Public Health England

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UK Measles and Rubella elimination strategy 2019

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Published January 2019
PHE publications
gateway number: 2018703

PHE supports the UN
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Acknowledgements

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1. WHO definitions

Clinically compatible measles case: a suspected case that has not been adequately tested by laboratory and has not been epidemiologically linked to a confirmed measles case.

Clinically compatible rubella case: a suspected case that has not been adequately tested by laboratory and has not been epidemiologically linked to a confirmed rubella case.

Discarded case: a suspected case that was investigated and discarded, either through negative results of adequate laboratory testing for measles and rubella or by an epidemiological link to a laboratory-confirmed case of another disease; or confirmation of vaccine-associated illness by detection of vaccine measles or rubella RNA. In addition, IgM-positive cases in recent vaccine recipients can be discarded if they meet all of the following criteria:

- history of vaccination with relevant vaccine 7 days to 6 weeks prior to specimen collection;
- onset of rash 7−14 days after vaccination;
- no evidence of virus transmission revealed by active search in community;
- no history of travel to areas in which the virus is known to be circulating.

Disease elimination: the absence of endemic measles or rubella cases in a defined geographical area for a period of at least 12 months, in the presence of a well-performing surveillance system. Regional elimination can be declared after 36 or more months of the absence of endemic measles or rubella in all Member States.

Disease eradication: worldwide interruption of measles or rubella transmission in the presence of a verified, well-performing surveillance system.

Endemic case: a laboratory-confirmed or epidemiologically linked case of measles or rubella resulting from endemic transmission of measles or rubella virus.

Endemic transmission: continuous transmission of indigenous or imported measles or rubella virus that persists for a period of 12 months or more in a defined geographical area.

Epidemiologically linked measles case: a suspected case that has not been adequately tested by laboratory and that was in contact with a laboratory-confirmed measles case 7–18 days before the onset of symptoms.

Epidemiologically linked rubella case: a suspected case that has not been adequately tested by laboratory and that was in contact with a laboratory-confirmed rubella case 12–23 days prior to onset of the disease.

Genotype: Operational taxonomic unit defined on the basis of nucleotide variation between viral sequences. Measles virus genotypes are defined on the genetic analysis of the N-450 sequence, which is the most variable coding region of the measles virus genome. Rubella virus genotypes are defined on genetic analysis of the E1-739 sequence.

Imported case: a case exposed outside the country during the 7-18 days (measles) or 12-23 days (rubella) prior to rash onset as supported by epidemiological and/or virological evidence.

Import-related case: a locally-acquired measles or rubella infection occurring as part of a chain of transmission originating in an imported case, as supported by epidemiological and/or virological evidence. (Note: if transmission of import-related cases persists for 12 months or more, cases are no longer considered as import-related but as endemic).

Laboratory-confirmed measles case: a suspected case that meets the laboratory criteria for measles case confirmation (i.e. measles IgM in blood or oral fluid (OF) in the absence of recent vaccination, or confirmed wild-type measles RNA in any clinical specimen).

Laboratory-confirmed rubella case: a suspected case that meets the laboratory criteria for rubella case confirmation (i.e. rubella IgM in OF, or rubella, IgM and low avidity rubella IgG in blood, in the absence of recent vaccination, or confirmed wild-type rubella RNA in any clinical specimen.

MeaNS WHO Measles Nucleotide Surveillance online database (www.who-measles.org*)*

Named strain (measles only): Measles virus variant specifically identified and named in MeaNS with a representative N-450 sequence (“distinct sequence ID”) due to its ongoing transmission in multiple countries. The distinct sequence is used to describe clusters. It allows us to describe viral diversity with finer resolution within a single genotype.

Re-establishment of endemic transmission: re-establishment of endemic measles or rubella transmission is a situation in which epidemiological and laboratory evidence indicate the presence of a chain of transmission of a virus variant that continues uninterrupted for a period of 12 months or more in a defined geographical area where disease was previously eliminated.

RubeNS: WHO Rubella Nucleotide Surveillance online database
www.who-rubella.org

Suspected measles case: a case with signs and symptoms consistent with measles clinical criteria: fever *and* maculopapular rash *and* cough or coryza (runny nose) or conjunctivitis (red eyes).

Suspected rubella case: a case with signs and symptoms consistent with rubella clinical criteria: maculopapular rash *and* cervical, suboccipital or post-auricular adenopathy, or arthralgia/arthritis.

2. Abbreviations

ADR	adverse drug reaction
BPSU	British Paediatric Surveillance Unit
CHIS	child health information systems
CHM	UK Commission on Human Medicines
CISID	Centralized Information System for Infectious Diseases
COVER	cover of vaccination evaluated rapidly
CRI	congenital rubella infection
CRPD	Clinical Practice Research Datalink
CRS	congenital rubella syndrome
CSF	cerebrospinal fluid
ECDC	European Centre for Disease Prevention and Control
FES	Field Epidemiology Services
GMS	general medical services contract
HCW	healthcare workers
HES	hospital episode statistics
HPT	health protection team
HPV	human papilloma virus
JCVI	Joint Committee on Vaccination and Immunisation
GUM	genitourinary medicine
LA	Local Authority
MCV	measles-containing vaccine
MHRA	Medicines and Healthcare Regulatory Agency
MMR	measles, mumps and rubella
MR	measles and rubella
NICE	National Institute for Health and Care Excellence
NIP	national immunisation programme
NIS	National Infection Service
NVC	national verification committee
OF	oral fluid
OFT	oral fluid test
ONS	Office of National Statistics
PCR	polymerase chain reaction
PCT	primary care trust
PHE	Public Health England
PMP	per million population
QOF	quality and outcomes framework
RCV	rubella containing vaccine
RIP	rubella infection in pregnancy
RVC	regional verification commission
SAGE	Strategic Advisory Group of Experts
SGSS	second generation surveillance system
SSPE	sub-acute sclerosing pan-encephalitis

TIP	tailoring immunisation programmes
VRD	Virus Reference Department
WHO	World Health Organisation

3. Executive summary

Building on the experience and success of fifty years of measles vaccination and thirty years of the Measles Mumps and Rubella (MMR) immunisation programme, this Strategy maps out how the UK can achieve a future that is free of measles, rubella and congenital rubella syndrome (CRS).

Since the introduction of the measles vaccine in 1968 it is estimated that 20 million cases and 4,500 deaths have been averted in the UK. From 1970 to 2017 it is estimated that rubella vaccination has averted 1,300 CRS births and 25,000 terminations. The childhood rubella vaccination programme alone has averted 1.4 million cases of rubella in the UK.

Eliminating measles and rubella is a core goal of the European Vaccine Action Plan 2015–2020 and an important part of global efforts to improve health and reduce inequalities. All Member States of the World Health Organization (WHO) European Region have a longstanding commitment to eliminating measles and rubella.

The WHO confirmed that the UK had eliminated rubella in 2015 and measles in 2016. This is a huge achievement and a testament to the hard work of health professionals in the NHS that led to uptake of the first dose of the MMR vaccine in 5 year olds reaching the 95% WHO target for the first time in 2016/17.

To achieve and maintain elimination, however, WHO recommends that we aim for 95% uptake with two doses of MMR by 5 years of age. Current UK performance for the second dose is sub-optimal at 88%. In addition, new PHE analyses suggest that population immunity levels are well below those required to interrupt measles transmission in many birth cohorts. Young people born between 1998/99 and 2003/04 (aged 15 to 20 years in 2018) are the most susceptible. London remains the most vulnerable region with immunity targets not achieved for many birth cohorts - including younger children of primary and secondary school age. There are also inequalities in vaccine uptake by ethnicity, deprivation and geography and the burden of measles and rubella falls disproportionately on certain communities.

Measles and rubella remain endemic in many other countries and, with current large measles outbreaks across Europe, imported infections pose a very real threat to the UK’s recent achievements. There is a risk that the UK will lose its elimination status for measles unless steps are taken to successfully address immunity gaps in the population

The Strategy focuses on four core components, all of which are required to maintain elimination going forward:

1. Achieve and sustain ≥ 95% coverage with two doses of MMR vaccine in the routine childhood programme (<5 years old)

2. Achieve ≥ 95% coverage with two doses of MMR vaccine in older age cohorts through opportunistic and targeted catch-up (>5 years old)

3. Strengthen measles and rubella surveillance through rigorous case investigation and testing ≥80% of all suspected cases with an Oral Fluid Test (OFT)

4. Ensure easy access to high-quality, evidence-based information for health professionals and the public

This Strategy has been independently assessed and endorsed by the UK National Verification Committee (NVC) and all of the UK nations have committed to taking the recommendations forward. In order to ensure successful implementation each of the countries must now draw up a national action plan with appropriate oversight from a multi-stakeholder group. Local teams will also need to take ownership of local plans to address the specific issues affecting their communities and services.

4. Background and rationale

Global measles eradication is considered feasible and cost-effective. In 2010, the WHO Strategic Advisory Group of Experts (SAGE) on Immunization conducted a comprehensive review of the evidence to establish the biological and technical feasibility of measles eradication and concluded that measles can and should be eradicated. They also concluded that, by using combined measles and rubella (MR) vaccines and conducting integrated surveillance for fever and rash, there is an opportunity to also eradicate rubella and to prevent congenital rubella syndrome.

Box 1. Criteria for disease eradication

Measles and rubella meet the necessary criteria for eradication:

- there is no animal or environmental reservoir and humans are critical to maintaining transmission
- accurate diagnostic tests are available
- vaccines and existing vaccination strategies for both diseases are highly effective and safe: the vaccine effectiveness of MMR is more than 90% for a single dose and more than 95% for two doses
- transmission has been interrupted in a large geographic area for a prolonged period of time

Eliminating measles and rubella is a core goal of the European Vaccine Action Plan 2015–2020 which all Member States have signed up to. Measles is highly infectious - the most infectious of all diseases transmitted through the respiratory route. As a result very high coverage (≥ 95%) with two doses of the MMR vaccine is necessary to interrupt virus transmission.

Measles (and rubella) elimination is defined by WHO as the absence of endemic transmission in a defined geographic area (e.g. UK) for a period of at least 12 months in the presence of a well-performing surveillance system. The elimination verification process is based on evidence documented by each Member State to show whether interruption of endemic transmission of measles and/or rubella at national level has been achieved and, if not, that a national plan has been developed to address this. PHE collates the required documentation on behalf of the devolved administrations for submission to the UK NVC and the WHO Regional Verification Commission for Measles and Rubella Elimination (RVC) for evaluation on an annual basis.

Before the introduction of measles vaccine in 1968 there were anywhere between 160,000 to 800,000 measles notifications and 100 deaths from acute measles in the UK each year. Similarly, more than 80% of adults had evidence of previous rubella

infection and before the introduction of a selective rubella vaccine programme in 1970; rubella infection in pregnancy (RIP) caused a significant burden in terms of terminations and babies born with Congenital Rubella Syndrome.

Thirty years on, the success of the MMR immunisation programme means that the UK has achieved both measles and rubella elimination. However more challenges lie ahead. We have yet to achieve the WHO target of 95% uptake with two doses of the MMR vaccine given by 5 years of age. We also know that population immunity levels are below those required to interrupt measles transmission in many birth cohorts with young people the most susceptible.

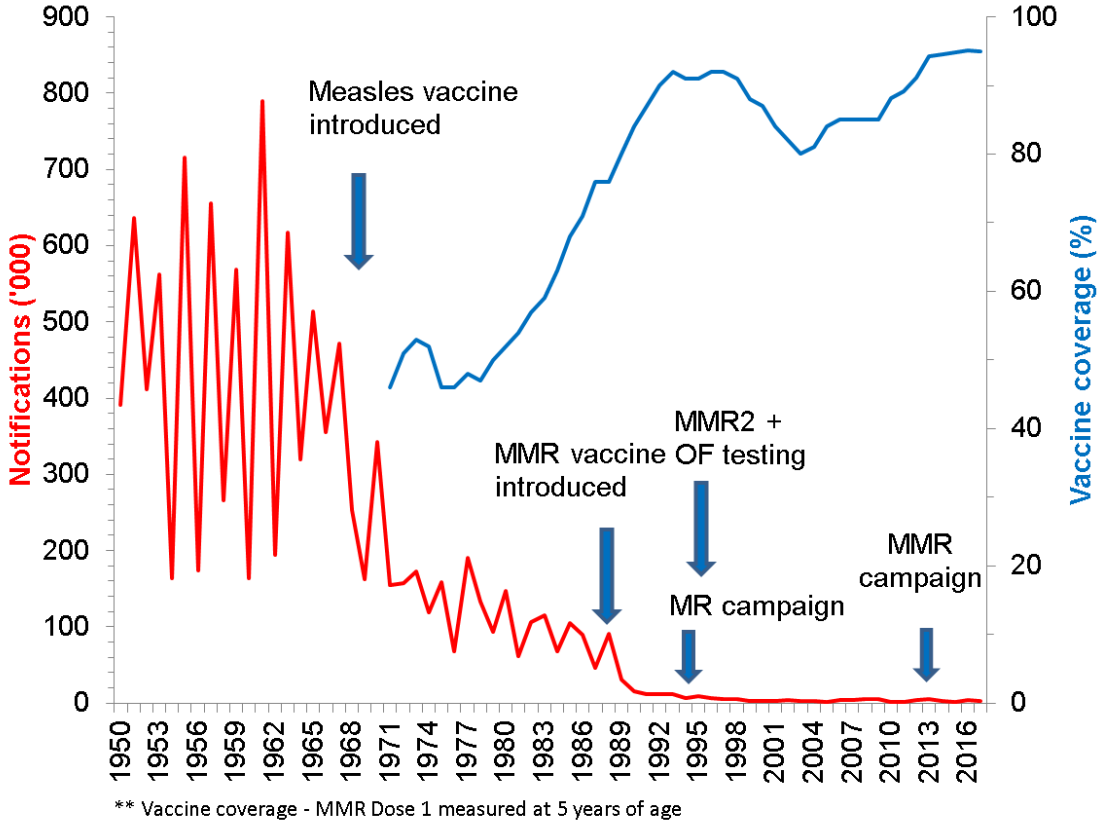
This document describes the evolution of the epidemiology of measles and rubella and associated burden of disease in the UK and captures fifty years of history of the national immunisation programme (NIP). It celebrates the successes that have been achieved in partnership with the NHS and highlights the gaps that still require our attention. In the final section we outline the steps needed to strengthen our immunisation programme and close the immunity gaps in the population to secure measles and rubella elimination for future generations.

Section 1. Situational analysis

1.1 History of measles epidemiology and immunisation in the UK

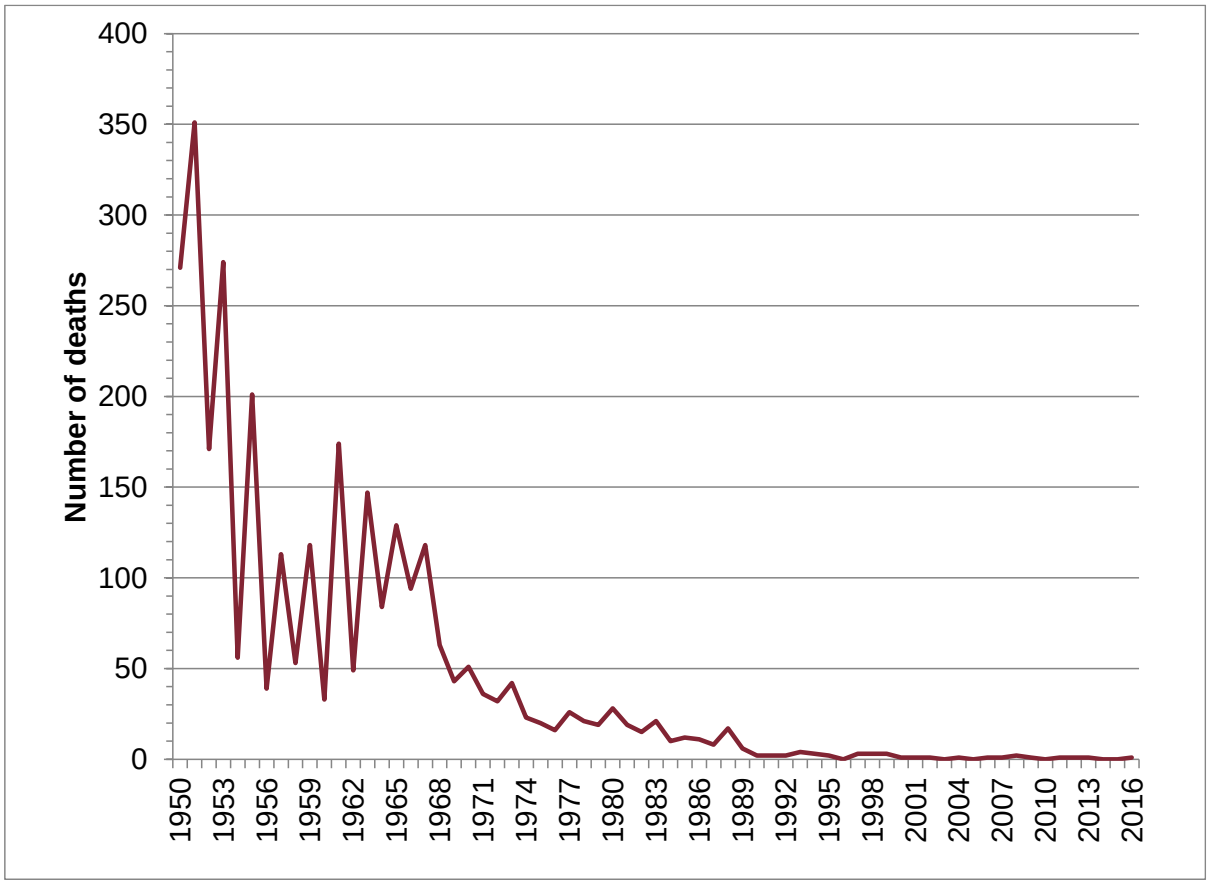
Notification of measles began in England and Wales in 1940. Before the introduction of measles vaccine in 1968, annual notifications ranged from 160,000 to 800,000, with peaks every two years (see Figure 1). More than 80% of adults had evidence of previous infection and around 100 deaths from acute measles were recorded each year. Vaccine coverage remained low until the late 1980s and was insufficient to interrupt measles transmission. Therefore, annual notifications only fell to between 50,000 and 100,000 and measles remained a major cause of morbidity and mortality.

Figure 1. UK coverage of measles vaccination and measles notifications from 1950 to 2016



Between 1970 and 1988, there continued to be an average of 13 acute measles deaths each year (Figure 2). Measles remained a major cause of mortality in children who could not be immunised because they were receiving immunosuppressive treatment. Between 1974 and 1984, of 51 children in remission from acute lymphatic leukaemia who died, 15 (29%) died from measles or its complications[1]. Between 1970 and 1983, more than half of acute measles deaths occurred in unimmunised children who were previously healthy[2].

Figure 2. Measles deaths, England and Wales, 1940 to 2016, Office for National Statistics



Following the introduction of measles, mumps and rubella (MMR) vaccine in October 1988 for children aged 13 to 15 months (with a catch up for children up to pre-school age), and the achievement of coverage levels in excess of 90%, measles transmission was substantially reduced and notifications of measles fell progressively to very low levels.

Because of the significant reduction in measles transmission in the UK, children were no longer exposed to measles infection and, if they had not been immunised, they remained susceptible to an older age. Seroprevalence studies confirmed that a higher proportion of school-age children were susceptible to measles in 1991 than in 1986/7[3]. A major resurgence of measles was predicted, mainly affecting the school-age population[3,4]. Small outbreaks of measles occurred in England and Wales in 1993, predominantly affecting secondary school children[5]. In 1993–94, a measles epidemic, affecting the west of Scotland, led to 138 teenagers being admitted to one hospital.

In order to prevent the predicted epidemic, a UK vaccination campaign was implemented in 1994. Over 8 million children aged between 5 and 16 years were immunised in school with MR vaccine. At that time, insufficient stocks of MMR were available to vaccinate all of these children against mumps. Susceptibility to measles

fell seven-fold in the target population and endemic transmission of measles was interrupted[6,7].

To maintain the control of measles established after the MR campaign, the second MMR dose was added in October 1996 to the existing routine pre-school booster immunisation programme. A one-off catch-up campaign was also implemented for those children who were too young to be immunised during the 1994 MR campaign but who were too old for the routine pre-school MMR second dose. A second dose of MMR helps to prevent an accumulation of susceptible individuals that could otherwise be sufficient to re-establish measles transmission. The efficacy of a single dose of measles-containing vaccine is around 90%[8,9]. A second dose of measles-containing vaccine protects those who do not respond to the first dose and boosts antibody levels in those who did respond. In order to eliminate measles, the WHO recommends two doses of a measles-containing vaccine.

By 1996 the UK appeared to have interrupted endemic transmission of measles and the two dose MMR schedule was well established with high coverage achieved for the routine childhood programme.

1.2 Review of measles epidemiology and immunisation programme from 2001 to 2017

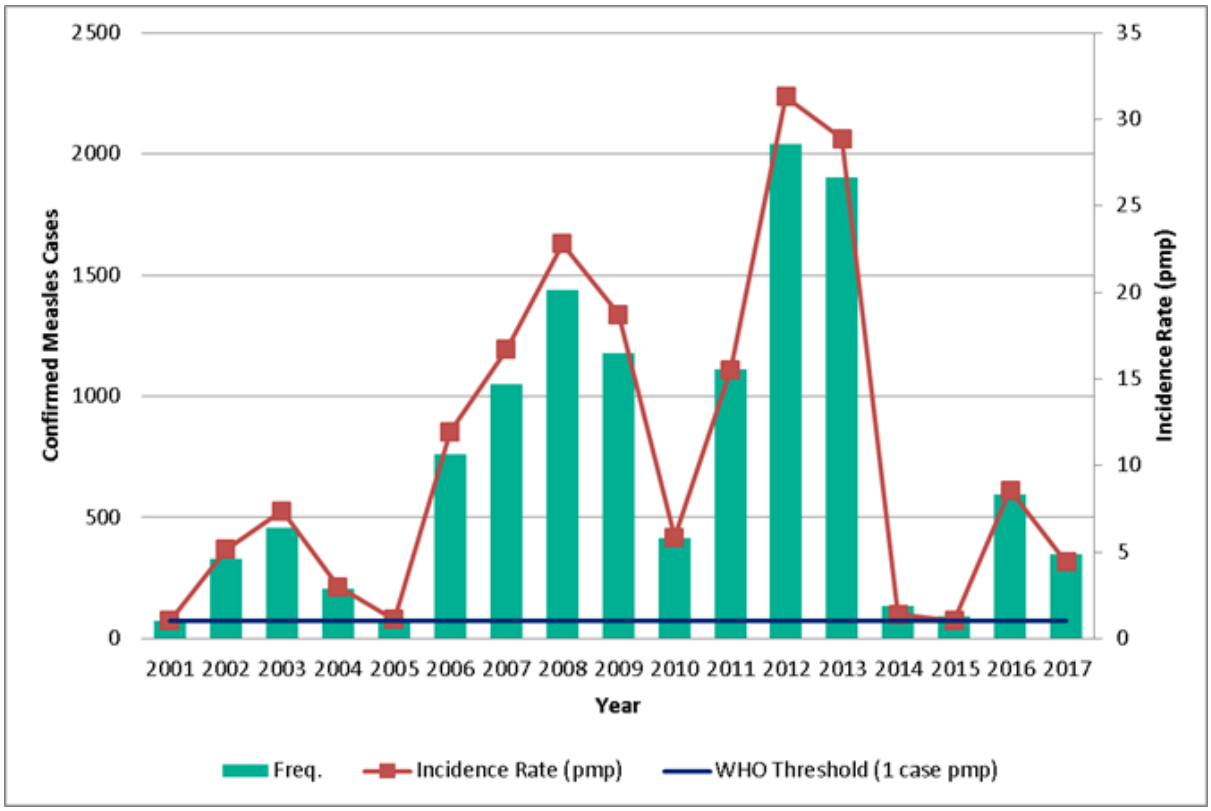
In 1998 Andrew Wakefield published his now infamous and discredited paper linking MMR to autism[10]. This resulted in intense media coverage in the UK and worldwide which peaked in 2002. It had an important impact on MMR coverage which dropped to about 80% nationally in the late nineties and early 2000s and took many years to recover.

During this period endemic transmission of measles remained interrupted and by 2004 it is likely that it was eliminated (this was not an official WHO status at that time). However the fall in MMR coverage led to a critical increase in the number of children susceptible to measles and it became clear that there was the potential for large outbreaks, particularly in cities, with London being the worst affected. In response, a London-wide ‘capital catch-up’ MMR vaccination campaign was launched targeting primary school-age children during the winter of 2004/05 during which it is estimated that about 40,000 children were immunised. Measles cases continued to rise and in 2006 endemic transmission became re-established in the UK with a disproportionate burden of cases in primary school children, the Irish traveller community, and the Orthodox Jewish community.

By 2007 the annual number of confirmed measles cases exceeded 1000 for the first time in a decade with the majority of cases in the 1 to 4 and 5 to 14 year old age groups (Figures 3 and 4). Modelling studies were conducted that predicted an epidemic of measles with the potential for 6,000 to 125,000 cases and the most

immediate risk of around 30,000 cases in London. In August 2008 the Chief Medical Officer called for a nationwide catch-up programme for MMR vaccination targeted at children of all ages from 13 months to 18 years in the main with individuals over 18 years leaving school to go to higher education or other further education establishments being included as a lower priority[11]. Primary Care Trusts (PCTs) were charged with implementing the campaign which was GP based and included the identification of eligible children, ensuring invitation for vaccination, and appropriate follow-up to encourage non-attenders to be vaccinated.

Figure 3. Annual number of laboratory confirmed measles cases and incidence* from 2001 to 2017 (n=12,201), UK.



* Incidence rate = confirmed measles cases / mid-year UK population. This excludes imported cases. Pmp = per million population.

A London evaluation estimated that the 2008 catch-up programme increased coverage with at least one dose of MMR in the under 5 year olds from 75% to 81%. However the impact on the 5 to 18 year olds was much more limited with less than a 1% increase in MMR coverage overall.

As a result there remained a significant proportion of susceptible children among the teenage cohorts who sustained another large outbreak in 2012 which started in Wales and spread to the rest of the UK. A national catch-up campaign was launched in April 2013 with the objective of ensuring that 95% of children aged 10 to 16 years received at least one dose of MMR. The campaign evaluation estimated that vaccine coverage (one dose of measles-containing vaccine) in England at

baseline was higher than routinely reported and was close to 95%[12]. Eleven per cent of the target population (previously unvaccinated children aged 10 to 16 years) were reached by the catch-up campaign at mid-point. Estimated coverage in London was 88%, significantly lower than in the rest of England. However it is believed that this is an underestimate due to less accurate data recording and higher mobility of the population when compared to the rest of the country. Nevertheless it was estimated that about 210,000 children aged 10 to 16 years remained unvaccinated nationally, with 80,000 (38%) of them in London.

By 2014 the UK had interrupted endemic transmission of measles (See Figure 4) and in 2017 the RVC for Measles and Rubella Elimination declared that the UK had eliminated measles[13]. In England, vaccine coverage of the first MMR dose evaluated in 5 year olds also reached the WHO 95% target for the first time in 2016/17. Annual vaccine coverage estimates for MMR1 at age two has never reached the WHO target of 95% in England and has been decreasing since 2013/14.

Figure 4. Imported, import-related and endemic measles cases in the UK from 2001 to 2017 (n=12,201)

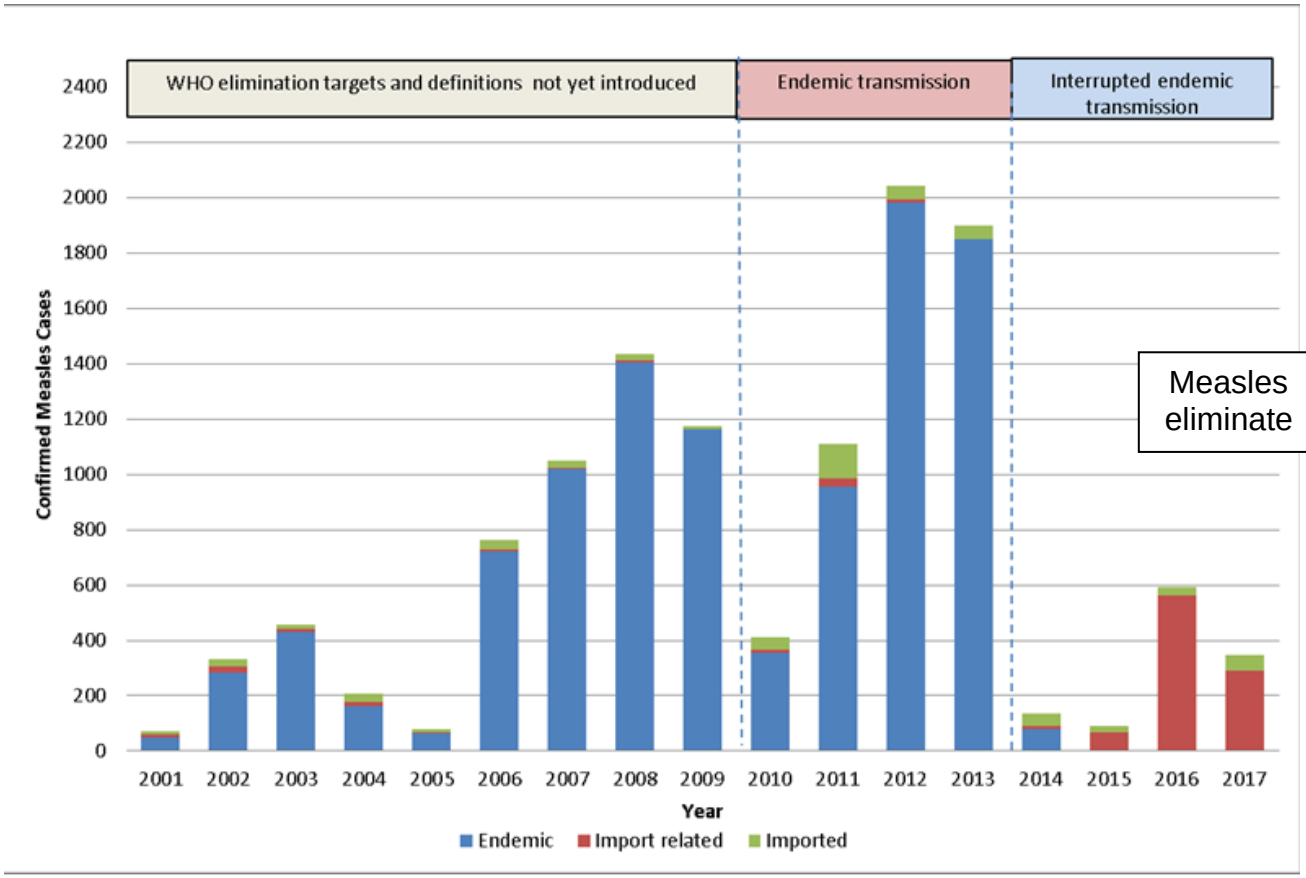


Figure 5 and Table 1 depict how the age profile of lab confirmed measles cases has changed over time. The burden of disease has moved from the younger age groups to those over 15 years of age in more recent years. However rates of disease remain highest in infants under the age of 1, reminding us of the importance of

achieving high coverage in the population in order to protect those who are not eligible for vaccination or cannot be immunised for other reasons.

Figure 5. Annual laboratory confirmed measles cases by age group from 2001 to 2017, UK (n=12,128 (Excl. age NK))

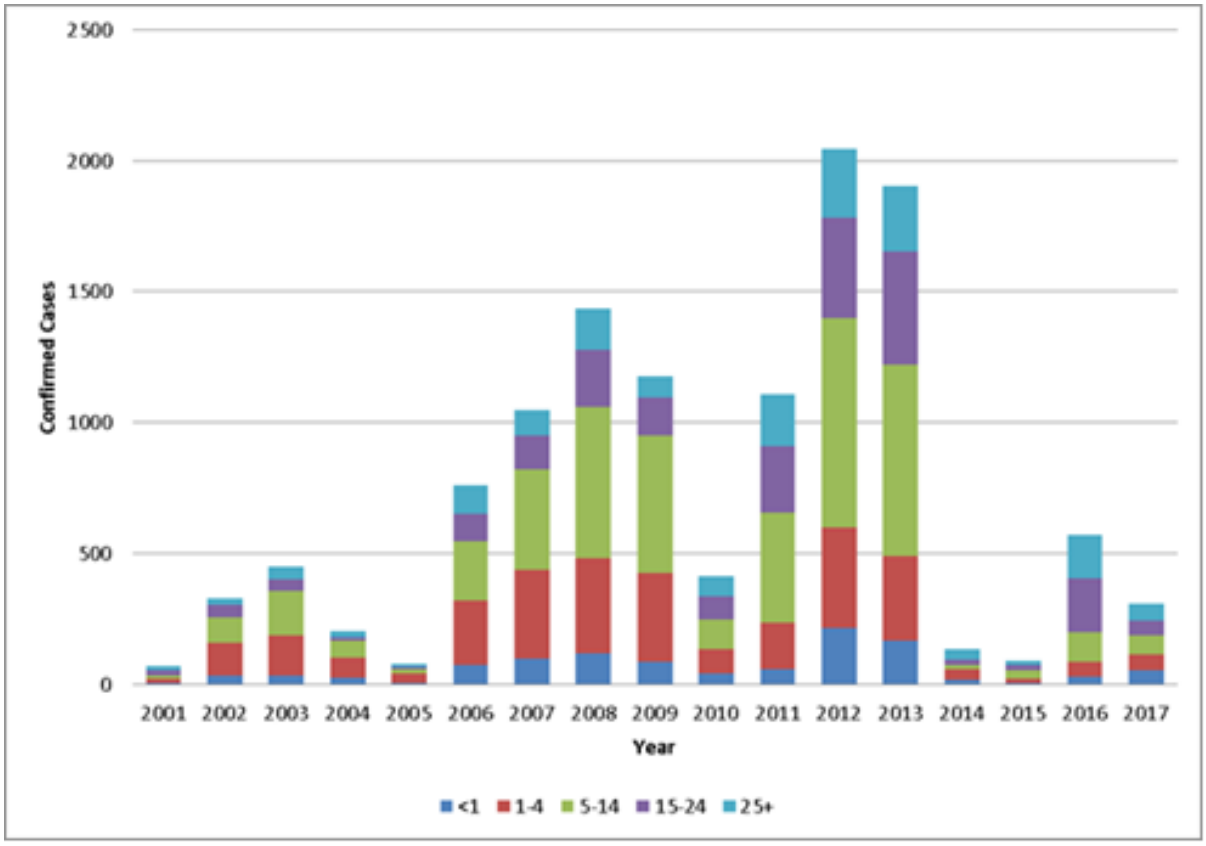


Table 1. Annual age specific rates of lab confirmed measles cases per 100,000 population, 2010 to 2017 in England and Wales.

Age group	2010	2011	2012	2013	2014	2015	2016	2017
under 1 year	4.51	8.06	29.37	22.93	2.58	1.15	3.84	5.41
1 to 4 years	2.96	6.14	13.57	10.79	1.24	0.51	1.90	2.07
5 to 9 years	1.38	5.63	11.17	7.05	0.23	0.25	1.22	0.91
10 to 14 years	1.86	7.39	13.59	15.17	0.22	0.63	2.19	1.05
15 to 24 years	1.16	3.31	5.16	5.74	0.33	0.32	2.66	0.64
over 25 years	0.19	0.50	0.67	0.60	0.10	0.04	0.38	0.15

Ninety three percent of the confirmed measles cases from 2001 to 2016 for whom vaccination status was known were unimmunised. Only 5% of cases had received one measles-containing vaccine and 2% had received two or more measles-containing vaccines.

Achieving measles elimination does not mean that measles has been wiped out. Measles remains endemic in many countries around the world and since 2016 there have been large measles outbreaks across Europe. Multiple importations to the UK

have led to a number of outbreaks in recent years, with some limited spread in the population, particularly young people and adults who missed out on MMR vaccine when they were younger and under vaccinated communities such as travellers, migrant populations and the Anthroposophic (Steiner) community[14].

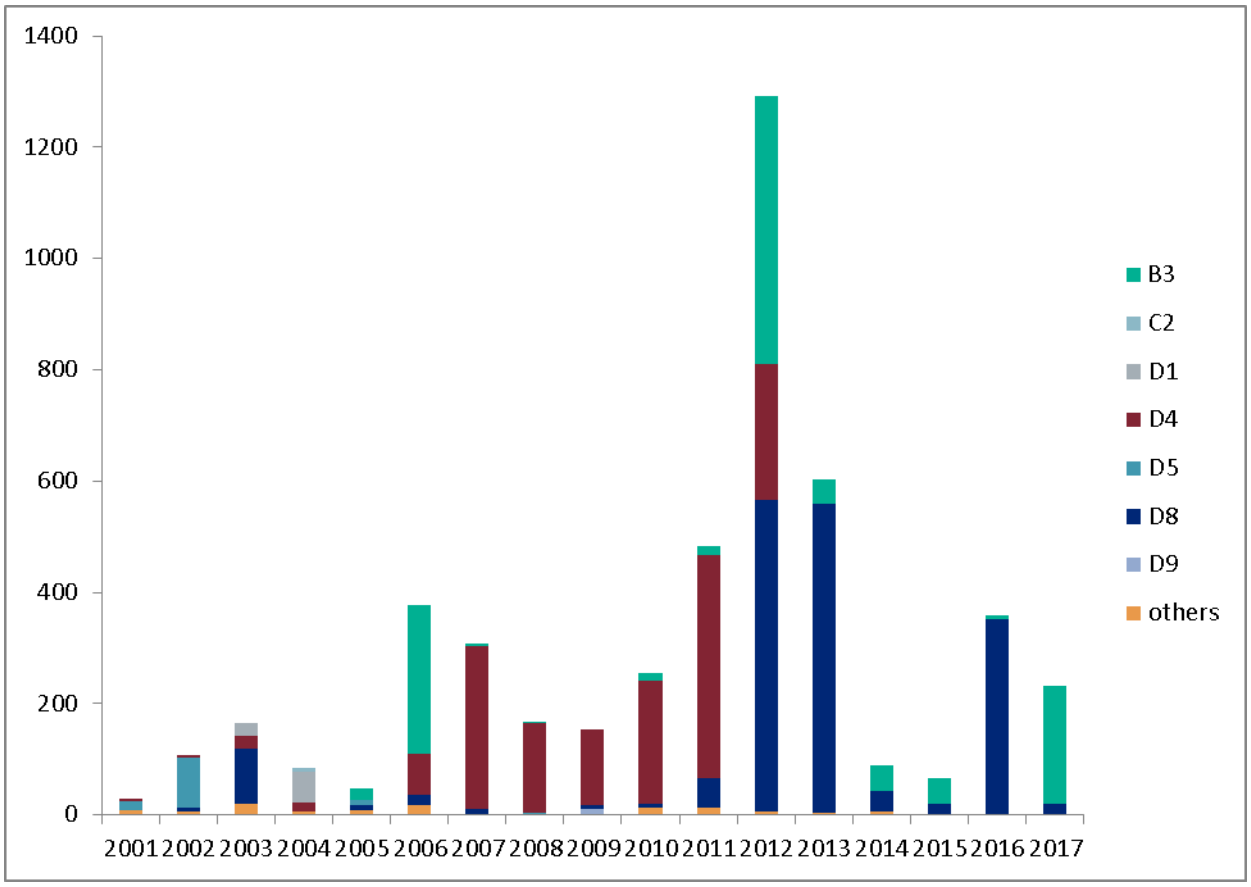
PHE National Measles Guidelines[15] outline how cases and contacts should be investigated and managed in order to achieve measles control.

1.2.1 Measles genotypes

Although 24 different genotypes have been described, with increased global control of measles infection the number of circulating genotypes has decreased. In the past, the requirement for sequence information was inversely proportional to the number of cases of measles described, in an outbreak situation only a representative sample of cases would have required sequencing. In general, countries without endemic measles will identify multiple genotypes among their cases reflecting importations from different parts of the world, whereas countries with endemic measles would normally only have one or two circulating genotypes.

In more recent years, as the number of global genotypes has decreased (only 5 circulating genotypes since 2016: B3, D4, D8, D9 and H1), even countries with sporadic cases only detect one or two genotypes. Distinction of importations is determined by strain information as well as by the genotype, and once elimination status is achieved sequence is required on more than 80% of clusters and sporadic cases.

Figure 6. Number of sequences and genotypes by year, UK, 2001-2017. Source: MeaNS database (n = 4,814)

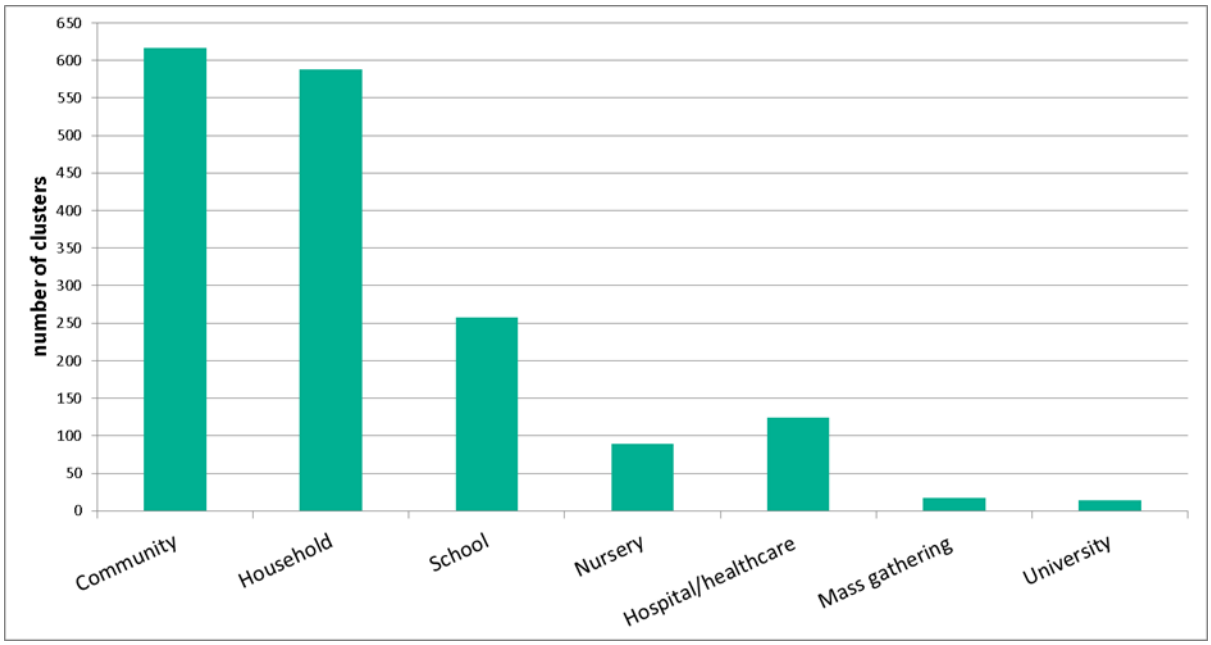


1.2.2 Clusters

An analysis of the clusters from 2010 to 2016 (Figure 7) reveals that most transmission occurs in the community or household setting. Traveller communities, the Orthodox Jewish community and Anthroposophic (Steiner) community suffer a disproportionate burden of disease due to lower vaccine uptake. Ethnicity and country of origin are not routinely captured in disease surveillance data and so identifying whether a case is a member of an under-vaccinated community requires the Health Protection Team (HPT) to flag them as such during the risk assessment.

Schools and nurseries are the main setting for the majority of outbreaks occurring outside of the household or community although there is also a significant burden associated with transmission in health care settings where the risk of exposing vulnerable individuals is greater.

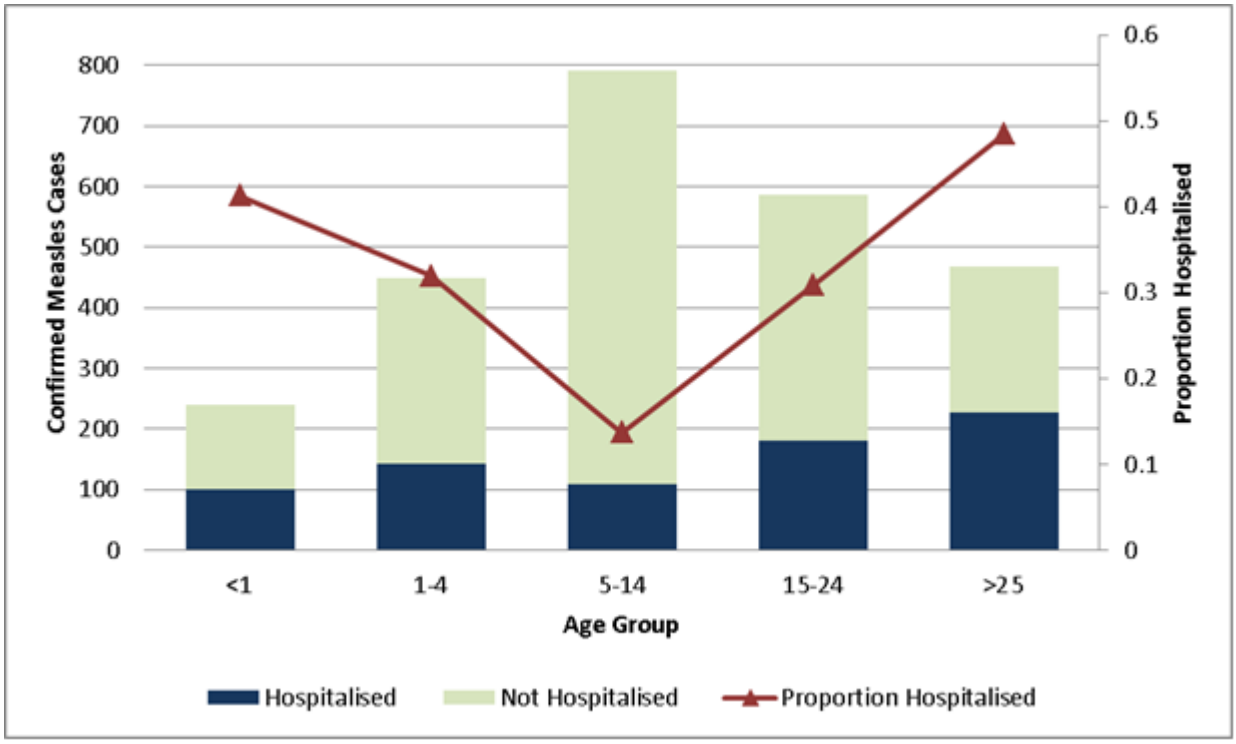
Figure 7. Measles cases in various communities across the England and Wales from 2001 to 2017 (n=1,707)



1.2.3 Hospitalisations

More than one in three (38%) of the measles cases in England and Wales confirmed between 2014 to 2016 were hospitalised, reflecting the age profile of the cases (Figure 8). As expected, the burden of hospitalisation is much higher in adults over 25 years (54.8%) who represent 27% of all cases confirmed during this time period. These data are based on reported hospitalisation on HPZone records and enhanced surveillance forms as Hospital Episode Statistics (HES) are not currently linked to routine surveillance data.

Figure 8. Hospitalisation rates in confirmed measles cases in the UK from 2013 to 2017 (n=2,553)



1.3 Sub-acute Sclerosing Pan-encephalitis

Sub-acute Sclerosing Pan-encephalitis (SSPE) is a rare, fatal neurological disease caused when measles virus establishes chronic infection in the brain. The UK SSPE registry, which is coordinated by PHE, was established in 1970, two years after the introduction of measles vaccine. SSPE cases were ascertained from a variety of sources in early years, including reports from paediatricians through the Surveillance Unit of the Royal College of Paediatrics and Child Health, reports from laboratories and reports from neurologists. In March 2002 a case finding exercise was undertaken, whereby virology and microbiology laboratories in England and Wales were contacted for reports of SSPE cases diagnosed since 1990, however no additional cases were identified. Death certificates for relevant categories from the Office for National Statistics (ONS) are routinely reviewed to identify any additional cases not reported to the registry. SSPE cases are formally reported to WHO.

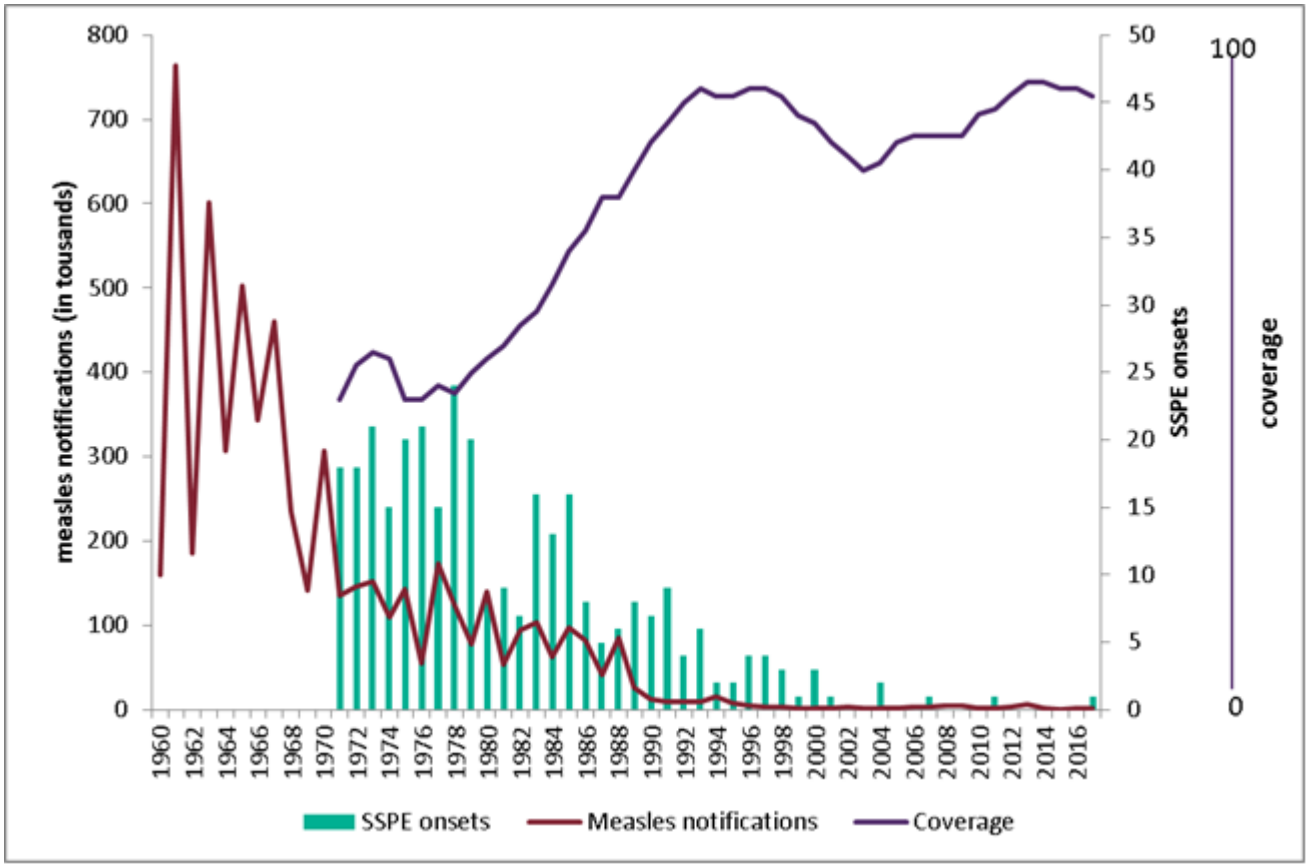
All the cases from 1990 onwards have been confirmed by the Virus Reference Department (VRD). The PHE VRD receives serum and cerebrospinal fluid (CSF) samples from laboratories for diagnostic confirmation and brain biopsy material where this is available. Diagnosis is based on finding a raised measles-specific IgG index, calculated using paired serum and CSF samples to compare the measles, rubella, Herpes Simplex Virus and Varicella Zoster Virus ratios (i.e. CSF measles antibody/ serum measles antibody) with the albumin ratio (CSF albumin/serum

albumin). Confirmation of the diagnosis can be achieved through detection of measles RNA or antigen in brain biopsy material.

The reduced incidence of measles, brought about by vaccination caused the almost total disappearance of SSPE in England and Wales. In the early 1970s, when the SSPE Register was put in place, around 20 cases were reported each year. By the early 1990s, the annual total had fallen to around six cases and this has fallen further to between one and none in recent years[16,17] despite testing an average of 20 clinically suspected cases each year.

In the twelve years between 2006 and 2017 only two cases of SSPE were identified with presumed UK measles acquisition. In addition there are currently six SSPE cases that are alive in the UK. Four of these cases were UK born with onset of symptoms between 1999 and 2010.

Figure 9. Measles notification, SSPE onsets and vaccine coverage in England and Wales 1960 to 2017



1.4 History of rubella epidemiology and immunisation in the United Kingdom

Before the introduction of rubella immunisation, rubella occurred commonly in children, and more than 80% of adults had evidence of previous rubella infection[18].

Rubella immunisation was introduced in the UK in 1970 for prepubertal girls and non-immune women of childbearing age to prevent RIP. Rather than interrupting the circulation of rubella, the aim of this strategy was to directly protect women of childbearing age by increasing the proportion with antibody to rubella; this increased from 85 to 90% before 1970 to 97 to 98% by 1987[6].

Surveillance for congenital rubella was established in 1971 to monitor the impact of the vaccination programme. During the period 1971–75 there were an average of 48 CRS births and 742 terminations annually in the UK[19].

Although the selective immunisation policy was effective in reducing the number of cases of CRS and terminations of pregnancy, cases of RIP continued to occur. This was mainly because the few women who remained susceptible to rubella could still acquire rubella infection from their own and/or their friends' children.

Universal immunisation against rubella, using the MMR vaccine, was introduced in October 1988. The aim of this policy was to interrupt circulation of rubella among young children, thereby protecting susceptible adult women from exposure. At the same time, rubella was made a notifiable disease. A considerable decline in rubella in young children followed the introduction of MMR, with a concomitant fall in rubella infections in pregnant women – from 167 in 1987 to one in 2003.

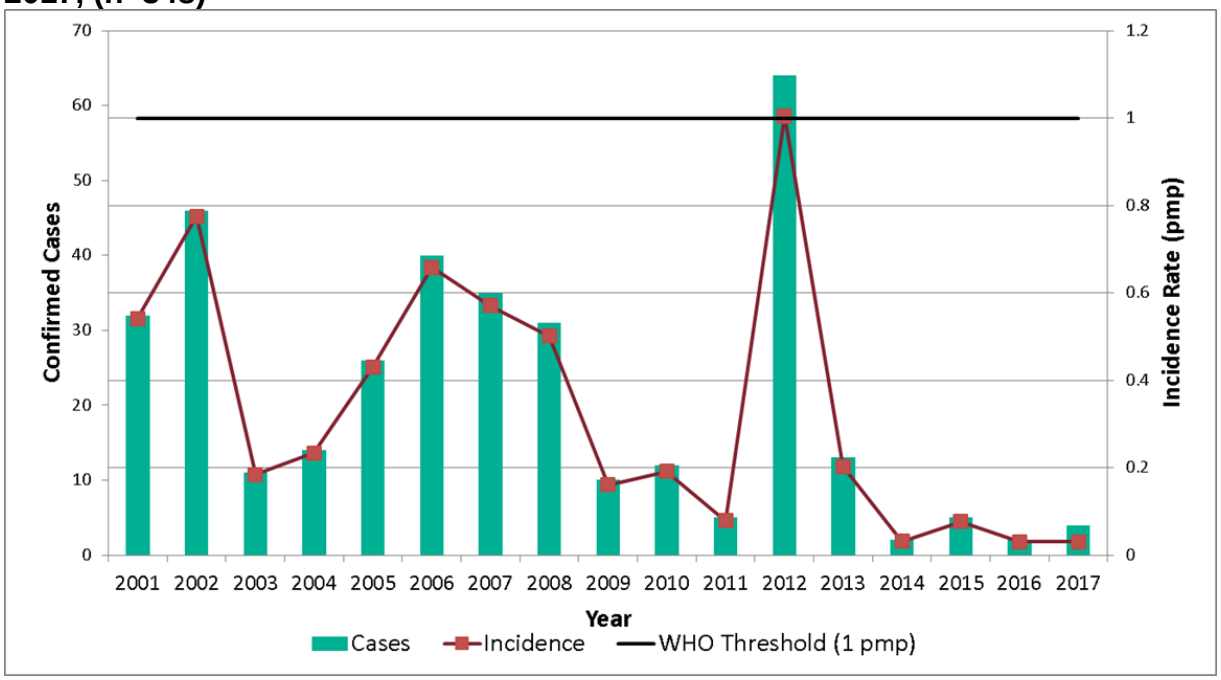
A seroprevalence study in 1989 showed a high rate of rubella susceptibility in school-age children, particularly in males[20]. In 1993, there was a large increase in both notifications and laboratory-confirmed cases of rubella. Many of the individuals affected would not have been eligible for MMR or for the rubella vaccine. For this reason, the combined MR vaccine was used for the schools campaign in November 1994. At that time, insufficient stocks of MMR were available to vaccinate all of these children against mumps. Over 8 million children aged between 5 and 16 years were immunised with the MR vaccine.

In October 1996, a two-dose MMR schedule was introduced and the selective vaccination policy of teenage girls ceased. A further resurgence of rubella was observed in the UK in 1996. Many of these cases occurred in colleges and universities in males who had already left school before the 1994 MR campaign[6].

1.5 Review of rubella epidemiology 2001 to 2016

The annual incidence of rubella in the UK has been well below the WHO threshold of 1 case per million population (pmp) over the last 15 years. (Figure 10) The peak in 2012 reflects an outbreak linked to importation from France that affected unvaccinated individuals attending a boarding school and a Steiner school.

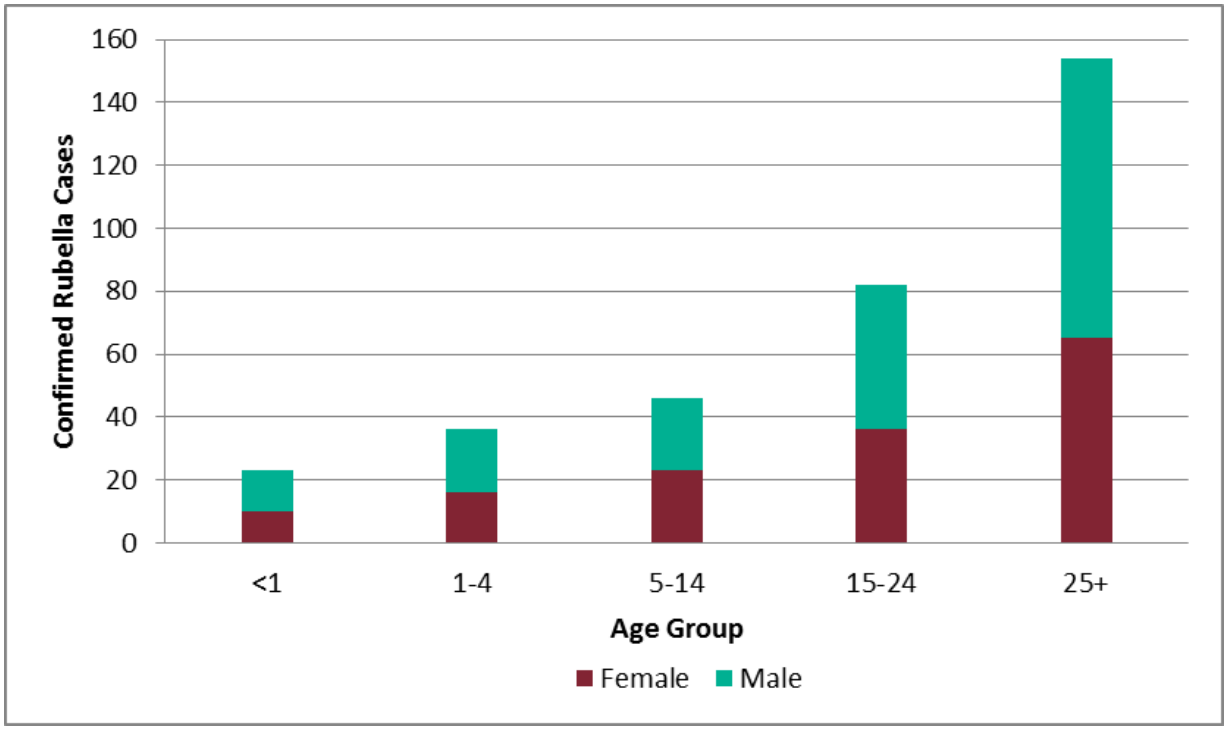
Figure 10. Confirmed rubella cases and incidence* in the UK from 2001 to 2017, (n=348)



* Incidence = confirmed rubella cases / mid-year UK population. This excludes imported cases. Pmp = per million population

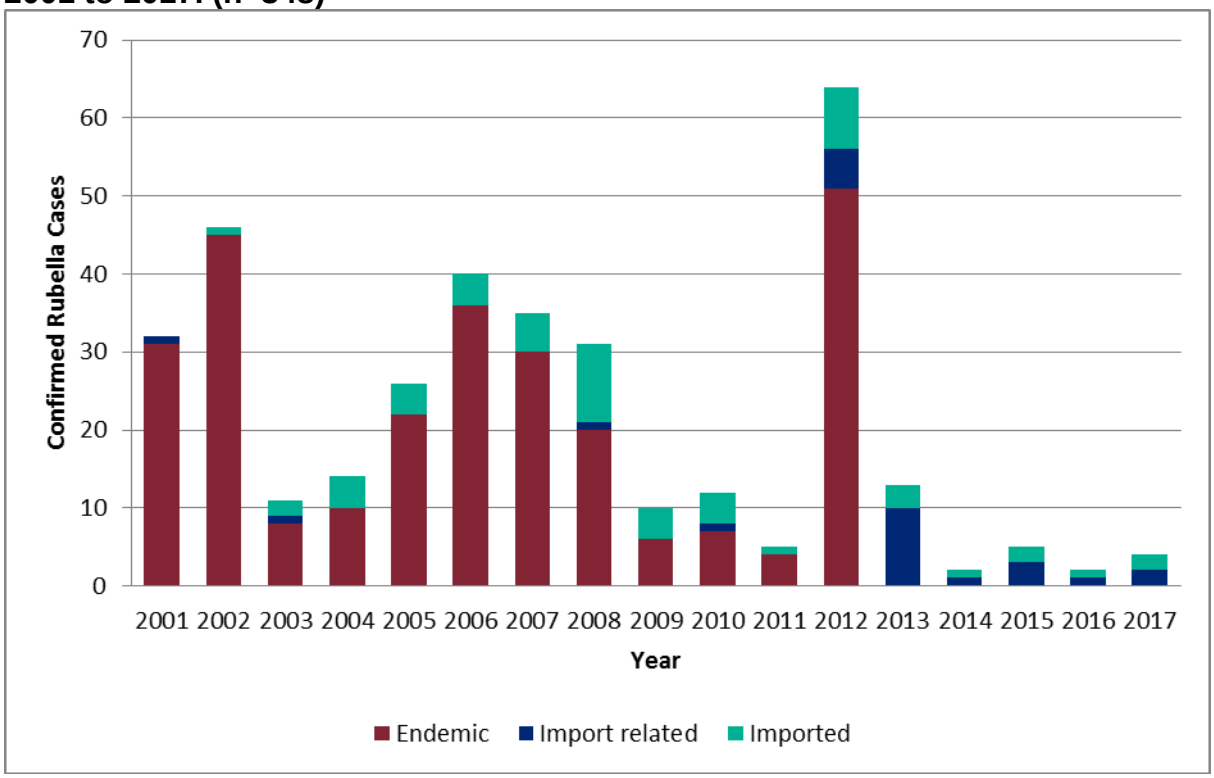
Most of the cases were reported in adults over the age of 25 (44% of cases), and men (58% of cases) are over-represented (Figure 11). London and the South East regions of England accounted for 67% of the cases confirmed during this time period.

Figure 11. Confirmed rubella cases by sex and age group in the UK from 2001 to 2017



In recent years cases have become sporadic with most classified as imported or import related and the RVC for Measles and Rubella Elimination declared that the UK eliminated endemic transmission of rubella in 2015.

Figure 12. Imported, import-related and endemic rubella cases in the UK from 2001 to 2017. (n=348)



1.6 Rubella infections in pregnancy (RIP) and congenital rubella infections (CRI)

The National Congenital Rubella Surveillance Programme, established in 1971 at the Institute of Child Health (London) captures reports of all suspected and confirmed cases of congenital rubella captured through the Royal College of Paediatrics and Child Health's British Paediatric Surveillance Unit (BPSU).

The PHE Guidance on Viral Rash in Pregnancy[21] outlines how every suspected case of RIP should be investigated. PHE conducts enhanced surveillance of reported RIP. Paired serum samples are requested from all suspected rubella cases in pregnant women in order to confirm the diagnosis and distinguish between primary infection and reinfection. Primary rubella infection is confirmed by a combination of rubella IgM plus either rubella IgG seroconversion, detection of rubella virus RNA and/or detection of low avidity rubella antibody. Rubella reinfection is distinguished by a significant increase in rubella IgG that has high avidity. The outcome of pregnancy and live birth (if relevant) is followed up and a

range of samples (cord blood, placenta, urine and OF) are collected from mother and baby for analysis.

Congenital rubella infection (CRI) is confirmed by detection of rubella IgM in serum or OF and/or detection of rubella RNA in body fluids. Infants with clinical features consistent with CRS are classified as CRS cases. Where possible retrospective laboratory investigations of maternal pregnancy samples are carried out for infants whose mothers were not previously diagnosed with infection in pregnancy.

Between 2010 and 2016, 13 RIP cases were diagnosed across the UK (0.19 infections per 100,000 pregnancies each year). This is a reduction from 18 infections in pregnant women that occurred in the previous seven years (0.27 rubella infections per 100,000 pregnancies each year, 2003-2009). Of the 31 infections identified in pregnancy over this fourteen year period, four were considered to have had a reinfection and 27 were primary infections. The risk to the fetus of subclinical maternal reinfection in the first 16 weeks gestation has not been precisely determined, but an overview would suggest the risk of congenital damage is less than 10%, and probably less than 5%. Maternal reinfection with a rash is very rare; it can be presumed to present a significant, but not quantified, risk to the fetus as viraemia will have occurred.

Almost all women diagnosed with a primary RIP between 2003 and 2016 were not born in the UK[22]. Country of origin was known for 21 out of the 27 women identified (78%) during this period and 20 (95%) of them were non-UK born. Origin of infection was known for 22 (81%) of the women, with 14 (64%) of them acquiring their rubella infection outside the UK. Only one of the mothers who had been infected in pregnancy had documentation of any prior immunisation with a rubella containing vaccine.

There were five CRS cases identified through the detection of RIP. Seven further cases were found through laboratory investigation of babies by the PHE VRD or the National Congenital Rubella Surveillance Programme. In these seven cases it was known that maternal infection was acquired abroad in rubella endemic countries. CRS rates fell from an average 0.17 per 100,000 live births annually between 2003 and 2009 to 0.05 per 100,000 between 2010 and 2016; a reduction of 71%. This fall was due to no babies being identified with CRS post-delivery in the most recent period.

1.7 UK population susceptibility to measles and rubella

In order to inform the development of recommendations and priority actions to be taken forward in the strategy up to date estimates of population susceptibility were

required. Population susceptibility can be measured either through seroprevalence surveys or through analyses of historical vaccine coverage data by birth cohort.

There is currently no established infrastructure to support a nationally representative UK sero-survey and resource would need to be identified and a case made for the added value such an exercise would bring. The residual blood sample scheme has been used in the past to estimate population susceptibility, however this has not been repeated because of concerns around the representativeness of the sample population. The scheme used excess diagnostic serology samples collected from NHS labs. The majority of samples from children were from a population undergoing chemotherapy or haematology investigations and the samples from young adults originated primarily from Genitourinary Medicine (GUM) clinics. Neither of these groups are thought to be representative of the general population and vaccination behaviour is likely to be significantly different to that of the general population, particularly for children with complex medical conditions and those who are immunosuppressed.

For this strategy PHE undertook new analyses of vaccine coverage data to generate population susceptibility estimates for measles and rubella by birth cohort for England.

1.7.1 Routine monitoring of MMR vaccine coverage

In England, MMR vaccine coverage has been estimated since its introduction in 1988 through the Cover of vaccination evaluated rapidly (COVER) programme using data from local Child Health Information Systems (CHISs)[23]. Prior to this, coverage estimates were generated for the routine single measles vaccine and the selective schoolgirl rubella vaccine programme.

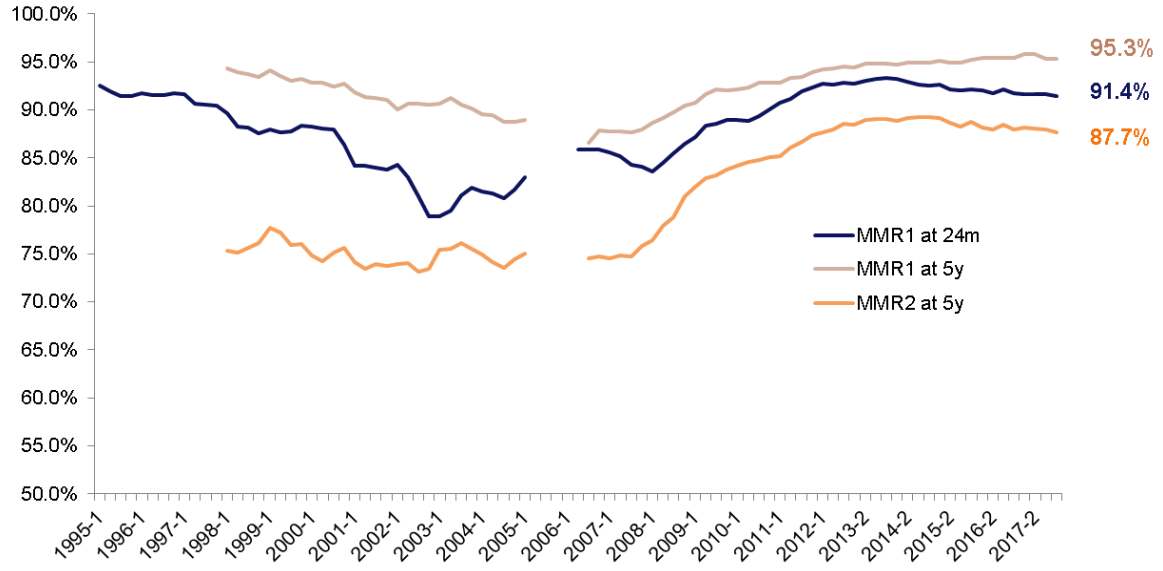
MMR vaccine coverage estimates are calculated as the proportion of individuals receiving MMR out of the total eligible responsible population in every local authority (LA) (i.e. those registered with a GP in the area and any additional unregistered individuals residing in that LA). Although the data extraction process varies from one CHIS to another, the specifications are standardised so that data is comparable across the country. Local and national MMR coverage estimates at 2 years (1 dose) and 5 years (1 dose and 2 doses since the introduction of the second dose in 1996) are published quarterly[24] and annually[25]. Vaccine coverage is one of the key elimination indicators that PHE reports on annually to the WHO RVC on behalf of the UK. However COVER data represent a snap shot in time for a particular birth cohort and are not updated as individuals get caught up with vaccination over time.

In 2012, an additional annual sentinel vaccine coverage collection was established using ImmForm, an online platform extracting immunisation data automatically from participating general practices in England (approximately 95% of GP practices in

England). This was used to generate baseline MMR vaccine coverage for 2 to 18 year olds in September 2012 ahead of NHS transition, and was used to monitor the impact of the 2013 MMR catch-up campaign.

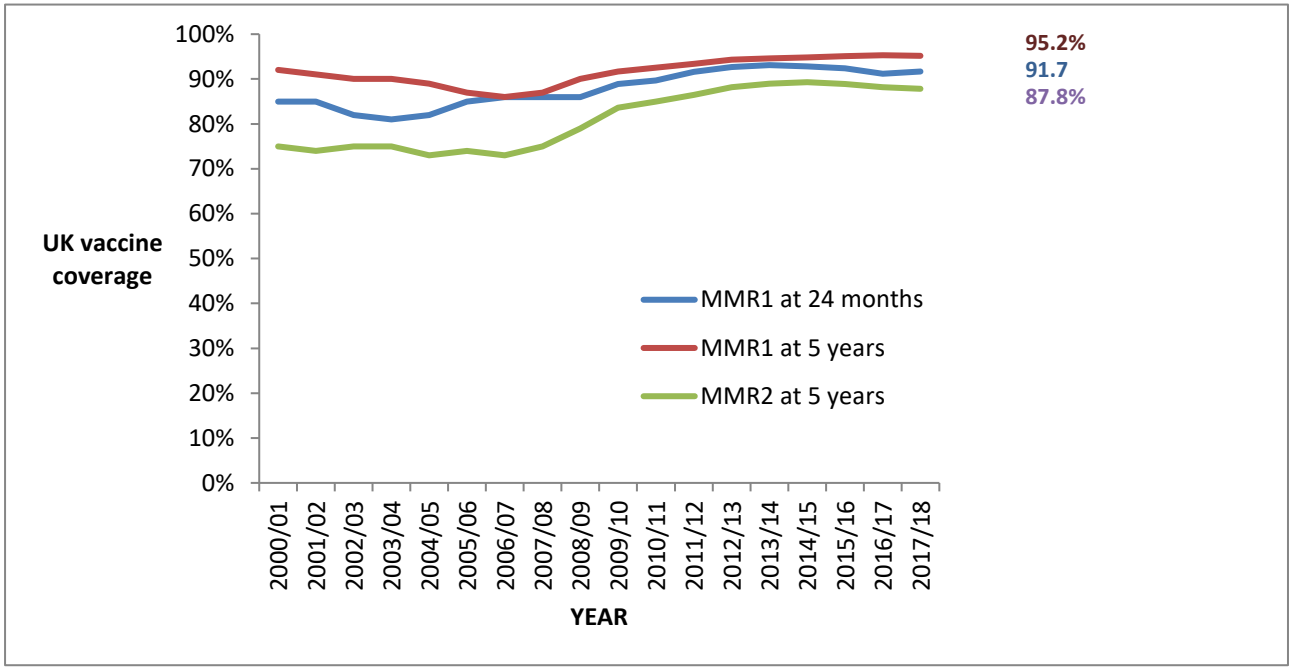
In 2015 this collection included MMR coverage for each birth cohort from 1985 onwards (individuals up to the age of 30) for approximately 45% of GP practices around the country. Unlike the COVER collection, this collection includes MMR vaccinations given at any age and includes anyone who arrived in England at any point in their lives, providing they are currently registered with a GP. Data quality is dependent on the completeness and accuracy of clinical coding at the practice level. Not all practices will retrospectively enter electronic vaccination records of vaccines given in previous practices or abroad, and those that do may not record these vaccinations using the correct clinical codes. As individuals get older and move practices data quality declines and vaccine coverage is underestimated. This means that vaccine coverage among adults born abroad before 2000 is not currently reliably captured. The evaluation of the 2013 MMR catch-up campaign showed that about 40-60% of individuals are incorrectly categorised as 'unvaccinated' in CHIS records and that this misclassification was more significant in older children and adults, and in London[26].

Figure 13. UK quarterly MMR coverage at 24 months and 5 years: April 1995 to March 2017.*



* N.B. Technical issues in 2005 and 2006 led to a temporary interruption of COVER data

Figure 14. UK annual MMR coverage at 24 months and 5 years: 2000/01* to 2017/18



*2001/01 to 2007/08: MMR1 and MMR2 at 5 years for England only

1.7.2 Birth cohort vaccine coverage and susceptibility estimates

In order to achieve a more accurate estimate of population susceptibility in England, MMR vaccine coverage estimates were calculated for each birth cohort from 1985-1986 to 2013-2014 using a combination of:

i) historical COVER (CHIS) data: Three vaccine coverage under-ascertainment scenarios were applied to annual vaccine coverage estimates, with assumptions made of a 10%, 25% or 50% misclassification of unvaccinated and under-vaccinated individuals within each cohort.

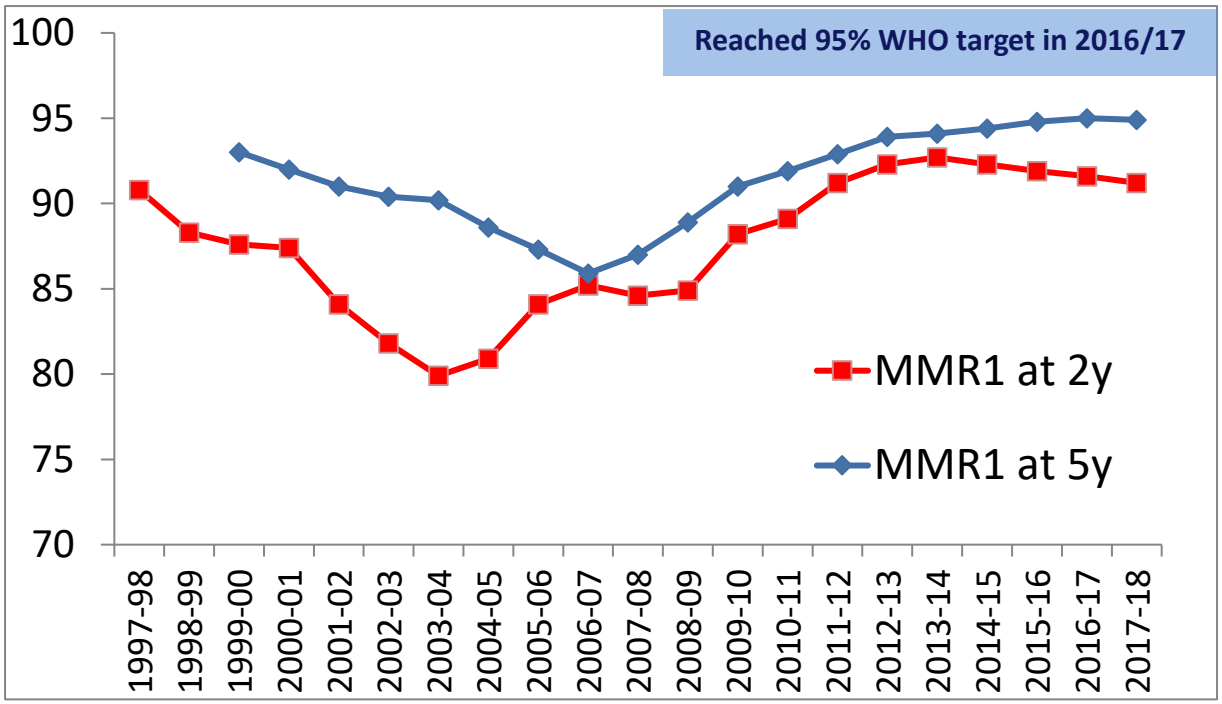
ii) ImmForm[27] (GP) data (extracted in 2016)

iii) coverage estimates for catch-up campaigns from 1985 to date (either using internal PHE data or published estimates[26,28] were applied to relevant cohorts:

a. MMR catch-up (2013)
b. MMR catch-up (2008)
c. MMR capital-catch up (London only, 2004)
d. MMR2 catch-up (1996)
e. Measles-Rubella (MR) catch-up (1994)
f. MMR catch-up (1988)

In England, MMR coverage is high, although the WHO targets of a 95% national coverage with one dose at two years and two doses at 5 years have never been achieved (See Figure 15). Nationally, MMR1 coverage at two years has been decreasing since 2013/14 (cohort born in 2011/12); this has been corroborated from coverage estimates extracted from both child health and GP IT systems, coverage at 2 years was 91.2% in 2017/18. MMR first dose as measured at five years reached 95% for the first time in 2016/17 and was 94.9% in 2017/18. Uptake of the second MMR dose by age five years was 87.2% in 2017/18[29].

Figure 15. MMR 1 coverage at two and five years of age, England 1997/8-2017/18



Vaccine effectiveness of 95% and 99.75% were assumed for one and two doses respectively, as well as no natural immunity. Susceptibility for each cohort was calculated nationally and for London as the proportion of individuals in the birth cohort likely not immune despite any routine or supplementary vaccination activities. (See Table 2)

A summary of overall population susceptibility for England and London is presented in Table 2 overleaf.

Table 2. Population susceptibility estimates for England and London

	National		London	
Under-ascertainment scenarios (%misclassification of unvaccinated and undervaccinated individuals)	Median susceptibility (%)	Range (%)	Median susceptibility (%)	Range (%)
10	8	2-12	11	2-16
25	7	2-11	9	2-13
50	5	1-9	6	1-9

The so called 'Wakefield cohorts' born in the late nineties and early 2000s (born between 1998 to 2004) have the highest proportion of susceptible individuals and this is even more pronounced in London.

In addition, when London is excluded from the analysis the cohorts born between 2008-2009 to 2010-2011 (aged 6 to 9 years in 2017) do meet the 95% MMR1target.

MMR1 coverage estimates were lower in primary care (ImmForm) data compared with child health (COVER) records (median 3.9%, range 1.5 - 5.3%) for the cohorts born from 2000-2001 to 2010-2011. In cohorts born prior to 2000-01, primary care data quality decreases and coverage is not interpretable.

The higher coverage in ImmForm compared with COVER in London for cohorts born 2000-2003 could result from the London specific capital catch up campaign increasing coverage in London, from a technical issue affecting London CHISs during this period causing a coverage underestimate[30], or a combination of both. Overall, the small difference between the two data sources suggests there are no large groups of unvaccinated foreign-born children in England and that little vaccination happens after 5 years of age. Low primary care data quality in older cohorts precludes estimating coverage or susceptibility in foreign-born adults- they remain a group with unknown coverage or susceptibility.

1.7.3 Target immunity levels and population immunity gaps

The herd immunity threshold for measles is often quoted at 90-95% for the whole population. In the 1990s the WHO European Region derived age-specific target immunity profiles, or the levels of immunity necessary in different age groups to achieve elimination[31]. Gaps in immunity can exist despite high routine MMR coverage if coverage targets were not met in the past, or because of population mixing patterns and migration. Funk and colleagues have recently updated these age-specific immunity targets taking into account the latest evidence around mixing

patterns in different age groups and settings[32]. The key message from this research is that 95% immunity needs to be achieved for each cohort at the time of school entry to guarantee elimination.

The England measles susceptibility estimates for each birth cohort were assessed against the age-specific immunity targets. (See Appendices 1 to 3). This analysis reveals that population immunity currently reaches sufficient levels in the youngest cohorts (born 2007-2008 to 2013-2014), in part because slightly lower levels of immunity are required to interrupt transmission in this age group than in the oldest cohorts (born 1985-1986 to 1988-1989). The immunity gap for England and London is most pronounced for the cohorts born between 1998-1999 and 2003-2004 (aged 14 to 19 years in 2017) who were negatively impacted by the fall in childhood vaccine coverage following the Wakefield scandal and have yet to be fully caught up despite several campaigns. Immunity levels in these cohorts are well below what is required to interrupt transmission of measles.

Compared with the rest of the England, London remains more vulnerable with immunity targets not achieved for the vast majority of the cohorts included in this analysis. The drivers for this are complex. London has a highly dynamic, mobile and diverse population with a significant proportion born abroad and therefore under-vaccinated communities are over-represented whilst data capture and quality remain a challenge.

Even in a scenario of high coverage under-ascertainment, measles susceptibility in England is likely to be sufficient to sustain disease transmission in particular age cohorts and in areas with lower coverage.

1.8 Under-vaccinated communities

There are inequalities in vaccine uptake by ethnicity, deprivation and geography and the burden of measles and rubella falls disproportionately on some communities. National Institute for Health and Care Excellence (NICE) guidance on Reducing differences in the uptake of immunisations[33] describes groups of children and young people who are at risk of not being fully immunised, for example, unregistered children, younger children from large families, children with learning disabilities and those from non-English speaking families. The main barrier to vaccination is access to immunisation services that meet the needs of the community. However there are also communities whose religious or cultural beliefs result in low or delayed vaccine uptake. Herd immunity extends the benefits of the national immunisation programme to unvaccinated individuals thus intrinsically reducing inequalities, however the extent of this effect will depend on overall vaccine coverage and population mixing patterns. When large numbers of unvaccinated individuals live in close proximity their communities become vulnerable to outbreaks.

Four case studies featured here highlight some of the issues and challenges faced by under-vaccinated communities.

Case study 1: Charedi Orthodox Jewish community in Hackney

The London borough of Hackney is home to one of the largest Charedi Orthodox Jewish communities, outside Israel and New York. The Charedi community was already established in Stamford Hill in the 1920s but the population increased significantly during the Second World War as new arrivals fled the Holocaust[34]. Membership of the community is not systematically recorded in medical records but is estimated at around 30,000. Immunisation uptake within the community is consistently lower than the rest of the borough and the rest of England. For example in the fourth quarter of 2014-15 General Practices serving the Charedi community achieved 78% uptake of MMR1 at 2 years of age compared to 86% in the rest of the borough[35]. Sub-optimal immunisation coverage has led to recurrent outbreaks of vaccine preventable diseases with measles outbreaks occurring in the borough of Hackney in 2007 and 2013. During these outbreaks the Charedi community suffered a higher burden of disease, with an estimated rate of measles five to tenfold higher than the rates observed in the rest of the population. The rate of measles for the Charedi community from 2006 to 2013 was 117 per 100,000 population compared to a rate of 29 per 100,000 for the rest of the Hackney population[35]. Due to close links with Charedi communities in other parts of the world, measles was exported from the UK to other countries including Israel[36] and Belgium[37].

Interventions such as: i) employing Charedi nurses to work with the community, ii) offering immunisation in community venues such as children's centres and iii) cultural awareness training for health professionals working with the community have been implemented with varying success. However a lack of rigorous evaluation and long-term recurrent funding within the context of an ever changing immunisation commissioning and provision landscape means that many interventions have been short lived.

More recently PHE and NHS England in collaboration with WHO Europe used the 'Tailoring Immunisation Programmes' (TIP) approach with the Charedi community. TIP was developed by WHO Europe to identify susceptible populations, determine barriers to vaccination and implement evidence-based interventions. The approach draws on health programme planning models, including the medical humanities, the social and behavioural sciences[38]. Community members and religious leaders were involved at all stages of the project and were key to its success. The chief Rabbi with responsibility for health who is very pro-vaccine and a representative from the Interlink foundation (an umbrella organisation for Orthodox Jewish charities) were keen supporters of the project and advocated for wider community engagement.

There was no evidence of religious or community-wide anti-vaccination beliefs. Due to larger than average families, there were significant issues with provision of and access to immunisation services within General Practice. Other issues identified included lack of up to date community specific communications, a need for improved recording of community membership and evaluation of any community specific interventions. The TIP report provided a series of recommendations for local commissioners and providers of immunisation services**Error! Bookmark not defined.**[35].

There are two smaller Orthodox Jewish communities in Greater Manchester (population, 11,000[39]) and Gateshead (population, 5,000) who also have lower than average immunisation uptake e.g. MMR1 coverage in Salford is around 60%. Some success in raising uptake has been achieved by implementing community specific interventions such as immunisation clinics in community settings, Sunday and domiciliary visits. Funding has also not been secure and often discontinued and rigorous evaluations of interventions are lacking.

Case study 2: Traveller communities

The majority of travellers in England are Irish Travellers, Gypsies or Roma. Irish travellers can be traced back to 12th Century Ireland, with migrations to Great Britain in the early 19th Century. The Irish Traveller community is categorised as an ethnic minority group under the Race Relations Act, 1976 (amended 2000); the Human Rights Act 1998; and the Equality Act 2010. Romani Gypsies have been in Britain since at least 1515 after migrating from continental Europe during the Roma migration from India. There are other smaller groups of Travellers who may travel through Britain, such as Scottish Travellers, Welsh Travellers and English Travellers.

Approximately half of all Travellers, Gypsies and Roma in the UK live in ‘bricks and mortar’ housing, many directly as a consequence of a shortage of Traveller sites. The majority (77%) of Travellers, Gypsies and Roma living in caravans live on either privately funded permanent authorised sites (46%) or on socially rented LA sites (31%). A minority of Travellers, Gypsies and Roma live on what are described as unauthorised sites (23%), of these approximately 10% own the land they are living on and 13% are camping on either private or LA land[40]. It is widely accepted that Travellers, Gypsies and Roma have some of the worst outcomes for a wide range of social indicators including health when compared to other communities.

In the 2011 census 58,000 people in England and Wales identified themselves as ‘Gypsy or Irish Traveller’ when the option was added to the ethnic classification for the first time[41]. This figure is thought to be conservative as it excludes non-white Gypsies and Travellers and non-Irish Travellers. Other estimates are based on

caravan counts or LA accommodation requirements. The traveller movement estimates that there around 120,000 travellers in England[42] and another survey carried out by the university of Salford estimated up to 500,000 indigenous and migrant Gypsies and Travellers[43].

Membership of traveller communities is not currently recorded or monitored by the NHS therefore assessing immunisation uptake and developing services to meet community needs can be challenging. A mapping exercise carried out in 2010 found that despite improvements in the provision of specialist services for the Gypsy, Traveller and Roma communities in England, only 16% o(PCTs were able to provide an estimate of vaccine coverage in Traveller communities. The majority of PCTs that could provide data estimated MMR1 uptake at less than 70%. The study concluded that there is an ongoing need to improve knowledge of population numbers and to provide accessible services that are culturally sensitive and responsive to the needs of Gypsy Traveller communities[44]. In 2015 an immunisation audit in a General Practice in the East of England serving a high proportion of Irish Travellers found that only 45% of Irish Traveller children had two MMR doses by 5 years of age compared to 90% of non-Traveller children. This General Practice had a good relationship with the local Traveller population and so coverage elsewhere could be even lower[45].

The low immunisation coverage rates are reflected in an increased disease burden and frequent outbreaks of vaccine preventable diseases in the Traveller communities[1],[2]. A retrospective analysis of 2006 to 2009 case management data estimated the excess risk of measles infection to be over one hundred fold[47].

The UNITING study[48] team carried out an interview study with Travellers and service providers followed by workshops to identify priorities. The study identified good examples of specialist immunisations services but these were not universally available. The researchers also highlighted that ‘recent cuts in funding and dispersal of public health expertise since the 2013 NHS reforms are hindering the co-ordinated and multi-agency approach advocated by those with the knowledge of the health needs of these communities’.

The study confirmed that the majority of Travellers are pro-vaccine and that most concerns and access issues were similar to those of the wider population. There were some community specific issues such as feeling judged unfavourably by some health professionals because of their lifestyle. Another qualitative study[49] also identified common barriers and facilitators to uptake of immunisations across all Traveller communities and confirmed that these were similar to those documented for the general population. All Roma communities experienced additional barriers of language and being in a new country. Men and women described similar barriers and facilitators although women spoke more of discrimination and low literacy. There was broad acceptance of childhood and adult immunisation across and within

communities, with current parents perceived as more positive than their elders. A minority of English-speaking Travellers worried about multiple/combined childhood vaccines, adult flu and whooping cough and described barriers to booking and attending immunisation. Language, literacy, discrimination, poor school attendance, poverty and housing were identified as barriers across different communities. Trustful relationships with health professionals were important and continuity of care valued.

The UNITING study participants identified and prioritised five interventions to improve immunisation uptake:

1. Cultural competence training for health professionals and frontline staff
2. Identification of Travellers in health records to tailor support and monitor uptake
3. Provision of a named frontline person in General Practices to provide a respectful and supportive service
4. Flexible and diverse systems for booking appointments, recall and reminders
5. Protected funding for health visitors specialising in Traveller health, including immunisation

Case study 3: Anthroposophic communities

Anthroposophy is a spiritual movement based on the teachings of Rudolf Steiner, an Austrian philosopher who suggested that febrile illnesses such as measles could benefit a child's spiritual development, and consequently parents may view immunisation negatively. It is generally accepted that the Steiner philosophy leads to a higher level of parents refusing or postponing vaccination until the child is older when compared to the wider population. It is not possible to estimate the numbers of people following the Steiner philosophy and their children's immunisation status as this information is not systematically recorded but there are a number of Steiner-Waldorf schools[50], early years providers and Camphill communities throughout England where under-vaccinated populations are vulnerable to vaccine preventable diseases.

The schools are a mixture of independent and state funded academies that have received Steiner accreditation or are affiliated. The Camphill communities provide care for people with special needs. Adults with learning disability live amongst co-worker families including their children, in active communities with a strong work ethic. There are 23 Camphill centres in England (schools, colleges for adolescents, training centres and working villages)[51]. Whilst there is no official Steiner-Waldorf position on immunisation, the schools do not generally promote immunisation or facilitate school based programmes.

Outbreaks of measles have occurred in Steiner schools and centres with spread to

other Anthroposophic communities. The vast majority of cases have been in unvaccinated members of the community[52,53,54] with some spread between communities[52] nationally and internationally and the wider population[53]. Interventions to improve uptake can be challenging due to the belief that the diseases bring spiritual development. Le Menach *et al*[53]. found that supplementary immunisation activity following an outbreak affecting the community was a successful strategy with a 114% increase in doses given the previous year. This was a more successful strategy in those whose children had a previous dose of MMR compared to those than those with no previous vaccinations[54]. Learning from local response to outbreaks in Steiner schools in England since continues to support this.

Case study 4: Migrants

A recent report from WHO Europe shows that migrants are more likely to be under-immunised—putting them at increased risk of vaccine-preventable diseases circulating in Europe—and may face greater disease, disability, and deaths from vaccine-preventable diseases than the host population.
The European Centre for Disease Prevention and Control (ECDC) noted that cross-border migration within the region has contributed to large measles outbreaks spreading to several countries with suboptimal vaccination coverage in Europe in 2017 and 2018.
Data show that newly arrived migrants to Europe have lower rates of vaccine coverage than the host population and might present with incomplete vaccination history or missing documentation of previous vaccinations. In the UK immunisation status should be checked at the GP practice on registration and new migrants should be brought up to date with the UK schedule for free. This can be a complex process if the patient's vaccination records are in a foreign language and the schedule of the country of origin differs from the UK. Health care workers (HCWs) may also mistakenly believe that European migrants will be up to date with their vaccinations, when in fact, many European countries have historically had low MMR uptake. It is also challenging to update these patients' vaccination record in the GP IT system and so even when vaccinated they may appear as 'unvaccinated' in the system.

Several measles outbreaks in the UK in 2017 and 2018 have been linked to importations from Europe, particularly Romania, with initial spread concentrated within the Romanian and other under vaccinated communities. Many of the cases were unregistered and did not speak English and so community engagement and outreach was a key component of outbreak response. Alternative service provision through domiciliary vaccination and community clinics were essential to ensure contacts were immunised.

European studies have highlighted that migrant women are less likely than native women to be immunised for rubella and the vast majority of RIP cases in the UK are in non-UK born women who were unvaccinated and also at greater risk of exposure to infection as they regularly travel to rubella endemic countries or have friends and

relatives who visit from those countries.

Compounding these issues are migrant's exposure to key social determinants including poor living conditions and disparities in access to health services on arrival due to language barriers, inability to pay, cultural beliefs, and fear of discrimination.

Consistently high levels of migration across Europe, coupled with low national MMR uptake in many countries, poses a challenge to achieving measles and rubella elimination in the Region.

1.9 High risk settings - healthcare related exposures

Although there is no evidence that HCWs have lower MMR uptake than the general population, the fact that they are in close contact with patients means that they are at increased risk of both catching measles and spreading it to patients and colleagues. A recent ECDC rapid risk assessment[55] on the measles situation in Europe highlighted HCWs as an important group to target as part of broader measles control plans. The cluster data presented in Figure 7 confirms that measles exposures in health care settings pose a significant burden in terms of transmission of infection. Due to the number of people HCWs are in contact with, the potential for onward spread of any infection is significant. This can result in amplification of measles transmission in health care settings but also in the community. Unvaccinated HCWs also pose a serious infection risk to vulnerable patients in whom measles infection can have very serious consequences.

In addition to the disease burden for individuals, outbreak management in health care settings is resource intensive. There are also implications for staff management as unvaccinated HCWs who are exposed to measles infection have to be excluded from the workplace to protect patients and colleagues placing an additional burden on other staff. An outbreak report from 2013 details an unvaccinated HCW who became infected with measles from an unvaccinated paediatric patient. Following infection the health protection team identified 110 contacts including patients, staff, and visitors. One 10 month old infant went on to develop measles[56].

In 2018 NHS Improvement issued a letter with recommended actions in response to an increase in healthcare-associated measles exposures and reminding trusts of their Occupational Health and Infection Control responsibilities.

1.10 National MMR programme delivery

The NHS public health functions agreement Service specification No.10[57] underpins national and local commissioning practices and service delivery of the MMR immunisation programme in England.

Immunisation against infectious disease[58] (known as 'The Green Book'), issued by PHE, provides guidance and the main evidence base for the programme. This should be read in conjunction with additional evidence, advice and recommendations issued by the Joint Committee on Vaccination and Immunisation[59] (JCVI) and the national guidance[15] on the public health management of cases, contacts and outbreaks.

PHE is responsible for the procurement and supply of the MMR vaccine (a combined live attenuated vaccine) for the national immunisation programme, working alongside the Department of Health and Social Care Commercial Directorate to deliver efficiencies and ensure continuity of supply to the NHS. GP surgeries and other providers such as school immunisers order vaccine direct from PHE using the 'ImmForm' website[60], volumes are determined locally to meet needs. GPs and other providers can order vaccine 24 hours a day and receive a delivery once a week, although this can be expedited for outbreak response purposes.

Nurses based in General Practices offer registered patients MMR vaccine according to the routine schedule, with first MMR dose offered at 1 year and the second MMR dose offered at 3 years and 4 months at the time of the pre-school booster. Individuals with uncertain or incomplete immunisation histories, including newly registered patients who have migrated to the UK should be brought up to date at the earliest opportunity as per national guidance[15].

The routine childhood immunisation programme is also supported by health visitors who at mandated baby visits at the ages of 10 to 14 days, 6 to 8 weeks and 1 year promote and discuss immunisations with parents[61].

Many countries around the world have not had a robust MMR programme and so patients without clear evidence of vaccination should be offered two doses of MMR – there are no negative effects from vaccinating people who are already immune. There is no upper age limit to offering MMR vaccine and GP practices and school immunisation services should maximise opportunities to ensure that patients are fully vaccinated. Other opportunities to offer catch up doses of MMR include entry into higher education, enlistment into the armed forces, prior to foreign travel and employment or study in the healthcare sector.

Catching up children aged 15 years or younger in primary care is covered under the global sum. An item of service fee can be claimed manually via the CQRS MMR

programme (aged 16 and over) for each dose of MMR administered to patients aged 16 years or over. This includes patients born before 1970 who have no history of measles or MMR. MMR is particularly important for women of child-bearing age, and should be assessed for example during consultation for contraceptive services, fertility problems, cervical screening, following miscarriage or termination of pregnancy and postnatally prior to hospital discharge and at the 6-8 week maternal check[61]. Post-natally, health visitors also have opportunities to assess mother's MMR immunisation status at the mandated new baby review (10 to 14 days) and 6 to 8 week assessment. It should be noted that central MMR vaccine stock can be used to catch-up anyone of any age.

The national S7A MMR service specification highlights key opportunities for school-based catch-up which has the potential of reaching unregistered children, unimmunised children who did not attend primary care for their immunisations and new-entrants to the UK. The evidence suggests that school-delivered immunisation programmes including catch-up are more equitable and can be more efficient in areas where MMR coverage at age 5 years is below the national average.

A high level of knowledge and a positive attitude to immunisation in healthcare practitioners are widely acknowledged as being important determinants in achieving and maintaining high vaccine uptake[62,63,64]. It is important that immunisers are confident, knowledgeable and up to date. PHE has published national training standards and core curriculum[65] for immunisers, which together with the Green Book, Vaccine Update[66], training slide sets and an e-learning module, support the delivery of a high quality programme. PHE also provide a suite of public facing online materials such as free to order leaflets, posters and social media banners that are available on the gov.uk website and the NHS website[67].

1.11 Monitoring vaccine safety and pharmacovigilance

The Medicines and Healthcare Regulatory Agency (MHRA) has a statutory responsibility across the UK to evaluate the safety, quality and efficacy of vaccines, medicines and medical devices. The UK Commission on Human Medicines (CHM) is the independent expert advisory body which advises the MHRA on the safety of vaccines and medicines.

Underpinning vaccine and medicines pharmacovigilance in the UK is the Yellow Card Scheme, which has been in operation since 1964. This is a voluntary reporting system through which any healthcare professional or member of the public can report a suspected adverse drug reaction (ADR) to any vaccine or medicine on the UK market. A Yellow Card report is not proof of a side effect occurring, but a suspicion by the reporter that the vaccine or medicine may have caused the side effect. Yellow Card reports may therefore relate to true side effects or they may be coincidental.

As well as using clinical judgement to detect new safety signals from the cumulative Yellow Card data, MHRA uses specialised IT software and statistical approaches, including disproportionality analyses, to systematically generate potential 'signals' from the Yellow Card data. MHRA also routinely evaluates all sources of safety data including clinical and epidemiological studies, published medical literature, and information from other regulatory authorities as well as pharmaceutical companies. MHRA also has access to electronic health record sources and record linkage databases such as the Clinical Practice Research Datalink (CRPD) and conducts ad hoc evaluation and research using such data, which may include near real-time 'observed vs expected' analysis, active safety surveillance of 'adverse events of interest', and formal epidemiological studies.

For any major new safety signals arising from its pharmacovigilance activities, MHRA has in place processes to obtain independent expert advice on the balance of risks and benefits from CHM and its sub-committees. Sharing international experience is also very important in vaccine pharmacovigilance, and MHRA works within a European regulatory framework in vaccine pharmacovigilance and also works closely with non-EU international counterparts.

The suggestion of a link between MMR vaccination and development of autism came to prominence following a paper by Andrew Wakefield *et al* published in *The Lancet* in 1998 which has since been withdrawn[10]. Around this time, the Committee on Safety Medicines established an independent MMR Working Party, which concluded that the available evidence did not support the alleged association or give cause for concern about the safety of MMR or MR vaccines. In 1999, *The Lancet* published a large epidemiological study[68] in North Thames region, which found no evidence of an association between MMR vaccine and autism. Over the next decade, several additional large epidemiological studies from a range of countries have consistently supported this conclusion. *The Lancet* subsequently retracted its 1998 paper after it emerged that conflicts of interest in the original study had not been disclosed, and the General Medical Council's findings regarding Andrew Wakefield's misconduct which led to him being struck off the General Medical Register in 2010. A 2014 meta-analysis of studies including over a million children confirmed that childhood vaccinations including MMR were not associated with the development of autism. There remains no credible scientific evidence that MMR vaccine or other vaccines cause autism[69].

1.12 Monitoring parental attitudes to vaccination

Parental attitudes, experiences and socio-economic background, influence whether a child receives a vaccine. Personal experience and knowledge of diseases influence perceptions about the seriousness of diseases and the likelihood of a child being affected[70]. In countries like the UK, where the national immunisation

programme is very well established, the challenge is maintaining high levels of vaccine coverage. In the absence of disease, the threat of that disease rapidly disappears and anxieties about the vaccine's safety may increase. A fall in vaccine coverage can lead to the return of disease as happened in the UK when rates of MMR immunisation fell from 1998 onwards as a consequence of loss of public confidence due to the negative publicity around the vaccine.

In 1991, the first of a series of surveys was undertaken in England to track parents' attitudes and experiences of immunisations and their recall of programme information materials. These surveys have improved understanding of parental views on: the seriousness of diseases that the vaccines prevent; concerns about vaccine safety; the type and amount of information they need; the service provided and what influences parental decisions to vaccinate. They provide a wealth of information on parents' perceptions and how they have changed over time and have been used to inform the planning and implementation of the national programme.

Interviews are carried out at the parents' home address with sampling undertaken to ensure a nationally representative sample. Prior to wave 24 (March 2003), interviews were carried out with mothers of children aged 0-2 years only. Wave 24 was the first wave in which men were eligible for the interview; provided they were the child's primary care giver (the person responsible for most of the decisions about the child's health care). In 2010 when the survey additionally included parents of children aged 3-4 years for the first time, the sample size was increased from 1000 parents overall to a minimum of 1,000 interviews among parents of 0-2 year olds and 1,000 interviews among parents of 3-4 year olds.

Prior to the 1998 survey the pertussis vaccine had caused parents the most concern due to a previous vaccine scare. Following the Wakefield paper and media hype around it, parental confidence in the MMR vaccine fell and despite a recovery in perception it wasn't until 2010 following the 2009 H1N1 flu pandemic that the 'swine flu' vaccine took over as being of most concern.

A paper published in 2007[71] detailed attitudes to the MMR over the first ten years of the surveys which tracked very clearly the impact of the vaccine controversy on parental confidence in the safety vaccine and the subsequent return to a more positive view of the vaccine (see Figures 16, 17, 18). In 2010 around eight in ten parents believed most vaccinations, including MMR, to be either completely safe or just a slight risk.

Figure16. Perceived safety of the MMR vaccine (1998-2006)

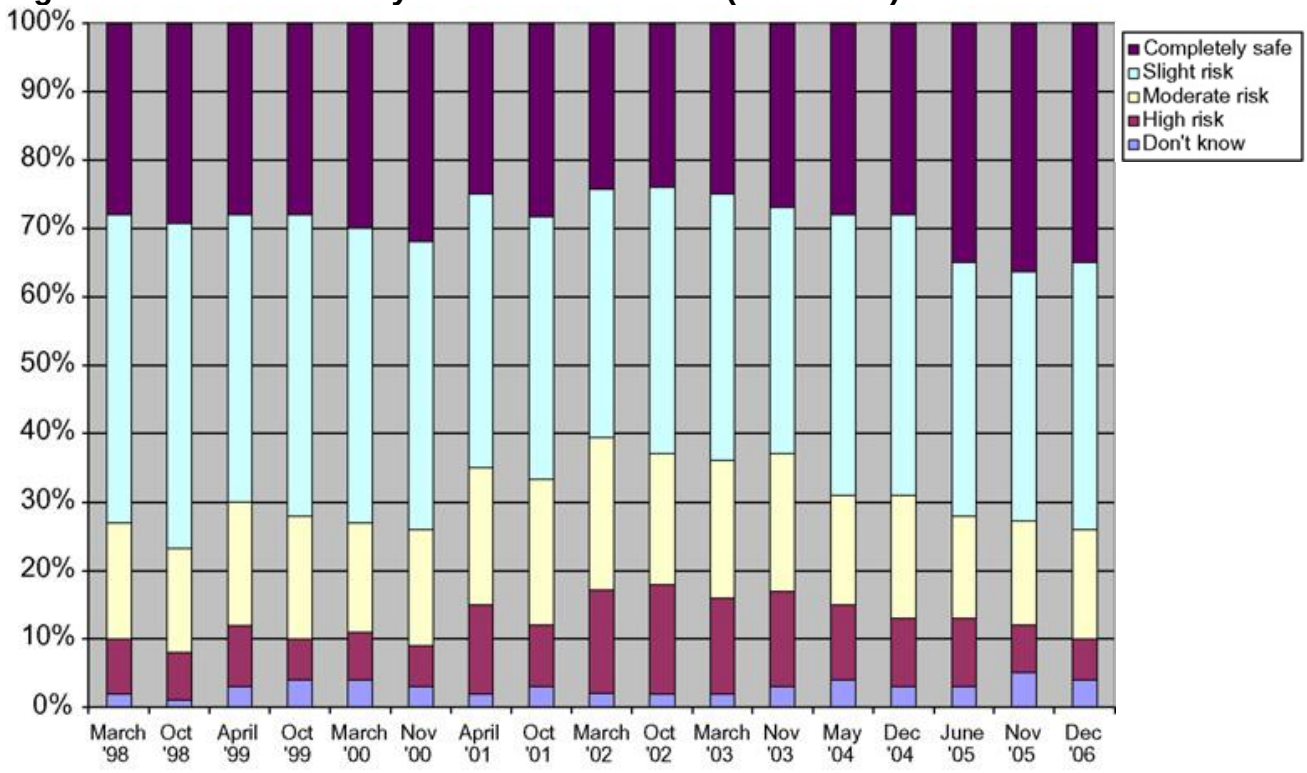
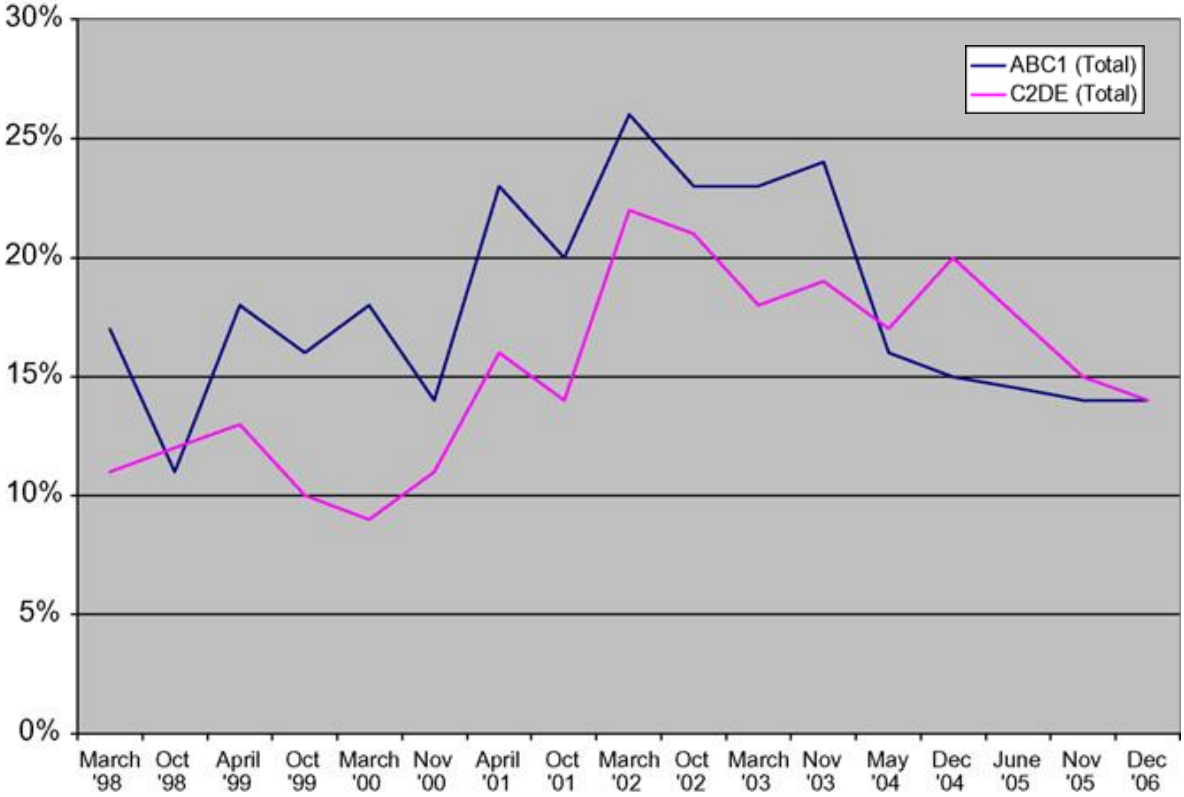
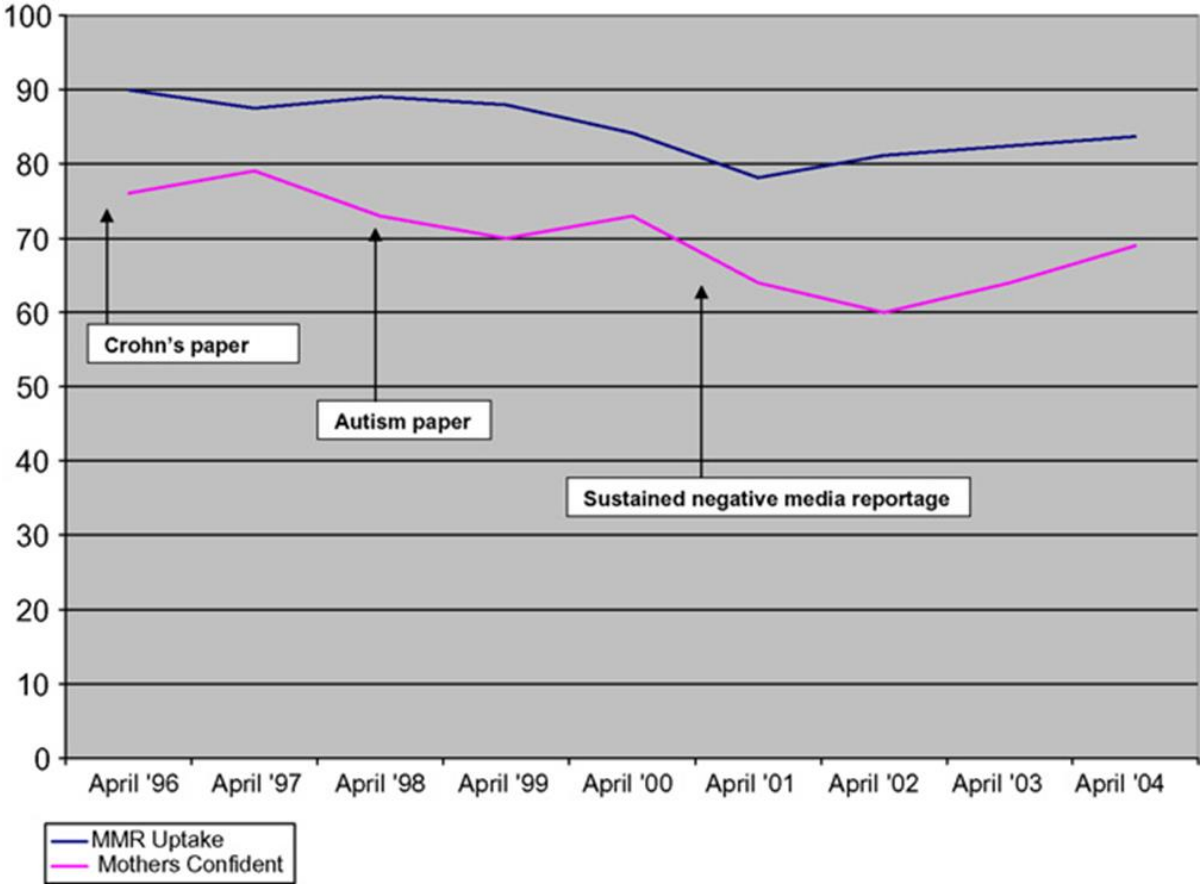


Figure 17: Proportion of parents who consider MMR a greater risk than the disease it protects against by social grade*



* Social grade is the socio-economic classification used by the Market Research and Marketing Industries based on the occupation of the main earner in the household. ABC1 refers to largely managerial and supervisory roles and C2DE refers to skilled, semi-skilled manual roles and the unemployed.

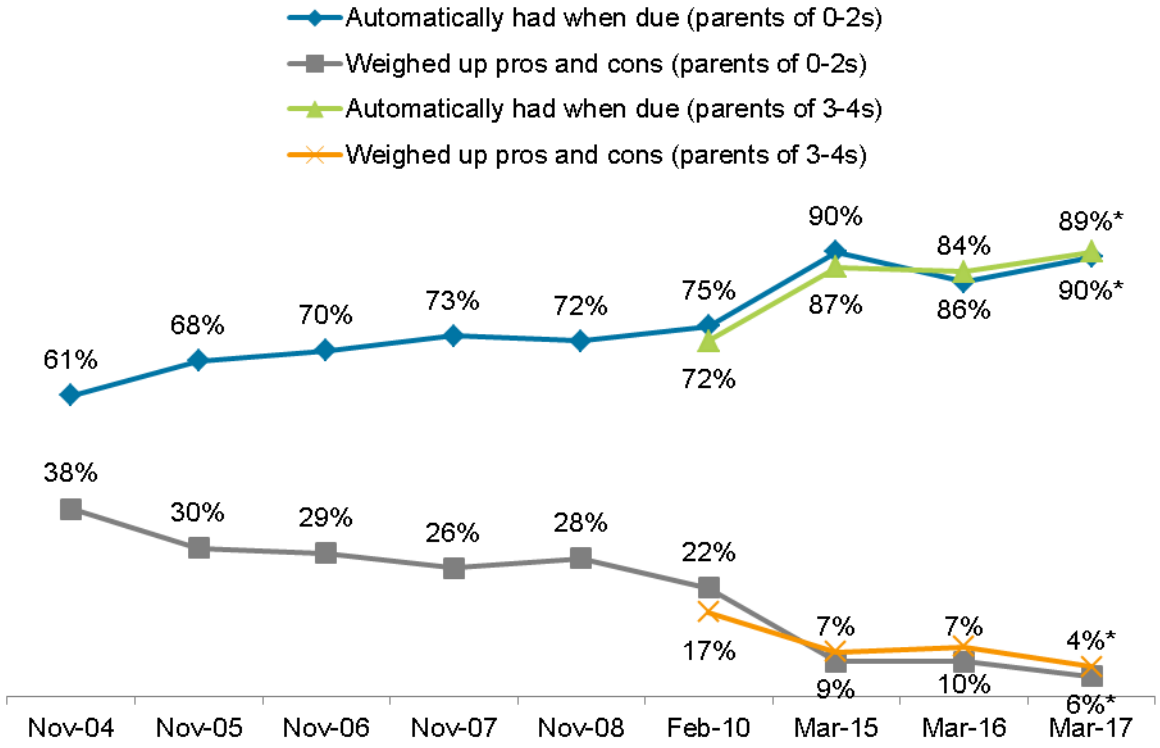
Figure 18: MMR vaccine coverage at 16 months (1996-2004) and proportion of mothers' confident in MMR vaccine (MMR completely safe or only poses a slight risk)



After a four year hiatus the surveys were started again in 2015. Ninety percent of parents reported having their child's immunisations done when they were due in 2015 compared to 72% reporting this in 2010. Only 2% of parents refused any vaccination and 7% delayed an immunisation (most of these went on to have it done later). MMR continued to be the most recalled vaccination with 84% of parents spontaneously naming it, down from 92% 2010. 80% of parents believed that the MMR vaccine was either completely safe or just a slight risk. There was also a significant increase in parents who believed that measles was a very serious disease up from 29% to 38%, perhaps reflecting the increased awareness of the disease due to a number of community outbreaks.

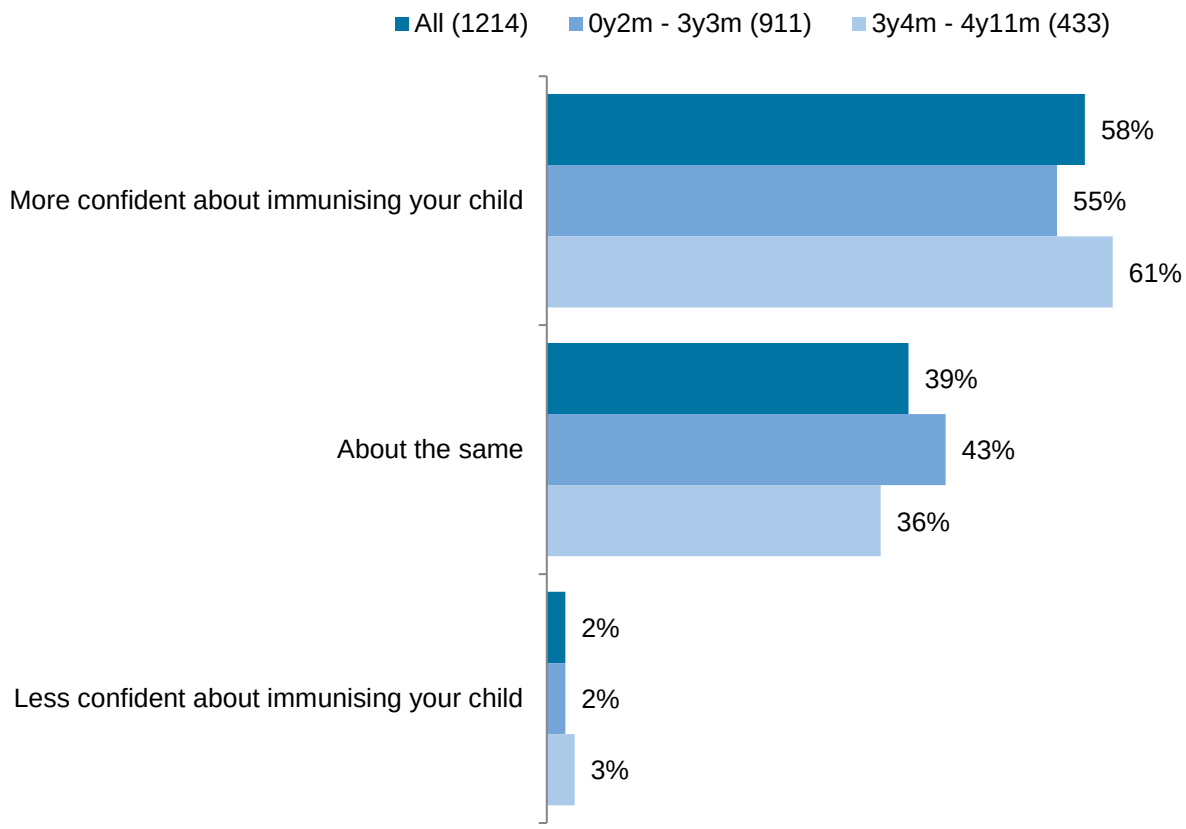
The most recent survey (2017) shows that the large majority of parents continue to be confident in the immunisation programme (93%), with 52% saying they were very confident. Around 90% of parents made the decision to immunise automatically. Only 23% of parents of 0-2 year olds who weighed up the pros and cons before deciding to vaccinate, mentioned MMR specifically in 2017 this is a steep decline from 88% of parents in 2008.

Figure 19: Proportion of parents (of 0-2 year olds and of 3-4 year olds) who automatically had child immunised or weighed up pros and cons (2003- 2017)



Health professionals are seen as the most trusted source of information (63% strongly agreed in 2017). Over 70% of parents had a discussion with a health professional before their child was immunised. Although prior to these discussions 86% of parents intended to fully immunise their child, 52% said they felt more confident following the discussion. Among parents of 0-2 year olds, 13% who had not intended to immunise changed their mind following discussion. The impact of discussions with a health professional was even greater in parents of 3-4 year olds with 22% changing their mind and deciding to go ahead and immunise, this proportion was even higher among parents from Black and Minority ethnic groups (29%) and among first time parents (38%).

Figure 20: Confidence in immunisation after discussion with health professional(s)



Only 7% (n=111) of all parents said they had seen or heard something that would make them doubt having their child(ren) immunised. Messages about side effects and MMR were the most likely to raise doubts. Although the overall numbers are small 34% of parents found these messages on the Internet, particularly social media sites such as Facebook and Twitter.

Section 2. Monitoring progress toward measles and rubella elimination

2.1 European Framework for measles and rubella elimination verification

The WHO European Region published a framework for the verification of measles and rubella elimination[72] in 2014 which describes the steps that need to be taken to document and verify that the elimination of measles and rubella has been achieved at the country and regional level.

The following **essential criteria** are required to verify elimination of measles and rubella in the UK:

- the absence of endemic measles and rubella cases for a period of at least 12 months from the last known case, due to complete interruption of endemic virus transmission;
- the presence of a high-quality surveillance system that is sensitive and specific enough to detect, confirm and classify all suspected cases; and
- genotype and sequencing evidence that supports the interruption of endemic transmission.

These essential criteria have to be supported by **evidence-based** information submitted to independent external panels of leading public health experts i.e. the NVC and the RVC on an annual basis to determine whether the UK has achieved and or sustained elimination. PHE takes on a coordination role on behalf of the UK to collate the annual report for submission to the NVC.

In addition a set of **measurable** surveillance performance indicators (see Table 3) and two markers (see Box 2) determine whether the national surveillance system provides timely and sufficient information based on pre-established quality criteria.

Table 3. Standard WHO indicators and targets for measuring performance of measles and rubella surveillance

Indicator	Description	Target
Timeliness of reporting (T)	Percentage of measles or rubella routine reports[a] submitted to national level by the deadline[b] *A:* number of reports submitted by the deadline *B:* number of expected reports *T* = (*A* * 100) / *B* (%)	≥80%
Completeness of reporting (C)	Percentage of measles or rubella routine reports[a] submitted to national level *E:* number of submitted reports *B*: number of expected reports *C* = (*E* * 100) / *B* (%)	-
Rate of laboratory investigations (L)	Percentage of cases suspected for measles or rubella with adequate specimens[c] collected and tested in a proficient laboratory[d] Note: Exclude from the denominator any suspected cases not tested by a laboratory and (a) confirmed by epidemiological linkage, or (b) discarded as non-measles/non-rubella by epidemiological linkage to a laboratory-confirmed case of another communicable disease or epidemiological linkage to a measles or rubella immunoglobulin M- (IgM) negative case. *F:* number of suspected measles or rubella cases with adequate specimens collected and tested in a proficient laboratory *G:* number of suspected cases *L* = (*F* * 100) / *G* (%)	≥80%
Rate of discarded cases (D)	The rate of suspected measles or rubella cases investigated and discarded as non-measles or non-rubella cases using laboratory testing in a proficient laboratory[d] and/or epidemiological linkage to another confirmed disease *H:* number of suspected measles or rubella cases investigated and discarded as non-measles or non-rubella cases *J:* population *D* = (*H* * 100 000) / *J*	**at least 2 discarded measles or rubella cases per 100 000**
Representativeness of reporting discarded cases (R)	Percentage of subnational administrative territories (e.g. at province level or its administrative equivalent) reporting the rate of discarded cases (*R*) at least 2 per 100 000 population per year *K:* number of subnational administrative territories reporting the rate of discarded cases (*R*) at least 2 per 100 000 population per year *M:* number of subnational administrative territories *R* = (*K* * 100) / *M* (%)	≥ 80%
Viral detection (V)	Percentage of laboratory-confirmed chains of transmission of measles or rubella with samples adequate for viral detection collected and tested in an accredited laboratory[e] *P:* number of chains of transmission of measles or rubella for which adequate samples have been submitted for viral detection/genotyping *Q:* number of chains of transmission identified *V* = (*P* * 100) / *Q* (%)	≥ 80%
Origin of infection identified (O)	Percentage of measles or rubella cases for which the origin of infection (e.g. imported, import-related or endemic) has been identified *W:* number of measles or rubella cases for which the origin of infection (e.g. imported, import-related or endemic) has been identified *X:* total number of measles or rubella cases *O* = (*W* * 100) / *X* (%)	≥ 80%
Timeliness of investigation (I)	Percentage of suspected measles or rubella cases with an adequate investigation[f] initiated within 48 hours of notification *Y:* number of measles or rubella cases with an adequate investigation *Z:* number of suspected measles or rubella cases, respectively *I* = (*Y* * 100) / *Z* (%)	≥ 80%

[a]Each surveillance reporting unit is to submit regular monthly or weekly reports, including "zero" reports.

[b] The deadline to submit data on the previous month or week is to be defined by the Member State.

[c] A single clinical sample obtained at the first contact with the health care system at any time within 28 days after rash onset is considered adequate for surveillance purposes (5)

[d]A proficient laboratory is WHO accredited and/or has an established quality assurance programme with oversight by a WHO accredited laboratory(6).

[e]Measles and rubella viruses can be detected in nasal secretions, urine, serum and whole blood, and dry blood spots up to seven days after onset of rash and in oral fluid for even longer (5).

[f] An adequate investigation includes the collection of at least the following essential data elements from each suspected measles/rubella case: case identifier, age (or date of birth), date of rash onset, date of specimen

Box 2. Measles and rubella eliminations markers

Vaccination coverage

The target for population immunity is the achievement and maintenance of **at least 95% coverage** annually with both first and second doses of measles and/or rubella vaccines in all districts (or their administrative equivalents) and at national level.

Incidence

The target for incidence is **< 1 measles or rubella case per million total population**. The numerator is the total number of measles cases, including laboratory-confirmed, epidemiologically linked and clinically compatible cases but excluding imported cases.

2.2 Measles and Rubella surveillance

2.2.1 Case-based surveillance

Measles (since 1940) and rubella (since 1988) are statutory notifiable infectious diseases. National enhanced surveillance of measles and rubella was introduced in November 1994 and laboratory notifications became statutory in October 2010. In line with WHO recommendations, countries with an elimination target are required to have intensive case-based surveillance to detect, investigate and confirm every suspected case. Notifications are made on suspicion or diagnosis of clinical disease without a case definition and clinicians are legally required to report any suspected cases to the appropriate officer of the local government authority. Notification of the local HPT fulfils the responsibility to notify the LA Proper Officer.

In England, Northern Ireland and Scotland local HPTs record clinical notifications of measles and rubella in real-time onto HPZone. Wales uses the Tarian case and incident management system with similar functionality. HPZone is a web based tool used for clinical and public health investigation and management of notified cases and outbreaks. HPZone data are accessible at the national level and used for surveillance purposes, although the level of national access varies by devolved administration. These systems ensure that we achieve WHO **targets for completeness (C) and timeliness (T) of reporting** of suspected cases to the national team.

Cases in HPZone are assessed for public health management by the health protection teams and then classified as confirmed, probable, possible or discarded. The public health assessment of measles and rubella cases is triggered on notification to the HPT ensuring **timeliness of investigation (I)**. Data from HPZone in England is extracted annually and reconciled with testing data from the National Reference Laboratory (WHO lab) and local and regional laboratories (WHO proficient). This step ensures that suspected cases that have been referred for measles and or rubella testing but not notified to the HPT are also captured. A similar process is undertaken in Wales and Northern Ireland, however Scotland do not currently have limited ability to link HPZone data to laboratory data.

The WHO classifies suspected measles cases on the basis of clinical symptoms (see Definitions section). However when measles is not endemic, the positive predictive value of a clinical diagnosis is generally poor and so to enhance the sensitivity of the surveillance system in the UK the suspected case definition is broader.

Box 3. Measles and rubella suspected case definition

Suspected case of measles[15]:

- any person in whom a clinician suspects measles infection, **OR**
- any person with fever **and** maculopapular rash (i.e. non-vesicular) **and** one of the following: cough or coryza (runny nose) or conjunctivitis (red eyes)

Suspected case of rubella:

- any person in whom a clinician suspects rubella infection, **OR**
- any person with fever **and** maculopapular rash (i.e. non-vesicular) **and** one of the following: arthralgia/arthritis or lymphadenopathy

In practice that means that in **England** 'suspected' measles/rubella cases include:

i) all possible, probable and confirmed cases on HPZone

ii) all clinically suspected cases that had a sample submitted for measles and or rubella testing to a PHE regional lab (positive and negative polymerase chain reaction (PCR) tests reported through DataMart) or national lab (MOLIS/LIMS) even if they were not notified to the local HPT

iii) all cases with an IgM positive serology test from regional and local labs (reported through PHE's Second Generation Surveillance System (SGSS) and Micropath)

iv) all cases that are measles RNA positive

2.2.2 Enhanced surveillance

All confirmed measles and rubella cases (regardless of where they were tested) are followed up by the national team with an enhanced surveillance form sent to their General Practitioner (GP) / requestor of testing. The information returned is entered onto a national database (Dataease). In England this is supplemented by information extracted from HPZone and laboratory records (SGSS, Datamart, MOLIS). (See Box 4).

Box 4. Measles and rubella enhanced surveillance form

Demographic details: name, sex, DOB, address, NHS number

Clinical features

- **Signs and symptoms** including onset dates of rash
- **Hospitalisation**

Individual epidemiological features

- **Travel:** any travel within and outside the UK during the incubation period, with an assessment of whether travel was in an area where measles is known to be circulating
- **Ethnic and cultural/religious background:** details on the patient's ethnicity, and whether the patient is a **member of an under-vaccinated population group** (e.g. Charedi Orthodox Jewish community)
- **Immunisation history:** any known vaccination history or history of measles
- **Epidemiological link:** assess if there has been a known epidemiological link with another laboratory or epidemiologically confirmed case

Pregnancy

2.2.3 Laboratory surveillance

The two key standard WHO indicators and targets for measuring the performance of national measles and rubella surveillance systems are the **rate of laboratory investigations (L)** (at least 80% of suspected cases) and the **rate of discarded cases (D)** (at least 2 per 100,000 population). In order to achieve these targets our focus is on ensuring that all suspected cases are appropriately tested.

IgM serology testing and OFT are the only two tests considered adequate by WHO for confirming and importantly discarding suspected measles and rubella cases. Measles PCR can be used for confirmed measles cases but NOT for discarding cases; rubella PCR is not considered sensitive enough for surveillance purposes. In order to facilitate universal testing of suspected cases for surveillance purposes OF testing was rolled out in 1994. Feedback from patients and parents suggests that, as a non-invasive test which is quick and easy to conduct, the OFT is highly acceptable. The National Infection Service (NIS) supplies each HPT with the OFT kits which are posted directly to the suspected cases for self-administration (or administration by the parent). The kit includes the swab, a request form and a sheet with instructions on how to take the sample and a package with pre-paid postage addressed to the VRD in Colindale which is a WHO Global Specialised Reference Laboratory for Measles and Rubella.

The OF samples are tested for virus-specific IgM, IgG measles RNA, and can therefore: i) reliably exclude measles and rubella diagnosis, as well as confirm it; ii) indicate whether the case is a primary or reinfection; and iii) genotype confirmed cases.

Return rates of the OFTs vary by area depending on how the service is organised locally. Paradoxically it is often challenging to get an OF sample on hospitalised patients who will have undergone multiple diagnostic investigations and so neither clinician nor the patient may understand the importance of submitting the OFT.

All positive diagnostic samples, such as serological samples, tested either through a regional PHE laboratory (entered on the DataMart database), a local NHS hospital laboratory (entered on the SGSS database) or private laboratory should be promptly forwarded to the VRD at Colindale for confirmatory testing which is conducted free of charge. In addition all regionally or locally confirmed cases should also get an OF sample taken.

Samples that have been confirmed positive for measles or rubella are further sequenced and entered on the WHO global Measles Nucleotide Surveillance (MeaNS) or the Rubella Nucleotide Surveillance (RubeNS) databases respectively which are hosted at the VRD, Colindale. Genotyping and further characterisation of measles and rubella is used to support investigation of transmission pathways and sources of infection. This system ensures we meet WHO targets for **Viral detection (V)** and **Origin of Infection identified (O)** and generates essential evidence to support confirmation of measles and rubella elimination status.

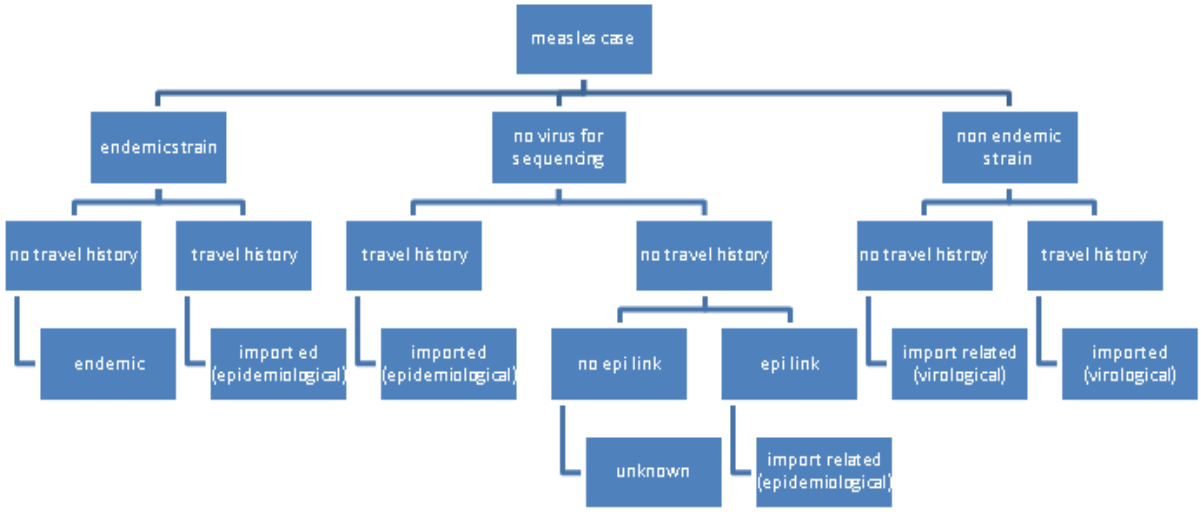
A subset of OFT samples that test negative for measles at VRD are subsequently tested for rubella and vice versa, if sufficient sample allows. This helps to increase the sensitivity of our surveillance system at a time when the positive predictive value of a clinical diagnosis for both of these infections is very low. It also ensures that we are meeting the required WHO discard rate of at least two discarded measles or rubella cases per 100,000 population which in practical terms requires a large throughput of samples to be maintained.

Results from all samples tested at Colindale are reported on the MOLIS/LIMS system and reported back to the patient's GP and local HPT. HPTs can also track samples and access the results which have been processed by the VRD in the previous 100 days through the MrEP site[73].

2.2.4 Case classification

For WHO reporting purposes cases are also classified as endemic, imported or import-related. Figure 21 depicts the decision tree used to classify cases using a combination of travel history, virological and epidemiological information.

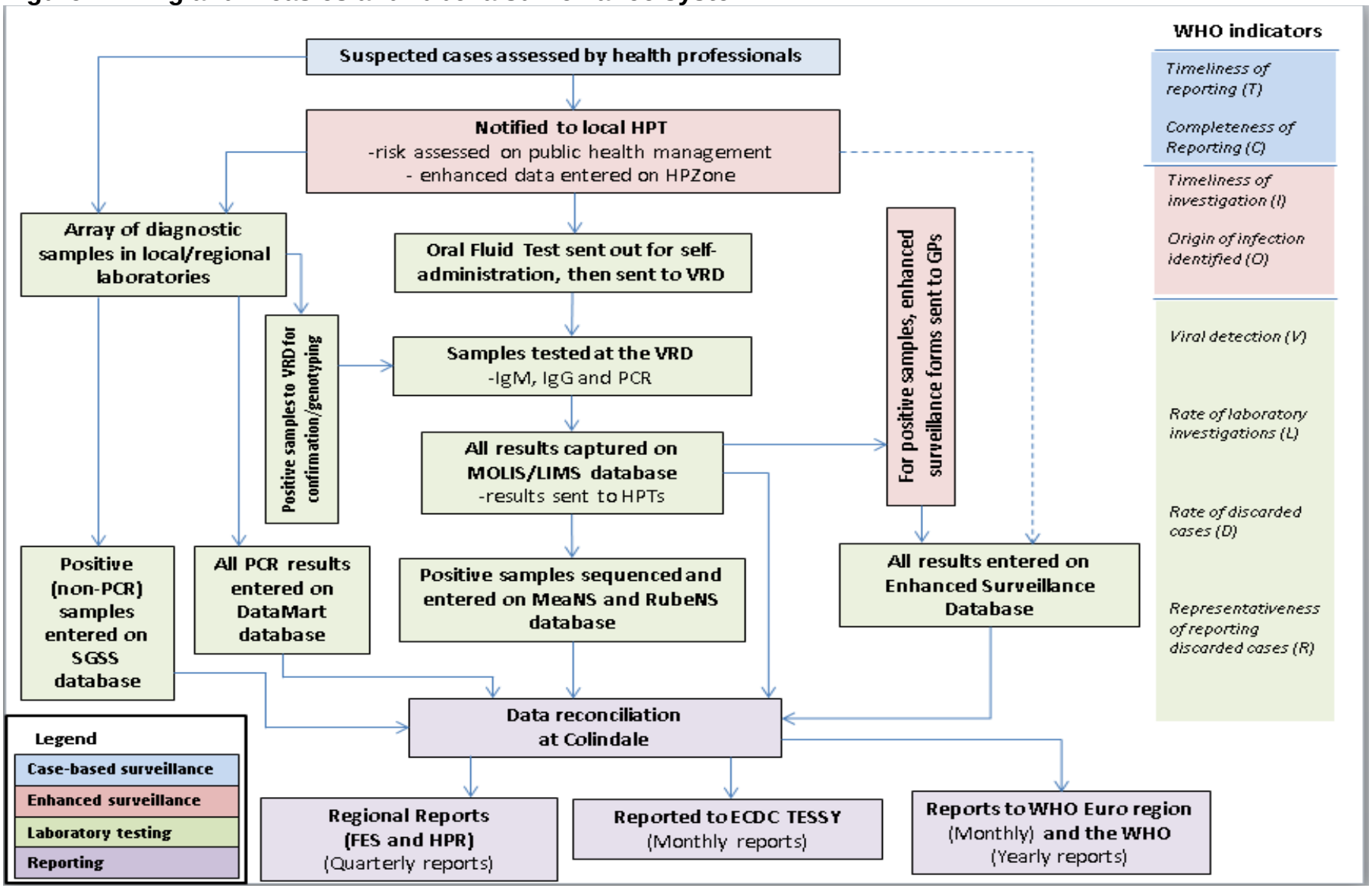
Figure 21. Classification of imported, import-related and endemic cases



2.2.5 Reporting

Data is extracted from the various databases (including MOLIS/LIMS, MeaNS, RubeNS, DataMart, SGSS, HPZone and the enhanced surveillance database Dataease) and reconciled by the national team. NIS is responsible for monthly reporting of epidemiologically and laboratory confirmed cases to the European Surveillance System, TESSy on behalf of the UK. This information is then forwarded to the WHO Region for Europe. VRD also report monthly data on the numbers of samples tested for measles to the WHO laboratory network via the Centralized Information System for Infectious Diseases (CISID). An annual report is compiled by PHE on behalf of the UK and is independently assessed by the NVC and submitted to the WHO Europe RVC.

Figure 22. England measles and rubella surveillance system



--------- Information only sought for positive cases through HPZone data.

Section 3. Achieving and maintaining elimination – how do we get there?

The evidence on how to achieve measles and rubella elimination is clear and the Region of the Americas demonstrated that it can be done at scale in 2016. In this section we capture the key recommendations for action for UK stakeholders to deliver on our commitment to maintain elimination. Recommendations are framed under four key building blocks in line with the strategy set out by WHO Europe:

1) Achieve and sustain ≥ 95% coverage with two doses of MMR vaccine in the routine childhood programme (<5 years old)

2) Achieve ≥ 95% coverage with two doses of MMR vaccine in older age cohorts through opportunistic and targeted catch-up (>5year olds)

3) Strengthen measles and rubella surveillance through rigorous case investigation and testing ≥80% of all suspected cases with an OFT

4) Ensure easy access to high-quality, evidence-based information for health professionals and the public

1. Achieve and sustain ≥ 95% coverage with two doses of MMR vaccine in the routine childhood programme (<5 years old)

95% immunity in the population needs to be achieved at the time of school entry in order to guarantee measles elimination. The WHO target of ≥ 95% uptake with the first dose of MMR (MMR1) at age 2 years and with two doses of MMR (MMR2) at age 5 years has never been achieved nationally. In addition MMR1 coverage at two years has been decreasing since 2013-14. Coverage for this vaccine is now at 91.2%, the lowest it has been since 2011-12. In England we achieved 95% uptake of MMR1 by age 5 years for the first time in 2016. London and the South East were the only two regions not to meet this target.

In order to achieve the 95% uptake with two doses of MMR by age 5 years the following actions need to be taken forward.

1.1 Strengthen routine national immunisation programme

Stakeholders to work collaboratively at the national and local level to address:

1.1.1 gaps in funding, commissioning, delivery and quality assurance of immunisation training

1.1.2 gaps in workforce planning and increasing pressure on the capacity of:

- primary care workforce, in particular practice nurses
- school immunisers
- health visitors

1.1.3 input into the implementation of NHS England's "Healthy Children: transforming child health information" strategy to ensure that it supports the elimination of Measles and Rubella

1.2 Investigate and address national decline in MMR1 coverage in cohorts born since 2011/12

1.2.1 local teams to develop an **MR elimination action plan** in partnership with local stakeholders which should include:

i) analysis of barriers to achieving the 95% target for MMR 1 and MMR 2 across the patch and a plan for how to address these. This should include an assessment of:

   - call recall practices (CHIS and GP)
   - immunisation clinic accessibility e.g. appointment times, locations, waiting lists

ii) opportunistic MMR check and offer at all contact points in primary care, health visiting, attendance at childcare centres and other community settings: 'making every contact count'

iii) how existing contract levers can be used and / or changed to improve uptake of routine programme

iv) assess opportunities to improve MMR uptake when reviewing broader plans for improved local service development and integration

1.2.2 national commissioning teams to identify additional support required for worst performing areas e.g. London

2. Achieve ≥ 95% coverage with two doses of MMR vaccine in older age cohorts through opportunistic and targeted catch-up (>5 year olds)

The immunity gap for England and London is most pronounced for the cohorts born between 1998/99 and 2003/04 (aged 15 to 20 years in 2018). Immunity levels in these cohorts are well below what is required to interrupt transmission of measles.

London remains the most vulnerable region with immunity targets not achieved for the vast majority of cohorts. In addition there are inequalities in vaccine uptake by ethnicity, deprivation and geography and the burden of measles and rubella falls disproportionately on some communities. Unless these immunity gaps are addressed through the strategies outlined below England will continue to remain vulnerable to measles outbreaks particularly in age cohorts with the highest susceptibility and areas and communities with the lowest coverage.

2.1 Address gaps in evidence on population MR susceptibility

2.1.1 generate susceptibility estimates for a wide range of age cohorts across the devolved administrations – including older ages (born before 1984)

2.1.2 estimate vaccine coverage in individuals born abroad before 2000

2.1.3 consider adding national routine coverage estimates at older ages (9, 14, 18) for MMR1 and MMR2

2.2 Build on legacy of 2013 MMR catch-up campaign

2.2.1 embed opportunities to check and where necessary offer individuals with unknown or incomplete history of MMR vaccination in all relevant national:

- commissioning documents
- contracts
- guidance

Particular areas of focus include:

Primary Care

Explore including additional MMR catch-up elements in the General Medical Services (GMS) contract and develop relevant indicators for quality and outcomes framework (QOF).

School immunisation providers

National team to engage with the Department for Education to strengthen commitment to support the roll-out of the NIP and school-based catch-up.

Local teams to:

i) review school based immunisation contracts and ensure:

- they include reference to routine immunisation checks at ages 4-5yrs, 10-11yrs and mid-teens.
- MMR check /offer is added on to human papilloma virus (HPV), teenage booster and MenACWY programme delivery.

LA public health teams and education departments should support school-based delivery of the immunisation programme including catch-up.

Maternity Services

Work with maternity services and primary care to ensure:

- 100% MMR check as routine part of antenatal care

- achieve 95% uptake of post-natal MMR for women without documentary evidence of two previous MMR doses.

Health visitors

Through the Best Start in Life programme, PHE has issued guidance for commissioners on the role of Health Visitors in the national immunisation programme. This includes utilising mandated contacts at the new baby review (10 to 14 days) and the 6 to 8 week review, to promote baby immunisations and assess maternal rubella status and follow up of two MMR vaccinations[61]. Health visitors have an important role to play in supporting the immunisation programme but can also be key to making

sure unregistered children or those who are unlikely to access primary care get immunised.

2.2.2 the MR local elimination action plan mentioned in 1.2.1 should also include:

i) a local population needs assessment

ii) an assessment of how existing contract levers can be used and / or changed to embed MMR check and offer for >5 year olds

iii) using the **NICE Quality Standard** (QS145)[74] on immunisation uptake in under 19 year olds to assess how the following key components of the programme are being implemented locally and identify areas for improvement:

- Recall invitations
- Offering outstanding invitations
- Recording vaccinations
- Checking immunisation status at specific educational stages
- Checking immunisation status of young offenders and offering outstanding vaccinations

iv) an assessment of any additional activity that is required to address the immunity gap:

v) whether there is a need for an additional catch-up campaign through schools or primary care

vi) whether alternative service provision is fit for purpose and how this can be strengthened to meet the needs of the population and reduce inequalities in uptake

2.3 Address the needs of under-vaccinated communities

2.3.1 local stakeholders to work together to:

i) use the WHO TIP tool to understand and address the specific needs of their under-vaccinated populations

ii) use NICE guidance on **Reducing differences in the uptake of immunisations**[75] to implement evidence based interventions locally

iii) evaluate local interventions and disseminate learning and examples of best practice

iv) strengthen plans for alternative provision of immunisation services for underserved / unregistered communities

v) address specific recommendations already identified through evidence collated to date:

1. improve recording of community membership on primary care medical records to enable accurate measurement of disease burden and planning of services

2. ensure community involvement and leadership in developing and implementing and evaluating community specific interventions

3. consider cultural awareness training for staff working directly with specific communities

2.4 Ensure health care settings are fully prepared for measles outbreaks

2.4.1 NHS Improvement/ regulators to remind health care employers of their public health, infection control and occupational health responsibilities through a national communication.

2.4.2 Local Clinical Commissioning Groups / equivalent to ensure MMR check and offer is conducted for all staff working in health care settings.

2.4.3 Acute and community NHS trusts to seek assurance that:

- Occupational Health provision is fit for purpose and that staff MR immune status can be accessed promptly in outbreak scenarios.
- Infection Control Teams are supported to implement national measles guidance.

3. Strengthen measles and rubella surveillance through rigorous case investigation and testing ≥80% of all suspected cases with an OFT

The quality of measles, rubella and CRS surveillance activities needs to be sufficient to ensure the detection of sporadic cases and provide adequate information on both the epidemiology and the virus genotype to allow case classification (endemic or

imported/import-related). This information needs to be collected, analysed and communicated effectively and in a timely manner to enable prompt and appropriate public health action and to ensure we provide the necessary evidence to the NVC and the RVC.

3.1 National Immunisation Team to:

3.1.1 publish updated Rash in Pregnancy guidelines and updated Green Book chapters for measles and rubella

3.1.2 review measles and rubella case management algorithms/guidance for the new CIMS (web-based case management tool) and enhanced surveillance data collection tools to improve routine collection of data on suspected cases e.g. ethnicity, member of under immunised communities etc.

3.1.3 link HES data to routine surveillance data to generate more accurate data on burden of disease

3.2 Field Epidemiology Services (FES) and Health Protection Teams to:

3.2.1 lead a national audit of OF testing for suspected measles and rubella cases with the aim of identifying interventions to achieve the following elimination indicators:

- at least 80% of suspected measles and rubella cases have an OFT
- a rate of discarded measles and rubella cases (those testing negative by OF testing / IgM serology) of ≥2 per 100,000 population.

3.3 The VRD to lead on implementing interventions to ensure measles and rubella cases are confirmed and excluded on the basis of an appropriate test (not PCR) at a WHO proficient lab. This work should include:

- ensuring that sufficient measles negative samples are dual tested for rubella to provide a discard rate above 2:100,000 population
- ensuring that suspected measles and rubella cases with an adequate specimen have an IgM result reported within 4 days of receipt at the lab
- ensuring that > 80% of confirmed sporadic cases of measles and >80% of chains of transmission are sequenced and genotyped
- an audit of the OFT kits arriving at the laboratory accessions service to inform improvements in design / packaging. The aim is to reduce the

proportion of samples received with inadequate information or incorrect packaging which can lead to samples not being processed
- collaborating with the Clinical Virology Network, Field Epidemiology FES, PHE Regional Microbiology Services and NHS Trusts to conduct a survey to assess the availability of measles testing (serology, PCR) in regional and local laboratories and if samples are being appropriately referred
- explore the possibility of obtaining negative measles and rubella tests from SGSS to capture additional testing done locally

3.4 Devolved Administrations to develop country-level action plans on how to achieve:

- at least 80% of suspected measles and rubella cases being investigated by an appropriate test (e.g. IgM serology)
- at least 80% of confirmed sporadic measles cases and 80% of chains of transmission are sequenced and genotyped
- a rate of discarded measles and rubella cases (those testing IgM negative by serology / OF testing) of ≥2 per 100,000 population. To achieve this target for rubella will invariably require that all measles negative samples are dual tested for rubella

4. Ensure easy access to high-quality, evidence-based information for health professionals and the public

A national communication strategy targeted at both health professionals and the public has to underpin the national MMR programme to increase and maintain the very high levels of vaccination coverage required to achieve measles and rubella elimination.

4.1 National Immunisation Team to continue to monitor changes in attitudes to MMR vaccine through annual survey with parents and monitoring of mainstream and social media.

4.2 National Immunisation Team to:

- develop MMR resources for schools and school immunisers to use at different educational stages
- develop an MMR marketing campaign targeted at 15 to 25 year olds, encouraging them to check their status and take up MMR through primary care

- collaborate with partners at the national and local level to raise awareness about MMR at summer festivals
- work with Universities UK to develop an MMR and MenACWY Universities toolkit to support MMR check and offer for students
- develop a measles resource for LAs

4.3 Local teams to:

- support and amplify national MMR messaging through mobilisation of local partners in the health and education sectors and beyond
- work with LA partners and community engagement groups to target messages at under-vaccinated communities as appropriate

Appendix 1. Reported Vaccine Coverage (COVER) and susceptibility by birth cohort, England, 1987-2016

Birth year	MMR1 coverage (%)	MMR2 coverage (%)	Catch-up campaign	Catch up Coverage (%)	Catch-up campaign	Catch up Coverage (%)	Under ascertainment scenario	Adjusted MMR1 coverage (%)	Adjusted MMR2 coverage (%)	% susceptible	Immunity target to keep R0<1?*
2013-2014	91.4						10%	92.2		12.4	YES
							25%	93.5		11.1	YES
							50%	95.7		9.1	YES
2012-2013	91.8						10%	92.7		12.0	YES
							25%	93.9		10.8	YES
							50%	95.9		8.9	YES
2011-2012	92.6						10%	93.3		11.4	YES
							25%	94.4		10.3	YES
							50%	96.3		8.5	YES
2010-2011	94.9	87.6					10%	95.4	88.9	5.2	YES
							25%	96.1	90.7	4.4	YES
							50%	97.4	93.8	3.0	YES
2009-2010	94.6	88.4					10%	95.1	89.5	5.4	NO
							25%	95.9	91.3	4.5	YES
							50%	97.3	94.2	3.1	YES
2008-2009	94.4	88.4					10%	95.0	89.6	5.5	NO
							25%	95.8	91.3	4.7	YES
							50%	97.2	94.2	3.2	YES
2007-2008	94.2	88.3			MMR Catch-up (2008)	n/a	10%	94.8	89.4	5.7	NO
							25%	95.7	91.2	4.8	YES
							50%	97.1	94.1	3.3	YES
2006-2007	93.5	87.0				n/a	10%	94.2	88.3	6.4	NO
							25%	95.1	90.2	5.3	NO
							50%	96.8	93.5	3.6	YES
2005-2006	92.4	84.6				n/a	10%	93.1	86.2	7.4	NO
							25%	94.3	88.5	6.2	NO
							50%	96.2	92.3	4.2	YES
2004-2005	91.5	83.0				n/a	10%	92.3	84.7	8.3	NO
							25%	93.6	87.2	6.9	NO
							50%	95.7	91.5	4.7	YES
2003-2004	89.9	80.1				n/a	10%	90.9	82.1	9.7	NO
							25%	92.4	85.1	8.2	NO
							50%	94.9	90.1	5.5	NO
2002-2003	87.3	74.7	MMR (2013)	10.8		n/a	10%	88.5	77.2	11.0	NO
							25%	90.4	81.0	9.2	NO
							50%	93.6	87.3	6.2	NO
2001-2002	86.8	73.2		10.8		n/a	10%	88.1	75.9	11.4	NO
							25%	90.1	79.9	9.5	NO
							50%	93.4	86.6	6.4	NO
2000-2001	86.0	73.0		10.8		n/a	10%	87.4	75.7	12.1	NO
							25%	89.5	79.8	10.1	NO
							50%	93.0	86.5	6.8	NO
1999-2000	88.6	74.0		10.8		n/a	10%	89.8	76.6	10.0	NO
							25%	91.5	80.5	8.4	NO

							50%	94.3	87.0	5.7	NO
1998-1999	89.6	74.6		10.8		n/a	10%	90.6	77.2	9.2	NO
							25%	92.2	81.0	7.7	NO
							50%	94.8	87.3	5.2	NO
1997-1998	90.5	74.6		10.8		n/a	10%	91.5	77.1	8.5	NO
							25%	92.9	81.0	7.1	NO
							50%	95.3	87.3	4.8	YES
996-1997	90.8	74.0		10.8		n/a	10%	91.7	76.6	8.3	NO
							25%	93.1	80.5	7.0	NO
							50%	95.4	87.0	4.7	YES
1995-1996	91.7	74.2				n/a	10%	92.6	76.8	8.4	NO
							25%	93.8	80.6	7.1	NO
							50%	95.9	87.1	4.8	YES
1994-1995	92.6	74.7				n/a	10%	93.4	77.2	7.6	NO
							25%	94.5	81.0	6.4	NO
							50%	96.3	87.3	4.3	YES
1993-1994	93.5	76.4				n/a	10%	94.2	78.8	6.8	NO
							25%	95.1	82.3	5.7	NO
							50%	96.8	88.2	3.9	YES
1992-1993	94.1	74.4				n/a	10%	94.7	76.9	6.4	NO
							25%	95.6	80.8	5.4	NO
							50%	97.0	87.2	3.7	YES
1991-1992	92.4		MMR2 catch up (1996)	60		n/a	10%	93.1		8.9	NO
							25%	94.3		7.8	NO
							50%	96.2		5.9	NO
1990-1991	92.7			60		n/a	10%	93.5		8.5	NO
							25%	94.6		7.5	NO
							50%	96.4		5.7	NO
1989-1990	92.0			60			10%	92.8		9.2	NO
							25%	94.0		8.0	NO
							50%	96.0		6.1	NO
1988-1989	89.8		Measles-Rubella (1994)	92			10%	90.8		1.7	YES
							25%	92.3		1.6	YES
							50%	94.9		1.2	YES
1987-1988	87.2			92			10%	88.5		2.0	YES
							25%	90.4		1.8	YES
							50%	93.6		1.4	YES
1986-1987	90.8			92			10%	91.7		1.6	YES
							25%	93.1		1.5	YES
							50%	95.4		1.2	YES
1985-1986	77.9			92			10%	80.1		3.0	YES
							25%	83.4		2.6	YES
							50%	88.9		2.0	YES

*Immunity above 85% for 0-4 years old and above 95% for 5+

Appendix 2. Reported Vaccine Coverage (COVER) and susceptibility by birth cohort, London, 1987-2016

Birth year	MMR1 coverage (%)	MMR2 coverage (%)	Catch-up campaign	Catch up Coverage (%)	Catch-up campaign	Catch up Coverage (%)	Catch-up campaign	Catch up Coverage (%)	Under ascertainment scenario	Adjusted MMR1 coverage (%)	Adjusted MMR2 coverage (%)	% susceptible	Immunity target to keep R0<1
2013-2014	84.9								10%	86.4		17.9	NO
									25%	88.7		15.7	NO
									50%	92.5		12.2	YES
2012-2013	86.3								10%	87.7		16.7	NO
									25%	89.7		14.8	YES
									50%	93.1		11.5	YES
2011-2012	86.9								10%	88.3		16.2	NO
									25%	90.2		14.3	YES
									50%	93.5		11.2	YES
2010-2011	90.9	79.3							10%	91.8	81.4	8.9	YES
									25%	93.2	84.5	7.5	YES
									50%	95.5	89.7	5.1	YES
2009-2010	91.1	80.5							10%	92.0	82.4	8.7	NO
									25%	93.3	85.4	7.3	NO
									50%	95.6	90.2	4.9	YES
2008-2009	90.9	80.2							10%	91.8	82.2	8.9	NO
									25%	93.2	85.1	7.5	NO
									50%	95.4	90.1	5.1	NO
2007-2008	91.3	80.6			MMR Catch-up (2008)	n/a			10%	92.1	82.6	8.5	NO
									25%	93.4	85.5	7.2	NO
									50%	95.6	90.3	4.9	YES
2006-2007	90.4	80.4				n/a			10%	91.4	82.4	9.3	NO
									25%	92.8	85.3	7.8	NO
									50%	95.2	90.2	5.3	NO
2005-2006	88.4	76.3				n/a			10%	89.6	78.7	11.2	NO
									25%	91.3	82.3	9.4	NO
									50%	94.2	88.2	6.3	NO
2004-2005	86.7	72.7				n/a			10%	88.0	75.5	12.8	NO
									25%	90.0	79.6	10.7	NO
									50%	93.3	86.4	7.2	NO

2003-2004	82.7	66.9				n/a			10%	84.4	70.2	12.7	NO
									25%	87.0	75.1	10.7	NO
								24	50%	91.3	83.4	7.2	NO
2002-2003	76.9	54.4	MMR (2013)	10.8		n/a			10%	79.2	59.0	15.3	NO
									25%	82.6	65.8	12.8	NO
								24	50%	88.4	77.2	8.6	NO
2001-2002	75.6	52.0		10.8		n/a			10%	78.1	56.8	16.1	NO
									25%	81.7	64.0	13.4	NO
								24	50%	87.8	76.0	9.0	NO
2000-2001	75.8	53.9		10.8		n/a			10%	78.3	58.6	15.9	NO
									25%	81.9	65.5	13.3	NO
								24	50%	87.9	77.0	8.9	NO
1999-2000	79.0	57.3		10.8		n/a			10%	81.1	61.5	14.0	NO
									25%	84.2	67.9	11.7	NO
								24	50%	89.5	78.6	7.9	NO
1998-1999	80.0	57.2		10.8		n/a			10%	82.0	61.5	13.3	NO
									25%	85.0	67.9	11.2	NO
								24	50%	90.0	78.6	7.5	NO
1997-1998	80.2	56.9		10.8		n/a			10%	82.2	61.2	13.2	NO
									25%	85.1	67.7	11.1	NO
								24	50%	90.1	78.5	7.5	NO
1996-1997	83.5	57.7		10.8		n/a			10%	85.2	61.9	11.2	NO
									25%	87.7	68.2	9.4	NO
								24	50%	91.8	78.8	6.3	NO
1995-1996	84.7	58.9				n/a	Capital catch-up (2004)		10%	86.2	63.0	11.7	NO
									25%	88.5	69.2	9.8	NO
								24	50%	92.3	79.5	6.6	NO
1994-1995	85.0	61.5				n/a			10%	86.5	65.4	11.4	NO
									25%	88.8	71.2	9.5	NO
								24	50%	92.5	80.8	6.4	NO
1993-1994	87.7	58.1				n/a			10%	88.9	62.3	9.7	NO
									25%	90.8	68.6	8.1	NO
								24	50%	93.9	79.0	5.5	NO
1992-1993	88.1	55.7				n/a			10%	89.3	60.1	9.5	NO
									25%	91.1	66.8	8.0	NO
								24	50%	94.1	77.9	5.4	NO
1991-1992	87.6		MMR2 catch up (1996)	60		n/a			10%	88.9		10.1	NO
									25%	90.7		8.7	NO
								24	50%	93.8		6.4	NO
1990-1991	87.7			60		n/a			10%	88.9		10.0	NO
									25%	90.8		8.7	NO
								24	50%	93.9		6.3	NO
1989-1990	86.8			60					10%	88.1		10.6	NO
								24	25%	90.1		9.2	NO

					50%	93.4	6.7	NO
1988-1989	81.1	Measles-Rubella (1994)	92	24	10%	83.0	2.1	YES
					25%	85.8	1.8	YES
					50%	90.5	1.4	YES
1987-1988	77.3		92	24	10%	79.6	2.4	YES
					25%	83.0	2.1	YES
					50%	88.7	1.6	YES
1986-1987	80.0		92	24	10%	82.0	2.2	YES
					25%	85.0	1.9	YES
					50%	90.0	1.5	YES
1985-1986	67.1		92	24	10%	70.4	3.3	YES
					25%	75.3	2.8	YES
					50%	83.6	2.0	YES

*Immunity above 85% for 0-4 years old and above 95% for 5+

Appendix 3. Reported Vaccine Coverage (COVER) and susceptibility by birth cohort, England (Excl. London), 1987-2016

Birth year	MMR1 coverage (%)	MMR2 coverage (%)	Catch-up campaign	Catch up Coverage (%)	Catch-up campaign	Catch up Coverage (%)	Under ascertainment scenario	Adjusted MMR1 coverage (%)	Adjusted MMR2 coverage (%)	% susceptible	Immunity target to keep R0<1?*
2013-2014	92.8						10%	92.2		11.1	YES
							25%	93.5		10.1	YES
							50%	95.7		8.4	YES
2012-2013	93.1						10%	92.7		10.9	YES
							25%	93.9		9.9	YES
							50%	95.9		8.3	YES
2011-2012	93.8						10%	93.3		10.3	YES
							25%	94.4		9.4	YES
							50%	96.3		7.9	YES
2010-2011	95.7	89.4					10%	95.4	88.9	4.4	YES
							25%	96.1	90.7	3.7	YES
							50%	97.4	93.8	2.5	YES
2009-2010	95.4	90.2					10%	95.1	89.5	4.6	YES
							25%	95.9	91.3	3.9	YES
							50%	97.3	94.2	2.7	YES
2008-2009	95.2	90.2					10%	95.0	89.6	4.8	YES
							25%	95.8	91.3	4.0	YES
							50%	97.2	94.2	2.8	YES
2007-2008	94.8	89.9			MMR Catch-up (2008)	n/a	10%	94.8	89.4	5.1	NO
							25%	95.7	91.2	4.3	YES
							50%	97.1	94.1	2.9	YES
2006-2007	94.2	88.4				n/a	10%	94.2	88.3	5.7	NO
							25%	95.1	90.2	4.8	YES
							50%	96.8	93.5	3.3	YES
2005-2006	93.2	86.4				n/a	10%	93.1	86.2	6.6	NO
							25%	94.3	88.5	5.5	NO
							50%	96.2	92.3	3.8	YES
2004-2005	92.5	85.2				n/a	10%	92.3	84.7	7.3	NO
							25%	93.6	87.2	6.1	NO
							50%	95.7	91.5	4.2	YES
2003-2004	91.4	82.9				n/a	10%	90.9	82.1	8.3	NO
							25%	92.4	85.1	7.0	NO
							50%	94.9	90.1	4.7	YES

2002-2003	89.2	78.5	MMR (2013)	10.8		n/a	10%	88.5	77.2	9.4	NO
							25%	90.4	81.0	7.9	NO
							50%	93.6	87.3	5.3	NO
2001-2002	88.8	76.9		10.8		n/a	10%	88.1	75.9	9.8	NO
							25%	90.1	79.9	8.2	NO
							50%	93.4	86.6	5.5	NO
2000-2001	87.4	75.8		10.8		n/a	10%	87.4	75.7	10.8	NO
							25%	89.5	79.8	9.1	NO
							50%	93.0	86.5	6.1	NO
1999-2000	90.3	76.8		10.8		n/a	10%	89.8	76.6	8.6	NO
							25%	91.5	80.5	7.2	NO
							50%	94.3	87.0	4.9	YES
1998-1999	91.4	77.9		10.8		n/a	10%	90.6	77.2	7.7	NO
							25%	92.2	81.0	6.5	NO
							50%	94.8	87.3	4.4	YES
1997-1998	91.9	78.2		10.8		n/a	10%	91.5	77.1	7.3	NO
							25%	92.9	81.0	6.1	NO
							50%	95.3	87.3	4.2	YES
1996-1997	91.7	76.0		10.8		n/a	10%	91.7	76.6	7.5	NO
							25%	93.1	80.5	6.3	NO
							50%	95.4	87.0	4.3	YES
1995-1996	92.9	76.7				n/a	10%	92.6	76.8	7.3	NO
							25%	93.8	80.6	6.1	NO
							50%	95.9	87.1	4.2	YES
1994-1995	93.9	76.9				n/a	10%	93.4	77.2	6.5	NO
							25%	94.5	81.0	5.4	NO
							50%	96.3	87.3	3.7	YES
1993-1994	94.4	79.5				n/a	10%	94.2	78.8	5.9	NO
							25%	95.1	82.3	4.9	YES
							50%	96.8	88.2	3.4	YES
1992-1993	95.3	78.9				n/a	10%	94.7	76.9	5.1	NO
							25%	95.6	80.8	4.3	YES
							50%	97.0	87.2	3.0	YES
1991-1992	93.2		MMR2 catch up (1996)	60		n/a	10%	93.1		8.1	NO
							25%	94.3		7.1	NO
							50%	96.2		5.5	NO
1990-1991	93.7			60		n/a	10%	93.5		7.7	NO
							25%	94.6		6.8	NO
							50%	96.4		5.2	NO
1989-	93.0			60			10%	92.8		8.3	NO

1990				25%	94.0	7.3	NO
				50%	96.0	5.6	NO
1988-1989	91.5	Measles-Rubella (1994)	92	10%	90.8	1.5	YES
				25%	92.3	1.4	YES
				50%	94.9	1.1	YES
1987-1988	89.4		92	10%	88.5	1.8	YES
				25%	90.4	1.6	YES
				50%	93.6	1.3	YES
1986-1987	93.2		92	10%	91.7	1.4	YES
				25%	93.1	1.2	YES
				50%	95.4	1.0	YES
1985-1986	80.8		92	10%	80.1	2.7	YES
				25%	83.4	2.4	YES
				50%	88.9	1.8	YES

*Immunity above 85% for 0-4 years old and above 95% for 5+

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