of a domestic refrigerator

4.3 Packing a vaccine refrigerator

Correct packing of the vaccine refrigerator is essential if vaccines are to retain their quality and properties.

In general:

- Place a warning sticker above the refrigerator power source stating 'DO NOT TURN POWER OFF' so that it is not unplugged or turned off accidentally (see Annex 6).
- Place a sticker on the refrigerator door reminding staff to only open the door when necessary.
- If the refrigerator is new or has just been turned on, wait until the temperature is between +2 °C and +8 °C before stocking with vaccine.
- The refrigerator is used exclusively for the storage of vaccines. Do not use the refrigerator to store food or drink.
- Allow good air circulation in the refrigerator. Do not overstock the refrigerator with vaccines.
- Always leave vaccines in their original packaging (box and product information leaflet). Do not remove them from their boxes to fit more in the refrigerator.
- Store the vaccines and other products in shallow plastic baskets or trays clearly labelled with the name(s) of vaccine(s).
- Allow space between the baskets or trays for air circulation.
- If there is a cooling plate in the refrigerator, make sure there is a gap of at least 4 cm between the vaccines and the back of the refrigerator.
- Organise the vaccines so that closer-expiry-date vaccine is in front and further-expiry-date vaccine is at the back.
- If there is a small amount of vaccine in the refrigerator, place cooled bottles of water or icepacks in the refrigerator to help stabilise the temperature.

Additional points to observe if using a modified domestic refrigerator

- ‘Know’ the refrigerator by:
 - recording temperatures throughout the refrigerator (this will help you find the ‘cold spots’); and
 - locating the air vents, which return cold air from the freezer.
- Only use shelves in the refrigerator where the temperature is known to be stable or between +2 °C and +8 °C. Fill the other shelves with cooled water bottles or containers.
- Fill the lower drawers of the refrigerator with plastic bottles or containers filled with water to help stabilise the temperature. Leave a small gap between the bottles or containers to allow air circulation.
- Place plastic bottles or containers filled with water in the door shelves. The temperature in door shelves is too warm to store vaccines, and when the door is opened shelves are instantly exposed to room temperature.
- Place water bottles or icepacks in the freezer compartment.
- Limit the number of times that the refrigerator door is opened, and do not keep it open unnecessarily. Doing so affects the temperature of the refrigerator and also exposes the vaccines to light. Make sure that the door is tightly closed at the end of each working day.
- Place a sticker on or near the thermostat, advising staff that only authorised personnel are permitted to adjust it.

4.4 How to keep cold boxes, vaccine carriers and coolers in good condition

- Clean and dry the cold box, vaccine carrier or cooler after every use.
- Keep the lid opened in the store while the box is not in use. This will increase the life of the rubber seal.
- Examine the inside and outside surfaces for cracks after every use.
- Check that the rubber seal around the lid is not broken; if broken, replace it immediately.
- Handle the cold box, vaccine carrier or cooler carefully. Do not drop or sit on it. Knocks and sunlight can cause cracks inside the wall and lid.
- Keep the vaccine carrier, cold box or cooler in the shade. Do not leave it in sunlight.
- Adjust the tension on the latches of the vaccine carrier or cold box (if fitted) so that the lid closes tightly.
- Regularly lubricate hinges and locks of the vaccine carrier or cold box (if fitted).

Case Study 3

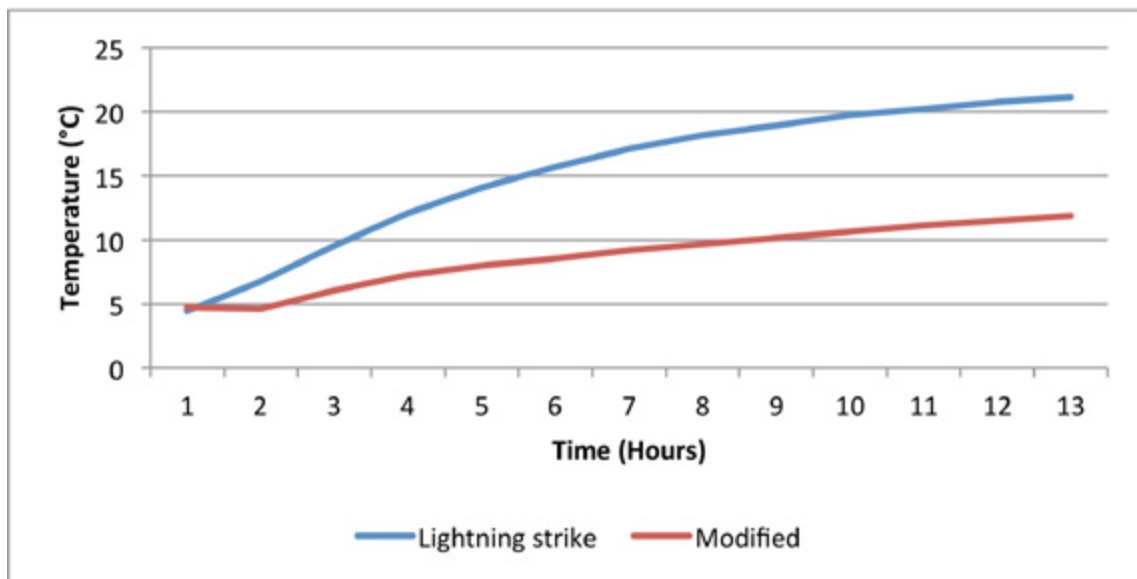
Protecting refrigerated vaccines with water bottles

A domestic refrigerator was used to store vaccines at a family medicine clinic. In accordance with standard practice, a data logger was placed in the refrigerator and recorded the temperature every hour.

Over a period of 7 months, two incidents occurred that demonstrate the effects of modifying the refrigerator for vaccine storage. The upper line in the graph below shows the temperatures recorded in the refrigerator after it was damaged by a lightning strike, resulting in the loss of vaccines worth US\$5,000. After this incident, staff at the clinic modified the refrigerator by increasing the 'cold mass', i.e. by placing water bottles on the refrigerator shelves.

A few months later, the refrigerator was unplugged by mistake and was disconnected from the mains electricity for 22 hours. The lower line in the graph ('Modified') shows the temperatures recorded in the refrigerator during the first 13 hours of the disconnection.

The temperature outside the refrigerator (ambient temperature) was approximately +23 °C at the time of both incidents.



The temperature within the modified refrigerator stayed below +10 °C for 4.5 hours longer than the unmodified refrigerator. Staff at the clinic documented the temperature excursions, performed a vaccine inventory, and communicated with the vaccine manufacturer and local health department, in accordance with the clinic's Standard Operating Procedures. As a result, the majority of vaccines were found to be safe to use.

Muegge, S. (2012). Protecting refrigerated vaccines with water bottles: an evidence-based strategy. *American Journal of Nursing* 112: 61–69.

4.5 Packing a portable cold box or cooler

The following equipment is required to pack a portable cold box or cooler:

- Cold box or cooler of an appropriate size. The minimum size of a cooler or cold box for storing vaccines is 10 litres.
- Icepacks.

Before you begin, ensure that you know how many icepacks are needed to maintain stable vaccine temperature. The number of icepacks will depend on the cold box volume and the amount of vaccine in the cooler (see section 3.4).

1. Confirm that there are no cracks in the walls of the cold box.
2. Chill the inside of the cold box or cooler prior to use by placing icepacks in it for a few hours.
3. Place the vaccine in the box.
4. Fill the empty space around the vaccine with polystyrene chips or pellets, and/or shredded paper. This prevents shifting of vaccines and cold packs during shipment and allows cold air to circulate, but does not provide reliable insulation. Fillers must also be used to separate frozen (unconditioned) cold packs from the vaccines to prevent freezing.
5. If using a small cold box or cooler, place the conditioned icepacks (see section 4.6) on top, close and seal the lid.
6. If using a large, portable cold box or cooler, place conditioned icepacks around the sides of the cold box as well as on top.
7. Ensure vaccine is not in direct contact with the icepacks to minimise risk of freezing.
8. Secure the lid tightly.

When vaccines are stored in a cold box or cooler, replace the icepacks every 24 hours or as needed.

4.6 Conditioning icepacks

Vaccines that are sensitive to freezing should not be placed in contact with icepacks taken directly from the freezer. Icepacks come out of the freezer at a temperature of about -20°C (WHO 2013c).

The icepacks should be ‘conditioned’, i.e. left at room temperature to allow the ice at the core of the pack to rise to about 0°C . This is also known as ‘sweating’ because of the beads or droplets of water that form on the surface of the icepack. When the ice is melting, the temperature in the icepack is not increasing but remains at 0°C until all the ice has melted.

1. Follow this procedure for conditioning icepacks:
2. Remove icepacks from the freezer.
3. Lay the icepacks out in a single row on their sides (where possible).
4. Leave a 5 cm space around each icepack to allow maximum air exposure, thereby reducing conditioning time.
5. Shake one of the icepacks. As soon as you can hear the water moving about inside, the icepack is conditioned.

Conditioning time depends on the ambient temperature and the size and/or weight of the icepack.

Remember: Unconditioned icepacks may damage freeze-sensitive vaccines.

If it is not possible to condition the icepacks prior to packing a portable cooler, wrap the icepacks to protect the vaccine, and monitor the portable cooler closely.

Key points

- If you are using a domestic refrigerator to store vaccines, remember to ‘modify’ it by following the instructions given in section 4.2.
- Always locate the refrigerator in a position that allows good air circulation.
- Place vaccines in areas of the refrigerator that have been demonstrated to maintain temperatures between $+2^{\circ}\text{C}$ and $+8^{\circ}\text{C}$.
- Pack vaccine in a vaccine carrier, cold box or cooler using the ratio of icepacks to vaccine vials that has been demonstrated to maintain the internal temperature at $+2^{\circ}\text{C}$ to $+8^{\circ}\text{C}$ for an appropriate time.
- Protect your refrigerator by connecting it to a voltage stabiliser.
- Remember to condition icepacks to avoid damage to freeze-sensitive vaccines.

Wrapping styles put to the test – which one is best?

Experiments were conducted to determine whether wrapping water-filled icepacks protected vaccines from temperatures below 0 °C and prolonged the duration that the temperature of vaccines remained below +8 °C and +10 °C. Wrapping materials tested were those commonly available in the working environment of sub-Saharan Africa: newspaper, bubble wrap, and dry and wet cotton cloth.

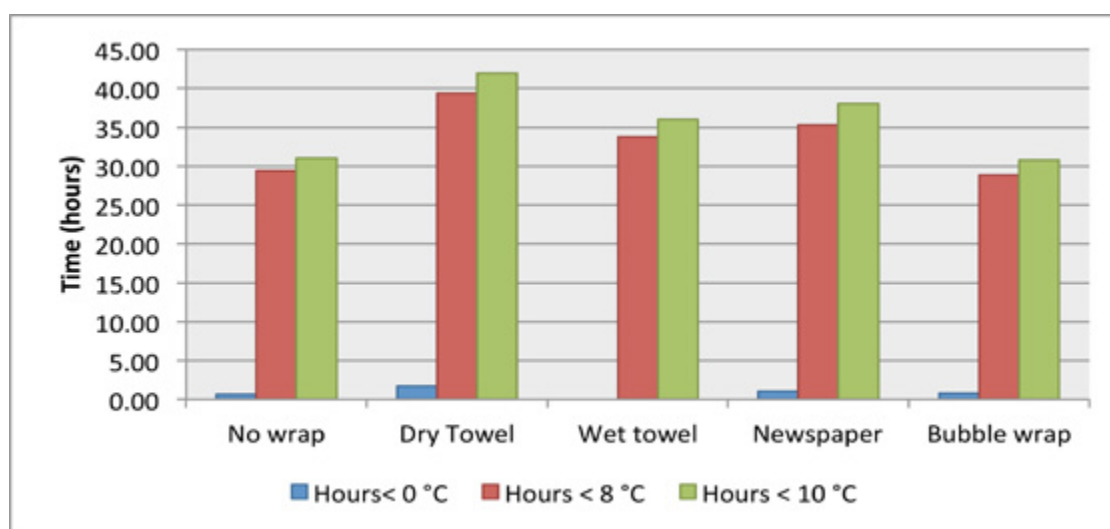
Jars were filled with tap water to simulate vaccine and placed in polyfoam coolers: one jar in each cooler. Three frozen icepacks were placed around the ‘vaccine’ in each cooler.

Data loggers were programmed to record the temperatures of the ‘vaccine’ in the cooler and the environment once every minute. The average environmental temperature during the experiments was +16 °C to +23 °C.

Only wrapping the icepacks in wet tea towel protected ‘vaccine’ from temperatures below 0 °C. For the other wrapping materials, the average duration that the ‘vaccine’ was exposed to temperatures below 0 °C varied from 27 minutes (no wrap) to 104 minutes (dry tea towel).

Wrapping type	No wrap	Newspaper (8 layers)	Bubble wrap (1 layer)	Dry cotton tea towel (2 layers)	Wet cotton tea towel (2 layers)
Average (range) minimum probe temperature, °C	-1.0 (+0.6 to +2.5)	-1.2 (-2.7 to +0.5)	-1.0 (-2.2 to +0.3)	-1.9 (-3.9 to +0.5)	+1.0 (+0.6 to +1.4)
Average (range) duration, water temperature <0 °C, minutes	42.3 (0 to 88)	66.5 (0 to 114)	50 (23 to 84)	104.2 (50 to 148)	0 (0 to 0)

The average duration that the temperature of the ‘vaccine’ remained below 0 °C, +8 °C and +10 °C for each of the wrapping materials is shown below.



The results show that the best wrapping to protect vaccine from temperatures below 0 °C and prolong the duration that the temperature of vaccine remains below +8 °C to +10 °C is wet cotton tea towel.

5. Cold chain monitoring

The purpose of cold chain monitoring equipment is to keep track of the temperature to which vaccines and diluents are exposed during transportation and storage.

5.1 Introduction

There are several different devices available to help you monitor the temperature in your refrigerator (or cold room). Some of these instruments show only one temperature, while others show the maximum temperature and the minimum temperature of the equipment during the period of measurement. Whichever instrument you have, remember that is an essential tool to help you effectively monitor and maintain the cold chain.

5.2 Equipment

Section E006 ‘Temperature Monitoring Devices’ of the PQS Devices Catalogue (WHO 2013a) provides information on thermometers, freeze indicators, temperature recorders, data loggers and event loggers recommended for monitoring temperatures at all levels of the cold chain. Some of these are listed below.

Built-in temperature chart recording system

Most cold rooms will have a built-in temperature probe and a dial so that you can read the temperature. Some may even have a chart recording system.

Dial thermometers

Dial thermometers have a dial with a moving needle to show the temperature of vaccine. Thermometers used for cold chain monitoring usually measure temperatures in the range of -30°C to $+50^{\circ}\text{C}$.

Alcohol stem thermometers

Alcohol stem thermometers are much more sensitive and accurate than dial thermometers. Thermometers used for monitoring refrigerators and freezers usually measure temperatures from -30°C to $+50^{\circ}\text{C}$. Alcohol stem thermometers should not be taken out of the refrigerator while reading the thermometer.

Maximum-minimum thermometers

Maximum-minimum thermometers are an essential requirement for monitoring the temperature of the cold chain. Battery-powered electronic digital thermometers are easy to use, display the current maximum and minimum temperatures, and can be reset after reading.

Single-use electronic temperature monitors

These are irreversible electronic temperature indicators that show whether a product has been exposed to temperatures beyond assigned settings. Q-Tag 2 or Freeze-tag® are two examples.

Electronic data logger

The electronic data logger is an electronic device placed with the vaccine, which records the vaccine temperature. It can be programmed to read temperature at intervals that you set and to store the data so that you can download it later.



Figure 8 Some cold chain monitors

5.3 Measuring and recording temperatures

Monitoring the temperature of the vaccine refrigerator is an essential element of good vaccine management and will help to ensure that vaccines remain safe and effective. When minimum and maximum temperatures are monitored and recorded each day, any cold chain problems are identified and addressed before vaccine (which may be damaged) is used.

Each refrigerator used for vaccine storage should have its own thermometer and temperature record book, chart or log. The thermometer or thermometer probe should be placed in contact with the vaccine.

Temperatures can vary in the refrigerator depending on the load, seasonal temperature variation, how often the door is opened and power interruptions. The only way to be sure the temperature in the refrigerator has remained within the recommended range is to frequently monitor and record the temperature using a minimum-maximum thermometer or data logger. It is strongly recommended that you check the temperature at the beginning and the end of each day. This will give a better indication of any problems in the refrigerator's function and temperature fluctuations over the course of the day. It is also good practice to read (and pay attention to) the temperature every time the refrigerator is opened.

In addition to daily monitoring and recording of the temperature of the refrigerator, you can help ensure safe and effective vaccines by:

1. Checking the minimum and maximum temperatures:
 - whenever you receive new stock of vaccine;
 - Friday afternoon and Monday morning, if the office closes over the weekend; and
 - every time you open the refrigerator.
2. Recording comments and any action taken in the temperature chart or log every time the minimum and maximum temperature exceeds the recommended range of +2 °C to +8 °C, e.g. if restocking or defrosting the refrigerator.
3. Remembering to record the temperatures before you reset the thermometer.

A break in the cold chain is indicated if the temperature in the refrigerator rises above +8 °C or falls below +2 °C. This is called a cold chain breach.

5.4 Monitoring the vaccine refrigerator

Follow this procedure for checking and recording the temperature of the vaccine refrigerator using a maximum-minimum thermometer:

At the beginning of the day (at the start of business):

1. Check the vaccine refrigerator thermometer.
2. Record the date, time, minimum and maximum temperature and your initials on the temperature chart or log. (Every vaccine refrigerator needs to have its own temperature chart or logbook.)
3. Reset the thermometer to clear the temperature memory. (Note: Resetting depends on the type of monitoring equipment.)

At the end of the day (at close of business):

1. Check the vaccine refrigerator thermometer.
2. Record the date, time, minimum and maximum temperature and your initials on the temperature chart or log. (Every vaccine refrigerator needs to have its own temperature chart or logbook.)
3. Reset the thermometer to clear the temperature memory. (Note: Resetting depends on the type of monitoring equipment.)

It is important to know what to do if the thermometer shows that the refrigerator temperatures have been outside the recommended range of +2 °C to +8 °C.

If a cold chain breach is identified, isolate the vaccines, notify other staff not to use them until further notice, and seek further advice.

5.5 Monitoring a cold box or cooler used for temporary storage of vaccine

Freezing happens very easily in cold boxes or coolers, usually in the first two hours after packing. Therefore, select a cold box or cooler that is large enough to store the vaccine and sufficient insulating material to ensure that the vaccine is protected.

Experiment with the cold box or cooler to confirm how many icepacks are required to maintain a stable temperature of a specified quantity of vaccine. Always monitor the temperature.

Always check the temperature:

- after packing;
- every 15 minutes for the first 2 hours, and then every hour after this;
- regularly, but at least hourly;
- before administering vaccine; and
- before returning vaccine to the vaccine refrigerator.

Use a minimum-maximum thermometer to monitor the temperature inside the cold box or cooler. Place the probe inside an empty vaccine box with the product information leaflet.

5.6 Using a data logger

It is important to measure and record both the maximum and minimum temperatures of the refrigerator at least twice each day; however, this does not give any information on the duration of the temperature changes. This is where a data logger is useful. If it is used in conjunction with a diary or log, then it is possible to measure and ‘see’ the effect that events such as those listed below have on the temperature:

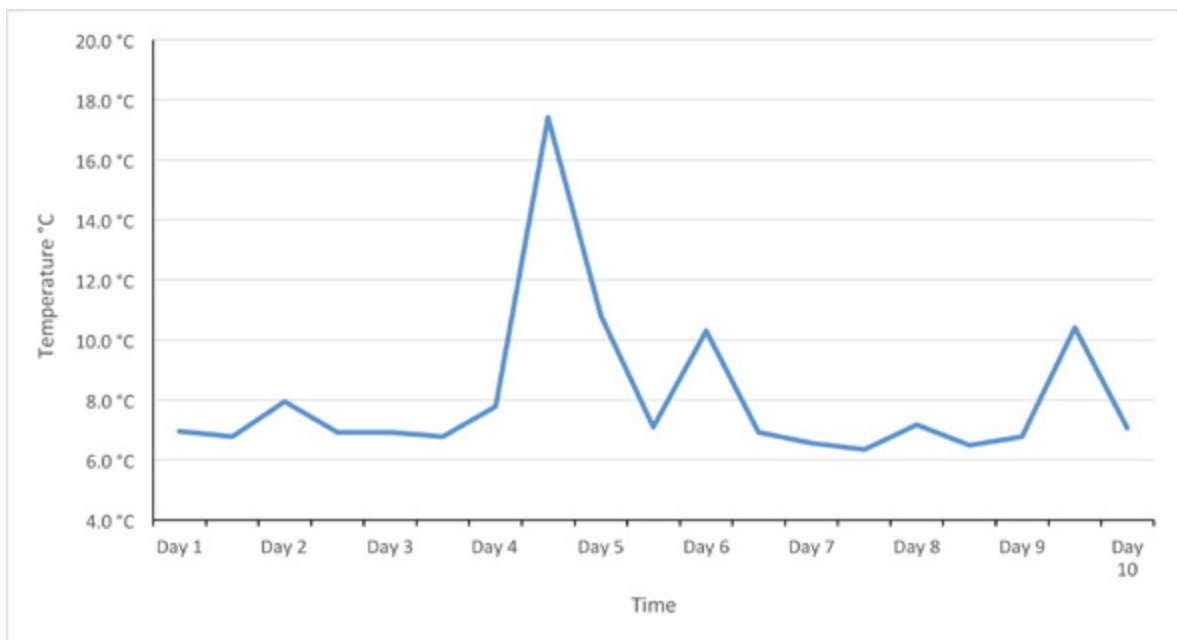
- What happens when the door of the refrigerator is opened? How long does it take for the temperature to return to normal?
- What happens if there is an electrical failure? How long does the temperature of the refrigerator stay within the safe range for vaccines (the holdover time)?
- What effect does the density of packing have on the temperature?
- What effect does increasing the cold mass have on the temperature of the storage refrigerator?

Case Study 4

Refrigerator monitoring

As part of a cold chain mapping study, a data logger, programmed to record temperatures at hourly intervals, was placed in close contact with vaccine stored in a standard household refrigerator in the office of an NGO. The data logger was removed for data retrieval after one month. Significant temperature spikes (temperatures greater than +10 °C) had occurred on three occasions. In addition, there were several smaller spikes during the recording period.

Part of the graph of the data is shown below.



Investigations revealed that staff were in the habit of turning the refrigerator off during power failures, which were relatively frequent. The usual duration of power loss was about 4 to 6 hours. On one occasion, however, it was found that the refrigerator had inadvertently been left off overnight.

Samples of vaccine were returned to the manufacturer for potency testing. Unfortunately, the vaccine titre was below the recommended minimum and had to be discarded, resulting in a significant financial loss to the NGO.

EFFECTIVE COLD CHAIN

A data logger will also help you to map the temperature zones in the refrigerator. It will also be invaluable as you experiment with packing the vaccine cold box or cooler: how many icepacks do you need to use for transporting vaccine?

The data logger can also be used to map the cold chain, giving you information on the temperatures to which the vaccines are subjected during the journey from the manufacturer to field administration (see section 8.2). The logging interval should be selected carefully. If you expect that the temperature will change rapidly, then the logging interval needs to be short, measured in minutes rather than hours.

It is important to remember that the battery in the data logger needs to be replaced. If the battery is not replaced at the interval recommended by the manufacturer, it will be unreliable.

Key points

Maintaining the cold chain demands constant vigilance.

- It is crucial that you and your staff understand and acknowledge that ongoing temperature monitoring is needed and why it is important.
- Use an appropriate monitoring device(s) – it should accurately record the minimum and maximum temperature.
- Make sure that you and your staff know how to read the monitoring device(s), including accessing the minimum and maximum temperatures.
- Make sure that the monitoring device(s) is correctly placed in the vaccine refrigerator.
- Make sure that you and your staff know how to interpret the temperature recordings, and can recognise:
 - exceptions (e.g. when the refrigerator is being restocked, the air temperature is higher than the vaccine temperature); and
 - breaches (e.g. when the temperature has been outside the acceptable range for an extended period).
- Make sure that you maintain your monitoring equipment correctly.
- Always reset the temperature monitoring device each time temperature is read and recorded (if required).

Case Study 5

Use precautions with all vaccine storage methods

In 2009–2010, extension educators in the United States conducted a study to identify vaccine refrigerator temperatures and animal health product handling practices of farmers and retailers; 127 livestock farmers and 43 retail outlets participated in the study.

Only one-third of farmers' refrigerators tested were operating within the appropriate temperature range. Almost one-third of those tested were operating within the recommended temperature range less than 5% of the time. Only one-third of the retailers' refrigerators tested were found to operate within the acceptable temperature range.

Forty-one per cent of the retailers surveyed reported that they did not do anything to monitor temperatures. Some of those who claimed to monitor temperatures did so by noticing that it was 'cool' when they removed some vaccine. "When we walk in the cooler to fill an order, if it is cold we know it is working."

Temperature monitoring was done in 16 farmers' coolers during vaccination cow-side. Only 6% of coolers held the vaccine between +1.5 °C and +7 °C. This is a concern not only for vaccine being used, but for any unused bottles that go back into the refrigerator.

These results suggest that many farmers are potentially compromising the effectiveness of the vaccines they store and use. Information gained from this study has led to the formulation of best management practices for vaccine handling by farmers.

Scott Jensen and Shannon Williams (2011).

http://www.progressivecattle.com/index.php?option=com_content&view=article&id=3637:use-precautions-with-all-vaccine-storage&catid=120:herd-health&Itemid=159

6. Cold chain maintenance

6.1 Introduction

Eventually, equipment will fail due to power cuts, breakdown, or normal wear and tear. Staff responsible for vaccine management must anticipate such failures and have backup plans and equipment ready. To ensure that vaccines and other products remain safe and effective, regular maintenance of your cold chain equipment (refrigerators, vaccine carriers, etc.) is essential. You should also install a voltage regulator to protect your refrigerator from voltage fluctuations (see Annex 5).

6.2 Maintaining the vaccine refrigerator

For vaccine refrigerators, this involves having a maintenance program in place, positioning the refrigerator in a suitable location and defrosting a domestic refrigerator (if not frost-free).

- Check the rubber seal around the door. If it is brittle or torn, replace it.
- If the refrigerator is not frost-free, defrost it at least every month (and replace it with a more appropriate refrigerator as soon as possible). Transfer the vaccines to a portable cold box or cooler and monitor the temperature.
- If there are exposed coils on the back of the refrigerator, keep them clean and dust free to improve operating efficiency.
- Deal with refrigerator breakdowns or problems immediately.

6.2.1 Location of the vaccine refrigerator

- Place the vaccine refrigerator away from warm external walls and out of direct sunlight.
- Ensure that the refrigerator is in a secure area only accessible to staff.
- Follow the manufacturer's instructions on positioning the refrigerator to enable sufficient air circulation around the back and sides.
- Ensure that the power source is labelled clearly to prevent the refrigerator from being accidentally unplugged or turned off. If the power source is exposed, a switch cover may be necessary.
- Limit the number of times the refrigerator door is opened, and avoid letting the door stand open unnecessarily. Not only does this affect the temperature in the unit, it also exposes the vaccines to light (which can affect the potency of some vaccines). Routinely check the doors throughout the day and at the end of the day to ensure they are tightly closed.

6.2.2 Defrosting a domestic refrigerator

A refrigerator works well only if it is properly installed, cleaned and defrosted regularly. Thick ice in the freezer compartment does not keep a refrigerator cool. Instead, it makes the refrigerator work harder and uses more power.

Refrigerators requiring defrosting are not recommended; however, if you use a refrigerator that requires defrosting, it should be defrosted when the ice is more than 0.5 cm thick, or once a month, whichever comes first (WHO 2004).

To defrost and clean a vaccine refrigerator that is not a frost-free unit:

- Take out all vaccines and transfer them to a second refrigerator (which must be monitored during this time) or a correctly packed portable cold box or cooler.
- Turn off the power supply to the refrigerator.
- Leave the door open and wait for the ice to melt, or place a pan of boiling water inside and close the door. (Using a knife or ice pick to remove the ice can permanently damage the refrigerator.)
- Clean the inside of the refrigerator and door seal with a clean, wet cloth.
- Turn the refrigerator on again.
- When the temperature in the main section falls to +8 °C or lower (but not less than +2 °C), pack the refrigerator according to best practice guidelines.

6.3 Cold boxes, coolers and vaccine carriers

Clean and dry the cold box, cooler or vaccine carrier after every use.

Keep the lid opened in the store while the box is not in use. This will increase the life of the rubber seal.

Examine the inside and outside surfaces for cracks after every use.

Check that the rubber seal around the lid is not broken; if broken, replace it immediately.

Handle the cold box, cooler or vaccine carrier carefully. Do not drop or sit on it. Knocks and sunlight can cause cracks inside the wall and lid.

Keep the cold box, cooler or vaccine carrier in the shade. Do not leave it in sunlight.

Adjust the tension on the latches (if fitted) so that the lid closes tightly.

Regularly lubricate hinges and locks (if fitted).

6.4 Monitoring equipment

Replace the battery of the thermometer or data logger at least every 12 months, or sooner if having thermometer or data logger problems. (It's a good idea to do this on a specific date each year. Do not wait until the battery is flat.)

Conduct an accuracy check of the external thermometer⁵ (also called the 'slush' test; see below). This should be conducted after receiving a new thermometer, after changing the battery and at least every 12 months, or sooner if having thermometer or cold chain problems. Record the results on the temperature chart or log for future reference.

Arrange for the data logger or temperature chart recorder to be calibrated at a frequency and using the method outlined in the manufacturer's instructions. (Note that it may need to be calibrated by the manufacturer.)

⁵ A thermometer that is not built into the equipment; includes dial, alcohol stem and maximum-minimum thermometers.

How to check the accuracy of an external thermometer

This procedure is quite simple and you do not need any sophisticated equipment. The test is also called the 'slush' test.

1. Two-thirds fill a polystyrene or plastic cup with cold water.
2. Place the cup in the refrigerator freezer until a fine layer of ice forms on the top and small sections of ice form within the fluid. This may take up to 2½ hours.
3. Using this method, the mixture is 0 °C once ice is present.
4. Place the thermometer or temperature probe into the middle of the container. Be careful not to let the probe touch the container.
5. Observe the temperature at 2 minutes.
6. The temperature will drop quickly at first and then more slowly; however, the temperature should drop to 0 °C within 2 minutes.

Interpreting the results:

- The results should be within one degree above or below 0 °C; therefore the display screen may show three possible readings: +1 °C, 0 °C, -1 °C.
- If the temperature reading is 0 °C, this demonstrates that the thermometer is accurate and can be used as normal.
- If the temperature reading is more than one degree above or below 0° C at 2 minutes and you are using a battery-powered thermometer, replace the battery and test again.
- If the temperature reading is either +1 °C or -1 °C, this demonstrates that the accuracy is within acceptable limits and the thermometer can continue to be used; however, this needs to be:
 - recorded on the temperature chart; and
 - taken into account should the thermometer record temperatures outside the +2 °C to +8 °C range.

6.5 Logbooks

Each large item of equipment such as the generator, a cold room or vaccine refrigerator should have a logbook that contains the following records:

- Date of installation.
- Equipment instructions and list of routine maintenance tasks.
- Dates of any routine tasks performed (e.g. cleaning).
- Dates of repairs or servicing.
- The name of the person, company and contact information (operational and after hours) of the company providing service.

6.6 Vaccine storage self-audit

A vaccine storage self-audit is an important part of routine quality assurance and risk management for vaccine storage. It enables staff to have confidence that they are providing safe and effective vaccines, and also identifies areas where improvement is needed.

Carry out a self-audit at least once every 6 months (or more frequently if equipment breakdown or cold chain breaches have occurred). The checklist in Annex 7 will assist you.

Key points

- Regular maintenance of cold chain equipment will help ensure that vaccines remain safe and effective.
- Always follow the 'Dos and don'ts' for vaccine storage refrigerators shown on the next page.
- Keep cold boxes, vaccine carriers and coolers in good condition to ensure that your vaccine is transported and stored correctly.
- It is important to ensure that the equipment used to monitor the cold chain is in good condition.
- Ensure that a logbook is kept for each large item of equipment.

Dos and don'ts for use of refrigerators

Do

- Keep the refrigerator in a cool room away from direct sunlight and at least 10 cm away from the wall.
- Keep the refrigerator properly levelled.
- Fix the plug permanently to the socket.
- Use a voltage stabiliser.
- Keep vaccines neatly stacked with space between the stacks for circulation of air.
- Keep the refrigerator locked, and open it only when necessary.
- If you have a refrigerator that requires defrosting, defrost it periodically.
- Paste a notice of the plan for a breakdown on the outside of the refrigerator.
- Check the temperature twice a day and maintain a record.
- Take remedial action if the temperature is not maintained within the safe range.
- Identify and organise an alternative place for storing vaccines.
- Know whom to contact and where to check for a blown fuse.

Don't

- Open the door unnecessarily.
- Keep food or drinking water in the refrigerator.
- Keep vaccines or other products that have expired.
- Sit on any cold chain refrigerator.
- Disturb the thermostat setting.

7. Cold chain risk management

7.1 Cold chain failure

Planning is an essential element of cold chain risk management. The objective of planning is to identify, before they occur, the potential cold chain problems that are most likely to have an impact on vaccines, as well as their causes. It is also important to review any problems after they occur and see whether improvements can be made.

The aim of cold chain risk management is to prevent (wherever possible) loss of vaccine through a cold chain breach. This is important at all levels: in the manufacturing laboratory, at the provincial or district animal health office, during transport, at the distribution centre, and when the vaccine is being used by the community vaccinator or farmer.

A cold chain breach occurs when vaccine storage temperatures are outside the recommended range of +2 °C to +8 °C for a specified period of time. This does not include temperature deviations up to +12 °C lasting no longer than 15 minutes during vaccine stocktaking or restocking a refrigerator.

A cold chain breach that is not identified and not managed properly could have serious implications – especially when it involves informing people that their animals may have received an ineffective vaccine and will require revaccination.

7.2 Factors

There are several factors or events that could cause a cold chain breach. The impact of any of these would be cold chain failure and, ultimately, loss of vaccine potency. They can be grouped in the following four areas.

Equipment

All equipment used to store, monitor and transport vaccines should be reliable, regularly maintained and serviced. This includes the vaccine refrigerator and monitoring equipment. Correct packing of the vaccine refrigerator is also essential if vaccines are to remain safe and effective.

Procedures

To ensure safe and effective storage and handling of vaccines, you should establish simple, routine, cold chain procedures and systems that are easily maintained. Your unit should also establish written protocols on effective vaccine management, which reflect the way the systems operate. To do all this successfully, it is helpful to have clear, accurate, written descriptions of the procedures (Standard Operating Procedures), and staff who have been trained in their implementation.

People

To ensure safe and effective vaccine storage and handling, staff need to understand the importance of vaccine management, follow correct procedures in storage and handling of vaccines, and must know how to identify and manage a cold chain breach. Staff must be provided with training, and backup staff should be appointed to cover for illness or absence of key personnel.

- One responsible person should be appointed to conduct and/or coordinate all aspects of vaccine management.
- A second person should be appointed as a backup.
- All staff members who are involved in vaccine management should be provided with training in vaccine management.
- All new staff members who are involved in vaccine management should be provided with a comprehensive orientation program when they start, to ensure that they know and understand their role and responsibilities.

External factors

External factors are those that are outside your immediate control, including power supply issues (such as power failure or load shedding of electricity) and natural disasters (severe storms and floods). External factors are generally unpredictable, so you can only really consider how they impact your operations and implement a pre-prepared plan of action in the event that they occur.

Table 2 shows power supply issues that may cause a cold chain breach and gives some possible solutions to the issues.

EFFECTIVE COLD CHAIN

Table 2 Power supply problems and possible solutions

Issue	Reasons	Possible solutions
Power failure	<p>A power failure is the loss of electricity supply to an area. The reasons for a power failure may include:</p> <ul style="list-style-type: none"> • damage to a power line; • overloading of electricity mains; • insufficient supply; • generator breakdown at the power station; or • a short circuit. 	<p>Install a generator if you experience frequent power failures (Annex 8).</p> <p>If a generator is not available, transfer vaccine to a portable cold box or cooler and/or to a location with a secure source of power and suitable facilities for storing vaccine.</p>
Power surges	<p>A power surge is a rapid, temporary increase in voltage in the local power lines. Power surges can permanently damage delicate electrical and electronic equipment.</p>	<p>To protect electrical equipment use a ‘surge protector’ (Annex 5).</p>
Brownouts	<p>A brownout is a temporary condition where power falls below the given level from the power station. Brownouts can damage electronic equipment.</p>	<p>Use a voltage regulator or surge protector (Annex 5).</p>
Load shedding	<p>Load shedding is a controlled means of rotating the available capacity of electricity among all customers.</p>	<p>If the duration of the load shedding is longer than the holdover time of the refrigerator, then treat it as a power failure and take the actions shown above.</p>

7.3 Actions to take in the event of a cold chain breach

Follow this procedure in the event of a cold chain breach:

1. Isolate the vaccines immediately to prevent further use (e.g. place a sign on the refrigerator door) and notify relevant staff.
2. Keep vaccines refrigerated between +2 °C and +8 °C.
3. Contact the manufacturer or supplier as soon as possible to inform them of the breach and to seek advice.
4. Have important details on hand, including:
 - the date of the breach;
 - the minimum and maximum temperature reading;
 - when the thermometer was last reset;
 - how long you think the temperature was outside +2 °C to +8 °C; and
 - what you think was the cause of the cold chain breach.
5. Only discard vaccines when advised by the manufacturer or supplier to do so.
6. Take active steps to correct the problem and prevent it from recurring.
7. Record notes on the temperature log or chart detailing what happened and how the problem was corrected.

Key points

Follow these simple principles to prevent cold chain problems:

- Establish simple, routine procedures.
- Ensure that staff receive appropriate training and understand the cold chain and its importance.
- Use appropriate vaccine refrigeration and monitoring equipment.
- Pack the vaccine refrigerator in accordance with best practice guidelines.
- Monitor and record the temperature of vaccines in accordance with best practice guidelines.
- Put procedures in place for ordering and receiving vaccines and disposing of expired or damaged vaccines correctly.
- Put procedures in place for managing a power failure.
- Put equipment and procedures in place for packing a portable cooler.
- Put procedures in place for maintaining the vaccine refrigerator and monitoring equipment.
- Conduct an annual vaccine management audit that covers people, procedures and equipment.
- Conduct cold chain risk-management planning.
- Conduct quality review procedures in the event that a cold chain problem occurs.

8. How to assess and map the cold chain

8.1 Conducting a cold chain assessment

The overall objective of a cold chain assessment is to gain an understanding of current vaccine cold chain facilities, personnel, procedures and knowledge in the area or district. The results of the assessment are used to identify priority intervention areas for cold chain improvement. You could use all or some of the following questions to carry out the assessment.

Information on the district

1. How many sub-districts and villages are in this district?
2. Please provide data on current animal species and population in the district.
3. Please provide a map of the district showing location of offices responsible for animal health and vaccine storage and distribution.
4. How many animal health offices are in the district? How many have working refrigerators?

Information on current vaccine storage facilities

5. Where in the district are livestock vaccines stored?
6. If the vaccines are stored at the district livestock office, what sort of cold chain equipment is available at the office for vaccine storage?
7. Is the temperature of the cold room or refrigerator monitored? If yes, how is it monitored?
8. Is the temperature recorded?
9. Is there an emergency plan for keeping the vaccines cold in case of cold chain failure? If yes, what is the plan?
10. List the products stored in the cold room or refrigerator. What proportion of the cold room or refrigerator space do they occupy?
11. Is diluent supplied with vaccine? If yes, where is it stored?
12. How long is vaccine stored at the district level before it is used in the field (average)?

Information on electricity supply

13. Is the office or facility connected to the electricity mains?
14. Is the electricity operating on the day of the visit?
15. Please circle the appropriate response: The electricity supply is reliable or unreliable.
16. Approximately how many times per week and for how many hours per day is the electricity generally 'off'?
17. Does the office or facility have a generator set up to provide power to the cold room or refrigerator when the electricity fails?
18. If yes, is it working? What is its capacity (kVA)? Please give the brand and model number.)
19. How does it switch on? Please circle the appropriate response: automatically/manually.
20. If the generator is switched on manually, who is responsible for turning it on? (Give job title.)
21. Who looks after the cold chain and the generator during weekends and holidays?

Information on vaccine ordering and delivery

22. When you receive vaccine, in what type of container is it packed? Is the container kept cold using icepacks or ice?
23. How can you tell if the vaccine has been kept cold during transport?
24. Who is responsible for transporting vaccines to your facility?
25. How is vaccine packed when taken to areas where it will be used? How is vaccine kept cold?
26. If ice or icepacks are used, where are they frozen before use?
27. What type of transportation is most often used to send vaccine to sub-districts or villages?
28. Is the temperature of the vaccine monitored during transport to the field? If yes, how?
29. Please give approximate driving times from the district Livestock Office to the district borders.

EFFECTIVE COLD CHAIN

Information on vaccine management

30. Please list the staff (position titles) whose responsibility it is to receive and monitor vaccine distribution? Have they received training in cold chain maintenance?
31. How do you keep track of vaccines received and/or dispatched? May we see the most recent page of these forms?
32. Are vaccine inventory reports sent to the national or provincial level? How often?
33. What is included in the reports? Quantities received? Stock on hand? Quantities used? Losses and adjustments, wastage?
34. Who determines how much vaccine you receive and when?
35. Do you receive supervision visits from national or provincial level? How often?
36. On average, how long does it take between ordering and receiving vaccines?

General information

37. Is the facility connected to 'town' water?
38. Is the water operating on the day of the visit?
39. Does the facility have a telephone?
40. Is the telephone operating on the day of the visit?

Date: _____

District: _____

Location: _____

Name of respondent: _____

Name of assessor: _____

Refrigerators and freezers (fill in one line for each cold room, refrigerator or freezer)

Cold room, refrigerator or freezer	Manufacturer	Model	Volume	Fuel source: Electricity (E) Kerosene (K) Gas (G) Solar (S)	Year of installation	Working Yes/No	Connected to voltage stabiliser

Cold chain transport equipment

Manufacturer	Model	Volume

Cold chain knowledge

1. What do you understand by the term 'cold chain'?
2. What happens if there is a break in the cold chain?
3. Can you tell if there has been a break in the cold chain? How?
4. Do you know what to do if there is a cold chain problem or if you suspect a break in the cold chain?
5. What is the best temperature to store and transport vaccines?

Case Study 6

Cold chain and vaccine management assessment for the animal vaccination program in Bali Province, Indonesia

An assessment of the cold chain and vaccine management was carried out to determine the actual field practice, equipment, resources, available staff, etc.

The assessment found that the cold chain, vaccine and logistics management situation in Bali needed significant improvement. The main points were:

- Most of the refrigerators, at all levels, were not appropriate for vaccine storage.
- Essential devices, such as thermometers, monitoring indicators, voltage stabilisers, etc., were not available.
- There were no Standard Operating Procedures (SOPs) for cold chain and vaccine management. As a result, vaccines were arranged inappropriately inside the refrigerator and were transported with frozen cold packs, without following bundling and 'First Expiry and First Out' (FEFO) principles.
- Animal health workers lacked the necessary information related to cold chain, logistics, and waste management. They also followed the-colder-the-better theory and applied it to all cold chain practices.
- Logistics management was limited to a logistics receipt form that listed only the item and quantity, but did not list expiry dates and batch numbers.
- Safe vaccination and waste management needed major improvements.

The results indicated an urgent need for improvements in the cold chain, and vaccine and logistics management, at all levels of the animal health program. The team made the following recommendations:

- Develop SOPs for cold chain, vaccine and logistics management to guide animal health workers in field implementation for vaccination programs.
- Develop SOPs for safe vaccination and waste management for animal vaccination.
- Build capacity for the cold chain and vaccine management for animal health personnel at all levels.
- Establish routine, standard, supportive supervision visits.
- Upgrade equipment and devices to assist in properly implementing a vaccination program.

These actions are expected to improve the cold chain and vaccine management practice, build capacity, and meet the vaccination program needs.

Vogel, Russell, Anton Widjaya, and Vanda Moniaga (2011). *Indonesia: Cold Chain and Vaccine Management Assessment for the Animal Vaccination Program in Bali Province*. Arlington, Va.:

USAID | DELIVER PROJECT, Task Order 2.

http://deliver.jsi.com/dlvr_content/resources/allpubs/guidelines/ID_ColdChaiVaccMgmt.pdf

8.2 How to map the cold chain

Many factors can contribute to weakness of the cold chain. These include poorly maintained or outdated refrigeration equipment, inadequate monitoring, and poor understanding of cold chain procedures. To identify specific problem areas the cold chain should be mapped, following the path of the vaccine as it travels through the cold chain, from manufacturer to intermediate storage points and distributors, and finally, to the field (WHO 2011). The goal of the study is to monitor the temperatures of a typical vaccine cold chain.

Equipment

Data loggers are used to monitor temperatures. A computer is required to configure the data logger and to download temperature data so that it can be analysed and printed.

Study design

Data loggers are packed within vaccine boxes and accompany vaccine shipments from the manufacturer to the field. The shipments should be packed, handled and stored using routine procedures. A monitoring form is also enclosed in the shipment. At each point in the cold chain, staff record the date and time of both arrival and departure of the shipment.

Study site(s) selection

Study provinces, districts and field sites should be selected to reflect broad areas of the country. Select areas that are average to below average in terms of performance, accessibility and temperature extremes, and that are staffed with responsible personnel.

Activating the data logger

Using the computer and software, activate the data logger and program it to read at 20-minute intervals.

Vaccine shipment preparation and storage

Place the data logger and monitoring form in the vaccine boxes. These boxes should be stored at the manufacturer's storage facility, the first link in the cold chain. The monitoring form must be completed with the date and time of start of temperature logging. Normal loading and handling procedures should be followed so the data loggers will be exposed to typical cold chain conditions.

Distribution and monitoring

At each point on the cold chain, identify a staff member who is responsible for vaccine storage and/or packing for transport. Vaccine should be stored in the cold room or refrigerator, along with other vaccines, following standard practice. Normal schedule and typical loading and transport procedures should also be followed.

At each point the staff member should record the time and date on the monitoring form.

On completion of vaccine administration in the field, the vaccinator should record the time and date on the monitoring form. The study is now complete and data loggers can be stored at room temperature.

Data collection and analysis

One person at each point should be trained to use the monitoring form and be responsible for completing it upon receipt and reshipment of the vaccine. An example of the form is shown on the next page and should be modified to indicate each of the cold chain points and the study vaccine.

Collection of data instruments

After the study has been completed, the study coordinator should visit each centre to collect the data loggers and monitoring forms. The coordinator may also conduct interviews with staff at this time.

Ambient temperature monitoring

If possible, measure and record the ambient temperatures along the distribution route. If this is not possible, try to obtain temperature records for the area from the local meteorological service.

Interviews

To collect additional information about staff attitudes and practices towards vaccine storage and handling, the study coordinator should interview all cold chain staff participating in the study. Cold chain personnel can be interviewed individually or in groups. The following questions and topics are designed to help determine their knowledge of and attitudes to the cold chain:

- What is the best temperature to store and transport vaccines?
- Have you heard the term ‘cold chain’? What do you understand by it?
- What happens if there is a break in the cold chain?
- Can you tell if there has been a break in the cold chain? How?
- Do you know what to do if there is a cold chain problem or if you suspect a break in the cold chain?
- Does freezing harm vaccines? Which vaccines?
- Can you tell if a vaccine has been frozen?
- What do you do if you know a vaccine has been frozen?
- Did you receive training on these topics?

During the visit, the study coordinator should inspect and record information on the refrigerator or cold room monitored in the study. The information recorded should include the brand name and model number, volume, fuel source and year of installation. Containers used to transport vaccine should also be inspected and described. Photographs should accompany the descriptions.

Data analysis

The study coordinator should retrieve the temperature data from the data loggers. The data from the monitoring forms and data loggers should be combined to create temperature maps of each shipment. The exact time that the vaccine was moved from transport to storage and back to transport should be clearly indicated on the monitoring form. From these maps, the severity of freezing or heating and number of times the vaccine was subjected to such conditions at each point in the cold chain can be determined.

Study report

Data from the data loggers and interviews should be combined into a report showing the number of times, approximate duration and locations where vaccines were exposed to inappropriate temperatures. The likely causes may also be identified. Responses to the interview questions will provide information on the knowledge, attitudes and practices that could contribute to cold chain problems. Descriptions of the refrigerators monitored in the study should be included. A completed report should be sent to all participants and partners in the study.

EFFECTIVE COLD CHAIN

Monitoring form

The staff member responsible for vaccine storage and/or packing for transport at each location should record the location and the time and date that the vaccine was received or dispatched. Any comments, including the type of vaccine in the shipment, should also be recorded.

			Vaccine In		Vaccine Out		
Facility name	Location	Name of vaccine	Date	Time	Date	Time	Comment

Key points

- Conduct a cold chain assessment to identify priority intervention areas for cold chain improvement.
- Map the cold chain to identify specific areas that may compromise vaccine quality.

9. Annexes

The annexes provide more information on various topics relating to the cold chain.

Annex 1 Vaccines and liquid nitrogen

Some vaccines, including East Coast fever vaccine and live Marek's disease vaccine, must be stored below $-100\text{ }^{\circ}\text{C}$ in order to keep them viable. Such vaccines are therefore stored in liquid nitrogen, which maintains the vaccine at $-196\text{ }^{\circ}\text{C}$.

Store the liquid nitrogen canister in a cool, well-ventilated area, and check the tanks routinely to ensure adequate levels of liquid nitrogen cover the vaccine. If vaccine is allowed to defrost at any stage, it cannot be refrozen and must be destroyed.

Always read the manufacturer's directions for handling, thawing and mixing the vaccine, and follow them exactly.

Liquid nitrogen is a hazardous substance. Take all precautionary measures when handling liquid nitrogen to ensure the safety of all persons handling it:

- Only properly trained personnel should handle the liquid nitrogen containers and vaccines. Know and follow all precautions and safety practices before handling liquid nitrogen.
- Liquid nitrogen is extremely cold. Accidental contact with the skin or eyes can cause severe frostbite. Protect eyes with goggles or a face shield.
- Wear leather gloves and long sleeves when removing and handling frozen ampoules or when adding liquid nitrogen to the container.
- Storage and handling of liquid nitrogen containers must be in a well-ventilated area. Excessive amounts of gaseous nitrogen in an unventilated space can cause asphyxiation.
- Remove from the liquid nitrogen only the ampoules that are going to be used immediately. (Note: Remove ampoules in descending order from each cane; only raise the aluminium cane to the neck of the canister to ensure remaining ampoules are not exposed to room temperature.)

First aid

- If drowsiness occurs, get to fresh air quickly and ventilate the entire area.
- If a person becomes groggy or loses consciousness while working with liquid nitrogen, get the person to a well-ventilated area immediately.
- If breathing has stopped, begin artificial respiration. Call a physician immediately.

Moving and transporting liquid nitrogen

Containers must always be stored in an upright position. Do not roll, either vertically or horizontally. Always use a cylinder cart when moving liquid nitrogen cylinders.

If containers of liquid nitrogen are to be transported by vehicle, a dry shipper should be used. Under no circumstances should liquid nitrogen be transported in an enclosed vehicle such as a sedan or station wagon, nor in the cabs of trucks and pickups. A utility vehicle may be used as long as the container is restrained.

The containers should be firmly secured to the vehicle and protected from other objects striking against them during transport. Containers should be inspected for structural integrity prior to transport.

Annex 2 Vaccine storage information

The storage and handling recommendations for a selection of vaccines are shown below. Storage and handling recommendations on the vaccine label or package inserts provide you with the most up-to-date information and should be followed carefully. If you suspect that vaccine may not have been stored or handled properly, contact the manufacturer's Director, Complaints Officer or Quality Control Office.

	Manufacturer	Type	Storage	Handling after reconstitution
Foot and Mouth disease in ruminants				
AFTOVAX FMD Vaccine FOTIVAX	BVI ⁶ NVI ⁷ KEVEVAPI ⁸	Inactivated (adjuvant: aluminium hydroxide and saponin)	Store in the refrigerator (between +2 °C and +8 °C), protected from the light. Do not freeze.	Once the bottle has been opened, the vaccine should be used within 24 hours, provided it has been stored between +2 °C and +8 °C.
Contagious Caprine Pleuropneumonia				
CAPRIVAX™ CCPP Vaccine	KEVEVAPI NVI	Inactivated (suspended in saponin)	Store in the refrigerator (between +2 °C and + 8 °C) for up to one year. Do not freeze.	Once the bottle has been opened, it must be used immediately and any remaining vaccine discarded.
Contagious Bovine Pleuropneumonia				
CONTAVAX™ CBPP Vaccine PERIBOV PERI-T1 T1/44 PERIVAX T1-44 PERIVAX T1-SR	KEVEVAPI NVI BVI LCV ⁹ ISRA-LNERV ¹⁰ LANAVET ¹¹ LANAVET	Freeze-dried, live attenuated	Store at -20 °C (freezer) away from light for up to 2 years. If stored in the refrigerator (between +2 °C and +8 °C), the shelf life is one month. Avoid continuous freezing and thawing.	Keep the reconstituted vaccine cool (not above +20 °C) and protected from sunlight. Once the vaccine has been reconstituted, it must be used within one hour. Any remaining reconstituted vaccine should be destroyed using bleach or boiling water.

⁶ Botswana Vaccine Institute in conjunction with Merial.

⁷ National Veterinary Institute, Debre Zeit, Ethiopia.

⁸ Kenyan Veterinary Vaccines Production Institute, Nairobi, Kenya.

⁹ Laboratoire Central Veterinaire, Bamako, Mali.

¹⁰ Institut Sénégalais de Recherches Agricoles – Laboratoire National d'Elevage et de Recherches Vétérinaires, Dakar, Senegal.

¹¹ Laboratoire National Veterinaire, Garoua, Cameroun.

	Manufacturer	Type	Storage	Handling after reconstitution
Peste des petits ruminants				
PPR – VAC	BVI	Freeze-dried live modified virus	Store in the refrigerator (between +2 °C and + 8 °C), protected from light. The product may be stored at +20 °C for a short period only (24 hours maximum).	The vaccine should be reconstituted immediately before use. Once reconstituted, the vaccine should be protected from light, high temperature and used within two hours. Any remaining reconstituted vaccine should be destroyed using bleach or boiling water.
Peste des petits ruminants (PPR) vaccine	NVI		Store at –20 °C.	
PPR	ISRA-LNERV		Store at –70 °C for 24 months. Protect from light and do not freeze.	Do not expose to sunlight. Reconstituted vaccine should be kept cold and used immediately. If a syringe of large capacity is used for vaccination, it should be wrapped in a cotton cloth soaked with cold water.
CAPRIPESTOVAX	LANAVET		In the freezer (–20 °C), away from light.	
Rabies infection				
RABISIN (dogs and cats)	Merial [MCI Santé Animale]	Inactivated (aluminium hydroxide adjuvant)	Store and transport at +2 °C to +8 °C (in a refrigerator), protected from light. Do not freeze.	
Defensor 3 (dogs, cats, cattle and sheep three months of age or older)	Zoetis	Cell-culture grown, chemically inactivated rabies virus	Store at +2 °C to +7 °C. Prolonged exposure to higher temperatures may adversely affect potency. Do not freeze.	Use entire contents when first opened.
RABDOMUN 1 VACCINE (dogs and cats)	MSD Animal Health [Intervet, Schering-Plough Animal Health, Merck Sharp & Dohme Ltd.]	Cell-culture grown, chemically inactivated	Store at +2 °C to +8 °C. Protect from light and do not freeze. Prolonged exposure to higher temperatures may adversely affect potency. Do not freeze.	

	Manufacturer	Type	Storage	Handling after reconstitution
Blackleg (Clostridium chauvoei) infection of cattle, sheep and goats				
Asymptol	BVI	Inactivated (aluminium hydroxide adjuvant)	Store and transport at +2 °C to +8 °C (in a refrigerator), protected from light. Do not freeze.	
Blackleg vaccine SYMPTOVAX	NVI LANAVET	Precipitated by 1% aluminium potassium sulphate	Store at +20 °C for 12 months; at +4 °C for 24 months. Keep away from sunlight, between +4 °C and +8 °C. Do not freeze.	
Fowl cholera infection of birds				
Fowl Cholera Vaccine Inactivated (Polyvalent)	Ventri Biologicals, India	Inactivated (oil adjuvant)	Store and transport at +2 °C to +8 °C (in a refrigerator), protected from light. Do not freeze.	Bring the vaccine bottle to room temperature. Shake well before and during use. Use entire contents when first opened. Do not store and reuse the leftover vaccine after opening the bottle.

Annex 3 Refrigerator selection

Points to consider when choosing a refrigerator

1. **Vaccine storage capacity**
2. **Icepack freezing capacity**
3. **External temperatures:** Performance of the refrigerator and/or freezer at the expected maximum ambient temperature
4. **Power source:** Which power sources are available? (See Figure 9.)
 - (a) Electricity: What voltage? Is supply continuous or not?
 - (b) Kerosene or bottled gas?
5. **Holdover time:** What holdover time is needed in case of power failure?
6. **Reliability:** Repair facilities and spare parts available for which types?
Spare parts and repairs account for 40–50% of the whole-life cost of a refrigerator.
7. **Price:** Which refrigerator meets requirements 1 to 6 at the lowest cost?
Remember to consider shipping costs!
8. **Training:** Is training available for users, and are those in charge of maintenance of the equipment properly trained?

When placing your order for a refrigerator or a freezer, include a request for a thermometer; order a voltage stabiliser for electrical equipment if local conditions require one; and remember to specify the language for user's and service manuals.

There are four energy sources available for vaccine refrigerators.

The most reliable refrigerators are powered by **electricity**, with lower capital and running costs than any others. Electric refrigerators, including ice-lined refrigerators, require at least 8 hours per day of mains electricity.

Areas without electric power have three options:

- **Solar refrigerators:** These are relatively expensive and are available as direct-drive refrigerators (without batteries) or with a high-quality industrial battery system to store solar energy. The refrigerators with batteries require much preventive maintenance, as well as periodic replacement of battery packs.

EFFECTIVE COLD CHAIN

Kerosene refrigerators: These require 0.5 to 1 litre of kerosene per day, and fuel contamination and ‘diversion’¹³ are a problem. Dirty kerosene shortens the units’ working life and leads to higher costs for spares.

Bottled gas refrigerators: These refrigerators require a constant supply of gas bottles. Diversion is less of a problem than with kerosene. Contamination is a practical impossibility.

Table 3 Comparison of energy sources for refrigerators

Energy source	Temperature control	Routine maintenance	Other
Electricity	Good thermostat control	Simple	Periodic replacement of heating element if voltage fluctuates
Gas	Thermostat control: partly influences temperature	Simple	
Kerosene (Also known as paraffin in some locations)	No thermostat; temperature is controlled manually by adjusting the wick of the kerosene burner up or down	Frequent cleaning of wick and flue	Filtering of kerosene; risk of fire or explosion
Solar	With or without thermostat	Simple	With or without battery; with battery – battery and regulator need replacement every five years; relatively costly

Kerosene or gas-fuelled refrigerators are difficult to maintain at proper temperatures, require significant maintenance, are not energy efficient, contribute to global warming, and the fuel is often diverted to other uses. Experience from many countries suggests that gas, despite the higher initial costs, is a more satisfactory fuel than kerosene. Temperatures are better maintained.

Table 4 Comparison of kerosene and gas refrigerators

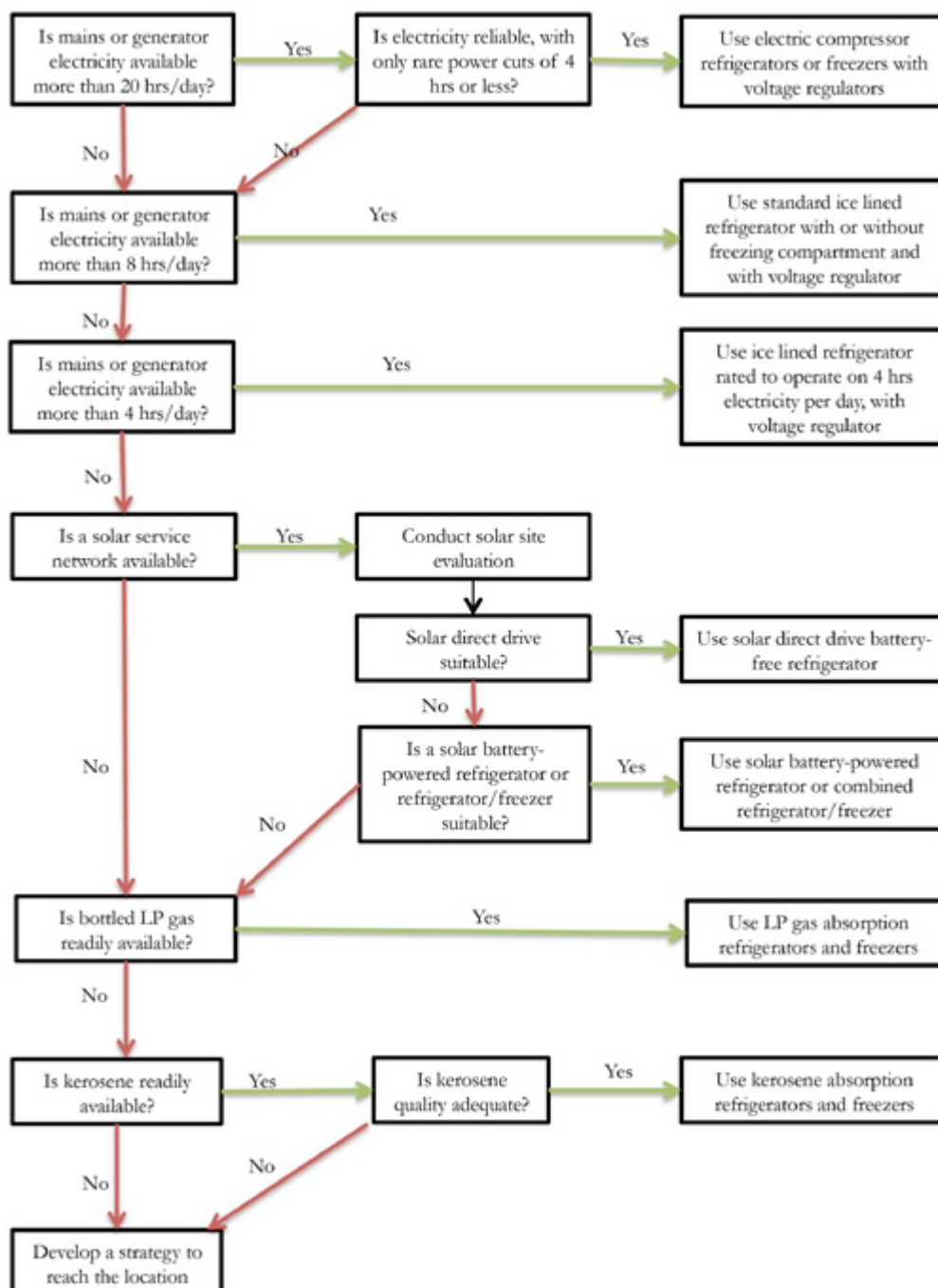
	Kerosene	Gas
Capital costs	Cheaper	More expensive
Running costs	Comparable; country analysis needed	
Efficiency	Unsatisfactory	More satisfactory
Fuel contamination	Common	Very rare
Fuel diversion ¹⁴	Frequent	Rare
Maintenance	Harder	Easier

¹³ As kerosene is used for cooking and lamps in many countries, the fuel may be ‘diverted’ for personal use.

¹⁴ Fuels used for cooking and lamps in many countries may be ‘diverted’ for personal use.

Ice-lined refrigerators maintain temperatures below +8 °C even with only 8 hours of electricity per 24 hours, day after day. The cooling is provided by an internal lining of water-filled tubes or packs that surround the vaccine storage area. Ice-lined refrigerators are strongly recommended where electricity supply is unreliable and standby electricity supplies are not practical. **Note that the temperature of the vaccine storage area in the bottom of the appliance may occasionally fall below 0 °C.**

Figure 9 Selecting a refrigerator for vaccine storage (WHO 2013a)



Annex 4 Mapping the refrigerator used for vaccine storage

Domestic refrigerators used to store vaccine often have ‘hot’ or ‘cold’ spots on different shelves and in different areas. Mapping the refrigerator assists in ‘getting to know’ your refrigerator and can avoid a cold chain breach.

In some refrigerators the coldest area is the top shelf, or the front of the bottom shelf. In others the coldest area may be near a cold-air outlet or the cooling plate. It is important that ‘cold spots’ are identified by detailed monitoring throughout the refrigerator. This can be done by placing data loggers or maximum-minimum thermometers in all areas of the refrigerator and recording the different temperatures before commencing vaccine storage.

The minimum time for monitoring in each position is 24 hours. This will capture all the fluctuations that occur in domestic refrigerators. During the mapping, use some type of ‘cold mass’ to imitate a batch of vaccine (e.g. cooled water bottles), as refrigerators behave differently when empty.

METHOD

Using a data logger:

1. Program the data logger to record temperatures at intervals of 5 to 15 minutes.
2. Record the temperatures throughout the refrigerator. Monitor the temperatures of the front and back of each shelf, and near the side walls.
3. Leave the data logger in each position for a minimum of 24 hours.
4. Record any refrigerator door openings, or events that may affect the temperature.
5. Download the data from the data logger.
6. Continue monitoring and recording temperatures and positions until the whole refrigerator has been ‘mapped’.
7. Analyse the results and identify the best places in the refrigerator to ensure safe storage of vaccines within the cold chain.

Using a minimum-maximum thermometer:

1. Using your minimum-maximum thermometer with a probe, record the temperatures throughout the refrigerator. Monitor the temperatures of the front and back of each shelf, and near the side walls.
2. Leave the thermometer in each position for a minimum of 24 hours.
3. Record any refrigerator door openings, or events that may affect the temperature.
4. Plot the minimum, maximum and current temperatures, date and time at each position.
5. Continue monitoring and recording temperatures and positions until the whole refrigerator has been ‘mapped’.
6. Analyse the results and identify the best places in the refrigerator to ensure safe storage of vaccines within the cold chain.

Annex 5 Protecting cold chain equipment

Any item of cold chain equipment that operates on electricity is designed to be used with a specific electrical supply voltage or, in some cases, with a choice of several different supply voltages. If the supply voltage is incorrect or fluctuates, the cold chain equipment can easily be damaged. This results in the need for costly repairs and replacement of electrical components.

Fluctuations can be controlled and damage to cold chain equipment can be avoided by installing a **voltage stabiliser** on the power line that supplies the equipment. A **surge protection** device is also recommended to prevent damage in the event of lightning-induced spikes on the supply line. In areas where lightning is common, lightning protection should also be included.

Damage can be prevented or reduced by installing a **voltage regulator** between the cold chain equipment and the electrical supply point. This corrects the supply voltage, removes the fluctuations, and so protects the equipment.

A voltage regulator should be considered an essential item of equipment for all cold chain equipment. This is particularly important in all areas where power supplies are irregular, or where cuts and interruptions are common.

When purchasing a voltage regulator it is important to know:

- the nominal voltage;
- the supply voltage range;
- the output voltage range; and
- the power rating.

The **nominal voltage** is the electrical supply voltage measured in **volts (V)** specified for the equipment that is to be protected. This may be e.g. 220 V, and the regulator selected must have a nominal voltage rated at this same value.

The **supply voltage range** defines the maximum and minimum supply voltage, e.g. 145–275 V, for which the regulator can provide protection for the equipment. This range should be **greater than** the highest and lowest supply voltages measured at the point where cold chain equipment is used.

The **output voltage range** specifies the maximum and minimum voltages, e.g. 200–225 V, which the regulator will pass on to the equipment it protects. This range should be **less than** the maximum and minimum permitted voltages stated by the equipment manufacturer.

The **power rating** is the load-carrying capacity of the regulator, and is measured in **volt-amps (VA)**, or in **watts (W)**. The power rating, usually specified as the continuous rating, e.g. 500 W continuous, must be greater than the power rating of the equipment to be protected. Power ratings for both cold chain equipment and regulators will be shown on data plates attached to an outer surface, usually on the back of a refrigerator or freezer, and on the top or underside for a voltage regulator.

EFFECTIVE COLD CHAIN

It is generally good practice to ensure that refrigerators, temperature-monitoring equipment and computers are supplied by separate dedicated supplies with separate voltage stabilisers. This ensures that the load variation of the refrigeration equipment does not adversely affect the electronic equipment, and allows the most appropriate type of voltage stabiliser to be chosen for each of the two load types.

Surge protector

There are various types of surge protector. Some can only survive a limited number of surge events, so it is essential to stock an adequate supply of replacement components and to know how to replace them in the event of a failure.

It is best to ask a qualified electrical engineer for advice.

Annex 6 Refrigerator warning signs

DO NOT
turn off or
disconnect this
refrigerator

Vaccine Refrigerator
STOP
Do you need to open
it?

EFFECTIVE COLD CHAIN

Annex 7 Vaccine storage self-audit

A self-audit is an important part of routine quality assurance and risk management for vaccine storage. It enables staff to have confidence that they are providing safe and effective vaccines, and also identifies areas where improvement is needed.

Carry out a self-audit at least once every 6 months (or more frequently if equipment breakdown or cold chain breaches have occurred). This checklist will assist you.

Name of facility:
Person conducting audit:
Date of self-audit:

PEOPLE			COMMENT
All staff handling vaccines have been trained in maintenance of the cold chain.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
All staff responsible for temperature monitoring know how to use maximum-minimum thermometers.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
Name of person responsible for vaccine storage and handling:			
Name of backup person for the designated person:			

EQUIPMENT			COMMENT
Vaccine refrigerator/cold room (If there is more than one refrigerator and/or cold room, please complete for each one.)			
The refrigerator is situated away from heat sources.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
The refrigerator is situated away from direct sunlight.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
The refrigerator/cold room is operating normally. Date of last service:	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
The refrigerator is only used for storage of vaccines and medicines.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
No more than 50% of the internal volume is used to store vaccines.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	

There are no vaccines stored in the shelves of the door of the refrigerator.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
There are no vaccines stored in the enclosed plastic drawers at the bottom of the refrigerator.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
A graph/logbook/chart for temperature recording is readily available for each refrigerator/cold room.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
A map/guide to location of the vaccines is on the door of the refrigerator/cold room.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
The electrical plugs are clearly marked 'Refrigerator: Do not switch off.'	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
If using a domestic refrigerator, there are water bottles and/or icepacks in the shelves of the door, the drawers and on the empty shelves.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
Cold boxes, vaccine carriers and coolers			
There are readily accessible written procedures for packing vaccine into cold boxes, vaccine carriers and/or coolers.	<input type="checkbox"/> Yes	<input type="checkbox"/> Yes	
Monitoring equipment			
The battery of the maximum-minimum thermometer is changed every year. Date the battery was last changed:	<input type="checkbox"/> Yes	<input type="checkbox"/> Yes	
The battery of the data logger is changed every year. Date the battery was last changed:	<input type="checkbox"/> Yes	<input type="checkbox"/> Yes	
Date of last thermometer accuracy check at 0 °C: Results:			

EFFECTIVE COLD CHAIN

PROCEDURES	<input type="checkbox"/> Yes	<input type="checkbox"/> No	COMMENT
A separate temperature-recording chart/graph/sheet is used for each refrigerator.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
The current maximum and minimum temperatures have been recorded twice a day on working days.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
The temperature record is kept close to the refrigerator.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
There is evidence that the thermometer is reset after each reading.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
The daily temperature records are signed by the person taking the reading.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
The designated person has reviewed the temperature records on a monthly basis.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
Any readings outside the recommended range have resulted in action to resolve the issue.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
Information about activities such as defrosting, etc., that may affect temperature is recorded.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
Temperature records are retained in accordance with quality management procedures.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
There are procedures describing action to be taken if temperatures outside the recommended range are recorded.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
Written vaccine storage and handling procedures are readily accessible to relevant staff. Last revision date:	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
Were there any cold chain breaches since the last self-audit?	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
What actions were taken in response to the cold chain breaches?			

ALTERNATIVE VACCINE STORAGE			COMMENT
A written procedure for alternative vaccine storage is readily accessible in the event of power failure or equipment breakdown.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
Alternative storage (e.g. cooler or monitored refrigerator) is available for vaccine storage in the event of equipment failure.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
Icepacks at the correct temperature are available.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	
A maximum-minimum thermometer is available to monitor the cooler/refrigerator.	<input type="checkbox"/> Yes	<input type="checkbox"/> No	

Annex 8 Generators

In places where mains electricity is not reliable, diesel backup generators are needed to ensure an energy supply to refrigerators. Backup generators should be of a sufficient capacity to run continuously for 72 hours if necessary. It is important to remember, however, that generators are costly to operate, difficult to maintain and repair, create air and noise pollution, and the fuel supply is subject to disruptions and may be diverted for other uses.

Selecting a sustainable, effective backup power system requires attention to four key areas: design, installation, operation and maintenance. Failure to properly address any of these issues can quickly lead to failure.

- Will the generator provide backup power to the entire facility, or to certain loads deemed critical? (Generator sizing)
- Will the system include an automatic transfer switch? (ATS)
- Is there a budget to pay for the ongoing fuel and maintenance costs associated with the generator? (Funding)
- Who will be responsible for the operation and daily maintenance of the generator?

Section E001.2 ‘Standby Generators’ of the PQS Devices Catalogue (WHO 2012) gives further information.

Generator sizing

A generator should be sized to handle the necessary loads with a 20% margin of safety. If a generator is too small, the operator must first go through the facility and turn off loads that cannot be powered by the generator. If the generator is too large, more fuel will be burned than is necessary. If the generator is loaded at less than 25% capacity, it becomes extremely inefficient, and the life of the generator will be shortened.

Automatic transfer switches (ATS)

An ATS is an electrical device located between the generator supply and the mains electricity system that detects when mains electricity is lost. When mains electricity is no longer present at the ATS, it immediately and automatically starts the generator and switches the power supply over to the generator. When there is no ATS, the switchover time is dependent on the notification and response of the operator.

Funding for operation and maintenance

Funds must be available to provide the budget for fuel, routine maintenance and regular servicing of the equipment.

Maintenance is critical to the continued operation of the system. Backup generators should be tested quarterly and should receive maintenance at least annually (check the manufacturer’s specifications for test procedures and maintenance schedules).

Ongoing operation and maintenance require training, which is needed for personnel, the hiring of permanent staff, and the allocation of appropriate funding to keep the generator running. If regular maintenance is not performed, the generator will be permanently damaged and its lifespan will be reduced.

Annex 9 Cold chain equipment suppliers

The *PQS Devices Catalogue* (WHO 2012) gives information on all immunisation-related products currently pre-qualified by WHO for procurement by United Nations agencies.

Refrigerators	Email	Web address
<i>Ice-lined refrigerator</i>		
Haier Medical and Laboratory Products Co., Ltd, People's Republic of China	wuwq@haier.com	www.haiermedical.com
Vestfrost Solutions, Denmark	js@vestfrostolutions.com; bjn@vestfrostolutions.com	vestfrostolutions.com
True Energy, United Kingdom	ian.tansley@trueenergy.com	www.trueenergy.com
<i>Refrigerator, solar direct drive</i>		
SunDanzer Development, Inc., US	jim@sundanzer.com	www.sundanzer.com
Vestfrost Solutions, Denmark	js@vestfrostolutions.com; bjn@vestfrostolutions.com	vestfrostolutions.com
Dometic Group SARL, Luxembourg	medical.systems@dometic.lu	http://www2.dometic.com/delu/Europe/Luxembourg/Medical-Systems/

Vaccine carriers, cold boxes	Email	Web address
Dometic Group SARL, Luxembourg RCW 4, 8, 12 and 25	medical.systems@dometic.lu	http://www2.dometic.com/delu/Europe/Luxembourg/Medical-Systems/
Apex International, India AIDVC 24 and AIVC 44	apexint07@gmail.com; mail@apexint.org	www.apex-international.org/
AOV International ADVC 24 and AVC 44	aov@airtelmail.in; aov@vsnl.com	www.aovinternational.com
Beijing Jialihengye International Trading Co., Ltd., People's Republic of China. LCB 8A	lihuayangsf@yahoo.com	www.bjllhy.com.cn/
Blowkings, India BK-VC2.6-CF. CB-55-CF	blowkings@vsnl.com	www.blowkings.co.in/
Colombo Smart Plastic S.p.A, Italy Gio' Style VC 2.6 L	stefano.petro@giostyle.com	www.giostyle.com/
Coldpack SA, France	alehideux@alexdist.com; beaupuy@alexdist.com	www.coldpack.com/
RMAX PharmaSafe	phil_rehmer@rmax.com.au	www.rmax.com.au

EFFECTIVE COLD CHAIN

Temperature monitoring devices	Email	Web address
<i>Digital maximum-minimum thermometer</i> EMT 888	sales@t-tec.com.au	www.t-tec.com.au/
<i>Dial thermometer</i> Rueger TFV100BI RUEGER SA, Switzerland		www.rueger.com
<i>Data Loggers</i> Logtag Recorders Limited, People's Republic of China Logtag TRIX-8 Logtag TRID30-7FW 30-day electronic temperature logger	sales@logtagrecorders.com	www.logtagrecorders.com/
Gemini Data Loggers (UK) Ltd, United Kingdom Tinytag Talk 2 Tinytag Plus 2	sales@tinytag.info.	www.gemindataloggers.com/
Berlinger & Co. AG Q-tag 2 plus Electronic temperature monitor Q-tag2 plus Fridge-tag® – 30-day electronic refrigerator logger Freeze-tag® – Freeze indicator Electronic temperature monitor Model Q-tag® CLm	andrea.berlinger@berling	www.berlinger.ch
Hastings Data Loggers Tinytag Talk 2 Tinytag Plus 2	DWilson@hdl.com.au	www.hdl.com.au

10. References and resources

Ahlers, C., Alders, R.G., Bagnol, B., Cambaza, A.B., Harun, M., M Gomezulu. R., Msami, H., Pym, B., Wegener, P., Wethli, E. and Young, M. (2009). Improving village chicken production: a manual for field workers and trainers. ACIAR Monograph No. 139. Australian Centre for International Agricultural Research: Canberra, p. 139.

Alders, R., dos Anjos, F., Bagnol, B., Fumo, A., Mata, B. and Young, M. (2002). Controlling Newcastle Disease in Village Chickens: A Training Manual. ACIAR Monograph No. 87, 128 pp.

Australian Government, Department of Health and Ageing (2013). National Vaccine Storage Guidelines ‘Strive for Five’. Second edition. <http://www.immunise.health.gov.au/internet/immunise/publishing.nsf/Content/IMM77-cnt>

Chicamisse, M., Harun, M., Alders, R.G. and Young, M.P. (2009). Evaluation of the cold chain encountered by ‘wet’ I-2 Newcastle disease vaccine from the Vaccine Production Department to the village chicken in Mozambique. In: Alders, R.G., Spradbrow, P.B. and Young, M.P. (eds), Village chickens, poverty alleviation and the sustainable control of Newcastle disease. Proceedings of an international conference held in Dar es Salaam, Tanzania, 5–7 October 2005. ACIAR Proceedings No. 131, pp 113–119.

Farrell, P., Young, M. and Alders, R. (2014). Insights for the Veterinary Industry. Control and Therapy Series, Series 46, Issue 277, Nos 5424–5442, Persp 110–113, pp 27–29.

Muegge, S. (2012). Protecting refrigerated vaccines with water bottles: an evidence-based strategy. *American Journal of Nursing* 112: 61–69.

USAID | DELIVER PROJECT, Task Order 2. (2009). Indonesia: Cold Chain Study—Operational Research in Indonesia for More Effective Control of Highly Pathogenic Avian Influenza. Arlington, Va.: USAID | DELIVER PROJECT, Task Order 2. http://deliver.jsi.com/dlvr_content/resources/allpubs/guidelines/ID_ColdChaiVaccMgmt.pdf

U.S. Department of Health and Human Services, Centers for Disease Control and Prevention (2014). Vaccine Storage and Handling Toolkit. <http://www.cdc.gov/vaccines/recs/storage/toolkit/>

World Health Organization (2004). Immunization in Practice: A Practical Guide for Health Staff. Module 3: The Cold Chain. World Health Organization, Geneva, Switzerland. http://www.who.int/immunization/documents/IIP2015_Module2.pdf?ua=1

World Health Organization (2005). User’s handbook for vaccine cold rooms and freezer rooms. World Health Organization, Department of Vaccines and Biologicals, Geneva, Switzerland. <http://apps.who.int/iris/handle/10665/67801>

World Health Organization (2011). Study Protocol for Temperature Monitoring in the Vaccine Cold Chain. World Health Organization, Department of Vaccines and Biologicals, Geneva, Switzerland. http://whqlibdoc.who.int/hq/2011/WHO_IVB_05.01_REV.1_eng.pdf?ua=1

World Health Organization (2013a). PQS Devices Catalogue. Pre-qualified equipment for the Expanded Programme on Immunization (EPI). WHO Department of Immunization, Vaccines and Biologicals – Quality, Standards and Safety. Version Date 7 November 2013. http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/

World Health Organization (2013b). Vaccines. Accessed 22 May 2013. <http://www.who.int/topics/vaccines/en/>

World Health Organization (2013c). Conditioning ice packs. Accessed 24 July 2013. apps.who.int/vaccines-access/vacman/transport/conditioningicepacks.htm

Young, M., Alders, R., Grimes, S., Spradbrow, P., Dias, P., da Silva, A. and Lobo, Q. (2012). Controlling Newcastle disease in village chickens: a laboratory manual. 2nd edn. ACIAR Monograph No. 87. Australian Centre for International Agricultural Research: Canberra. 143 pp.

Young, M., Alders, R., Coucelo, J., da Silva, M., Costa, R., Tavatava Ferreira, I., do Araújo Barbosa, I., Eudes da Costa, J. e dos Santos, A. (2012). Guião de conservação de vacinas: 5 é certo. Ministério da Agricultura Desenvolvimento Rural e Pescas, Projecto Redução e Controlo da Doença de Newcastle.



ACIAR

Research that works for developing
countries and Australia

aciarc.gov.au

