IN-06 Making antibiotics: penicillin from mould, sulfa from coal tar, phages from sewage, and why it is harder than it looks

HEALING after the FALL, research library, IN-06

Researched 10 October 2026 by Claude Opus agent for THRIVING after the FALL, Book Four. Library document, unverified.

How to read this report

This report answers one question: can a village of 300 or a district of 3,000 make an antibiotic that saves a life. It answers from the record, by asking who managed it, with what, at what yield, and what happened to the patients.

Under the rules of this library, no part of this report gives a method of manufacture. There are no culture recipes, media formulations, extraction or purification steps, reagent quantities or synthesis routes. What is given instead is the ledger: what each rung of means can and cannot do, and where the attempt kills people.

One rule is absolute and recurs throughout. **Crude mould broth is never injected into a human being, and never put into an eye socket, a joint, the belly or a deep wound.** Everything else here is a matter of degree. That is not.

Findings by section

1. What a dose is, and why the unit matters

The Oxford unit was an activity, not a weight, defined by the smallest amount that stopped *Staphylococcus aureus* growing in a fixed volume of broth, 50 ml in the Oxford museum's account. Sherstneva gives the calibration of the day: the Oxford standard was 42 units per mg (Sherstneva 2019). The unit was fixed internationally in 1945 at 0.0006 mg of pure crystalline penicillin (Inventing Europe), refined in 1953 to 0.0005988 mg (WHO Expert Committee, abstract only). In round numbers, **600 mg of benzylpenicillin is one million units** (eMC SmPC, HPRA PA1122-038-003).

The commonest error in popular accounts is to confuse a unit with a dose. Albert Alexander's whole course was 220,000 units, which Harold Ellis calls "today, a small single injection" (Ellis 2016).

Modern labels give 600 to 3,600 mg daily (1 to 6 million units) for ordinary indications, up to 14.4 g (24 million units) for adult meningitis, 7.2 to 12 g for endocarditis and up to 43.2 g (72 million units) for rapidly spreading gas gangrene (eMC SmPC). Sherstneva's wartime archival figure is the more useful anchor: **a course needed 50,000 to 1.5 million Oxford units depending on the disease** (Sherstneva 2019, citing GARF f. 8009).

Two facts close off the easy routes. Benzylpenicillin is destroyed by stomach acid and only a small, inconsistent fraction of an oral dose is absorbed (*Drug and Therapeutics Bulletin*). And it does not keep: a 2024 study found unbuffered solutions not measurable after eight days even refrigerated, while buffered ones held 95 to 98 per cent over seven days at 2 to 8 degrees C (PMC11504374). At warm room temperature degradation approaches complete within a day. **A village cannot store what it makes.**

2. Oxford, 1940 to 1941: the ceiling of a good laboratory

Fleming published in 1929. He, Frederick Ridley and Stuart Craddock failed to isolate the active substance because it did not survive their concentration steps, and Fleming concluded in print that penicillin was too unstable to be a practicable antiseptic (Understanding Animal Research, Lobanovska and Pilla 2017). Harold Raistrick, one of Britain's best biochemists, also failed. This is the first point of the report: **the difficulty was never growing the mould. It was getting the drug out of the broth and keeping it.**

Florey and Chain took it up at the Dunn School in 1938, with Heatley devising the potency assay. On 25 May 1940 four infected mice given penicillin survived while four controls died, and a repeat two days later saved six of six against three of four dying (Ellis 2016).

Heatley grew the mould in pie dishes, biscuit tins, petrol cans and borrowed hospital bedpans, then had a stackable ceramic vessel made by James Macintyre and Co of Staffordshire. Accounts differ on number and price: 700 at ten shillings in the museum's account, several hundred at six shillings in Bruggink's. The first 174 arrived within two months and half were seeded on Christmas Day 1940 (MHS Oxford, Bruggink 2021). Six women worked them in shifts around the clock.

Yield and purity are the numbers that matter. Kenneth Raper recalled the English were getting **about four units per millilitre** (UW-Madison CALS 2017). Heatley's own description of the crude brown powder sent to the Radcliffe was **almost certainly less than 40 units per mg**, under 3 per cent pure. Abraham and Chain's purified but non-crystalline preparation announced in *Nature* in March 1942 reached 450 to 500 units per mg, of the order of 30 per cent. The Dunn School's maximum was about **500 litres of broth a week**, and **about 2,000 litres of culture fluid were needed to treat a single case of sepsis** (MHS Oxford).

So: a university pathology department with a biochemist, a mycologist, a bacteriologist, six full-time assistants, organic solvents, an animal house and a hospital next door produced, at full stretch, **enough penicillin for about one septic patient a month at 1941 doses.**

3. The first patients, and the cost in litres

The first human recipient was Elva Akers, a woman dying of cancer, who volunteered for a toxicity test. Within about three hours she had fever and a rigor, attributed to pyrogenic impurities (Lobanovska and Pilla 2017, Fletcher oral history). **The first thing a crude preparation did to the first person who received it was give her a violent fever.**

Albert Alexander, a 43-year-old Oxford policeman with combined staphylococcal and streptococcal septicaemia, lung abscesses and osteomyelitis of the humerus, had his first infusion on 12 February 1941, improved within a day and was vastly better after five. The supply ran out, he relapsed and died on 15 March 1941. Total dose 220,000 units (Ellis 2016). To stretch supply, penicillin was recovered from his urine and reinjected, because most of a dose is excreted unchanged. The rose-thorn story of his injury is doubted.

The rest of the series: a boy of 15 with sulphonamide-resistant streptococcal septic arthritis recovered rapidly from 22 February, a man with a large carbuncle responded, a boy with cavernous sinus thrombosis recovered and then died a week later of a ruptured mycotic aneurysm, and a boy of 14 with staphylococcal osteomyelitis of the femur was cured in two weeks (Ellis 2016). Series size is disputed: six in Ellis, ten in a record of the 1941 *Lancet* paper, which I could not read.

The arithmetic a district needs, which is my own [VERIFY]: at 2,000 litres per septic case, a village producing 500 litres a week at Oxford's standard treats **one septic patient a month**. At a modern severe-sepsis dose of 12 million units a day for ten days, that patient needs 120 million units, which at four units per millilitre and perfect recovery is **30,000 litres of broth**. Oxford did not give modern doses. It gave 220,000 units, and the patient died when it ran out.

4. Peoria: the yield was the war, not the chemistry

Florey and Heatley carried the mould to the USDA Northern Regional Research Laboratory at Peoria in July 1941. Andrew J. Moyer, with Heatley, raised yields about tenfold by 26 November 1941 using a medium based on corn steep liquor, a waste stream of wet corn milling (USDA ARS).

Raper's oral history gives the sequence in units per millilitre: English material about **4**, Peoria by that Christmas about **40**, a wild mould from a Peoria cantaloupe (NRRL 1951) about **100**, selections from it **250**, an X-ray mutant from Cold Spring Harbor (X-1612) **500**, an ultraviolet mutant from Wisconsin (Q-176) **900** (UW-Madison CALS 2017). Demerec's team tested 5,000 mutant strains individually, of which 504 justified further analysis, to get X-1612 (Alfano 2016).

That 225-fold increase was the work of **a national laboratory, a Nobel-calibre genetics institute, two state universities, more than fifty scientists at Wisconsin alone, 21 drug companies and the War Production Board.** United States output went from 21 billion units in 1943 to over 6,800 billion in 1945 by one tabulation (Indiana Historical Society), and tabulations differ. Sherstneva's archival figure for 1943 is 21,192 million units. Roughly 2.3 million doses existed by D-Day.

5. The improvised programmes: the Soviet Union, Delft, Kunming

The Soviet Union. Zinaida Yermolyeva's group at the All-Union Institute of Experimental Medicine isolated a mould identified as *Penicillium crustosum* and called the product krustozin. Popular accounts say her assistant Tamara Balezina collected about a hundred samples and that the 93rd, from a bomb-shelter wall, worked. Sherstneva's archival study, which I read in full in Russian, dismantles much of the legend.

From declassified State Archive documents: the topic "Obtaining penicillin" entered the institute's plan only in the first quarter of 1943. At a joint session in Moscow on 5 February 1944, with Florey present, Yermolyeva said openly that her laboratory turned to penicillin when the work of Florey and Abraham appeared and information on purification and clinical use reached her. Florey's delegation handed over materials on culture methods and media. What the Americans withheld was submerged fermentation. In March 1944 she reported production of 200 to 300 litres of liquid penicillin a month, a figure Sherstneva calls a typical report of success because it was never converted into Oxford units, which would have shown how few patients it could treat.

Two Moscow plants began liquid production only in late autumn 1944 and dry in 1945, on "semi-factory installations and laboratory-type equipment", with a combined capacity of **500 million Oxford units a year**, which Sherstneva states was **enough for at most 300 to 400 patients a year**. A single American plant using submerged fermentation reached 500 billion units a year, a thousand times more. In 1945 Soviet military medicine received 10 billion units of imported penicillin against 120 million domestic, about 83 to 1, and all five Soviet plants together made 1,170 million units in nine months of 1945 against an estimated 1946 requirement of 3,200 billion.

On the claim that krustozin was better: Professor I.G. Rufanov, in whose clinic the two were compared in February 1944, reported that the Soviet antibiotic "in some respects surpasses the foreign preparation". Nikolai Burdenko refuted him on clinical observation and prevailed: the May 1945 official Instruction on the Use of Penicillin named both producing organisms and prescribed **the same dose and the same indications for each**. A VOA fact check adds that krustozin caused fever, was unstable in storage and was discontinued (Martynyuk 2023, citing TASS), which Sherstneva does not report and I could not verify archivally [VERIFY].

Delft. At the Nederlandsche Gist- en Spiritusfabriek under occupation, a group working under the cover name Bacinol, advised by Albert Kluyver and the physician Andries Querido, began penicillin work in 1943 or 1944, with moulds arriving from the Centraalbureau voor Schimmelcultures from 19 January 1944. They used milk bottles as fermenters and tested on mice. By spring 1944 they had a golden-brown powder at about **50 per cent purity** and by April 1945 several ampoules. The first patient, Maria Geene, recovered in November 1945, **after** the liberation

(Bruggink 2021, drawing on Burns 2005, not read). A group with an industrial fermentation plant and a world-class microbiologist treated nobody while the occupation lasted.

Kunming. The National Epidemic Prevention Bureau under Tang Feifan achieved small-scale domestic production, and a paper by Chu, Wong, Fan and Tang appeared in the *Chinese Medical Journal* in 1945 as "Experimental Production of Penicillin in China". **I could not read it, nor Xu's 2013 note on the same work.** The word "experimental" in both titles is the honest signal. I found no figure for Chinese wartime yield or patients treated, and could not confirm the brief's 1944 date.

6. The folklore, and what a mould in a jar actually makes

Mouldy bread was applied to wounds in ancient Egypt, and mouldy bread and jam were used in folk therapy in Quebec, Devon and Kansas. Poultices of mouldy chewed barley and apple were used on surface wounds in Asia. A London apothecary in 1640 advised that moulds cured infections (Alnaimat et al 2015). The brief attributes that to John Parkinson's *Theatrum Botanicum*, which fits, Parkinson being apothecary to James I with a book published in London in 1640, but Alnaimat does not name him and **I could not confirm the passage from the book** [VERIFY]. Wainwright's 1989 *Mycologist* article is the standard citation here and I could locate only its bibliographic record.

The record shows use, not cure: there is no counted series anywhere in the pre-modern literature of mould applied to infection with outcomes against a comparison. The nearest hard evidence of ancient exposure is chemical, Nelson and colleagues having found tetracycline embedded in Sudanese Nubian bone of 350 to 550 CE, attributed to *Streptomyces* in grain used for beer (Nelson et al 2010, press summaries only). That is exposure, not benefit, and Hummert and Van Gerven found no relationship between tetracycline labelling and disease markers in the same population.

The modern test of the folklore is Alnaimat and colleagues, Wainwright among them (2015). They isolated *Penicillium* from four mouldy shop-bought foods (apple, beetroot, lemon, orange) and laid mycelial discs on plates seeded with methicillin-sensitive and methicillin-resistant *S. aureus*. All four inhibited both, with zones of 16 to 19 mm against MSSA and 17 to 18 mm against MRSA. A 6 microgram penicillin G disc gave 30 mm against MSSA and nothing against MRSA. Penicillin was detected in all filtrates. **Patulin was detected in the apple and beetroot isolates.** A separate study found more than fivefold differences between *P. chrysogenum* isolates by HPLC and **no activity against MRSA** (Dayalan, Darwin and Prakash 2011). Wainwright and colleagues have themselves suggested that patulin rather than penicillin may be the active agent behind folk cures. That is not a reassurance. The thing in the poultice that kills bacteria may be the thing that damages kidneys.

So a mould on fruit or bread may well make some penicillin, and is quite likely making a mycotoxin. The quantity is unknown, unmeasurable without an assay, variable between isolates by a factor of five or more, and dissolved in a liquid that also holds fungal protein and bacterial contaminants. Alnaimat's authors draw the conclusion themselves: such use would likely be rejected by regulators and ethics panels, and they see a possible application **only in extreme situations, or with a pure culture known to produce penicillin without patulin or other toxicants.**

The hazards are specific. *Aspergillus flavus* makes aflatoxin. The 2004 eastern Kenya outbreak, from maize with aflatoxin B1 up to 4,400 parts per billion, produced 317 cases of acute hepatic failure and 125 deaths, about 39 to 40 per cent case fatality, with 51 per cent of cases under 15 (CDC MMWR 2004). The 1981 Makueni outbreak had 20 cases and 60 per cent mortality. *Penicillium expansum* is the main producer of patulin, which in animal and cell studies degenerates glomeruli and renal tubules, and citrinin is nephrotoxic. Field surveys of bread moulds find *A. niger*, *A. flavus*, *Mucor*, *Rhizopus* and *P. chrysogenum* together. **Nothing visible to the eye distinguishes a penicillin producer from an aflatoxin producer.** Colour does not do it. Smell does not do it.

7. Crude filtrate on the surface: Paine's four cures, and the price

Cecil George Paine, a pathologist at the Royal Infirmary in Sheffield and a former student of Fleming's, obtained the mould and in 1930 and 1931 applied crude unpurified filtrate topically. The surviving case notes, recovered and

published by Wainwright and Swan in *Medical History* in 1986, are the earliest documented evidence anywhere of successful penicillin therapy, covering ophthalmia neonatorum in infants and a patient with a corneal laceration and pneumococcal contamination. Paine's own recollection was **five eye patients with four cures**, and **three patients with sycosis barbae who were not helped**. Results elsewhere were failures, the effective dose was unknown, and nobody could overcome the instability and variability of the material (Wainwright and Swan 1986, read through secondary summaries only).

In the war crude penicillin was used in compresses and ointments, and Robinson and Wallace described a gauze pad on which *Penicillium* had been grown directly (*Science*, 8 October 1943). The Tripoli conference of August 1943, with Florey present, reported consistent eradication of streptococci and staphylococci from wounds dosed every eight hours for four to five days, no effect on Gram-negative bacilli, cure of osteomyelitis only with large intravenous doses, and no improvement in fractures with long-standing infection (New Zealand official medical history).

Then came the harm that closed the door. A survey of about 350 patients treated with penicillin ointments described pruritus, urticaria, toxic erythemas and vesicular and bullous dermatitis, and a 1946 study showed guinea pigs could be anaphylactically sensitised to commercially prepared penicillin, so impurities were not the whole story. First reports of penicillin urticaria and contact dermatitis date to 1943, first anaphylaxis to 1945, first fatal anaphylaxis to 1946, and a 1946 *JAMA* review put delayed serum-sickness reactions at about 1 in 1,500 to 1 in 2,000 courses (period articles, read as search summaries).

The verdict is narrow. A crude filtrate on a superficial conjunctival infection has a thin but real evidence base from one investigator, four cures in five patients, no controls, no known dose or purity. Against it stand two hard facts. The active substance cannot be distinguished from the mycotoxin without a laboratory. And sensitising a person topically can make a later life-saving injection of salvaged penicillin kill them. **A village that uses mould filtrate on eyes today may lose the ability to use its last ampoule of real penicillin on the same person in five years.**

8. Why crude broth is never injected

Four mechanisms, each sufficient alone.

Pyrogens. The first human to receive Oxford penicillin had fever and a rigor from pyrogenic impurities. Oxford had a biochemist, a chromatography column and rabbits for pyrogen testing. A village has none. Modern intravenous preparations are held to 5 endotoxin units per kg per hour, and the Patterson phage team had to dilute preparations averaging 1,640 to 5,890 units per millilitre to meet it (Schooley et al 2017). A crude broth is nowhere near that, and cannot be measured without a laboratory.

Mycotoxins. Injection bypasses every barrier the gut provides.

Bacterial contamination. An unfiltered broth grown in a warm jar is a bacterial culture as well as a fungal one. Injecting it is injecting sepsis. WHO's work on unsafe injections, counting only reused equipment and not contaminated product, attributed up to 1.7 million hepatitis B and as many as 33,800 HIV infections in 2010 to unsafe practice (Pépin et al 2014). A deliberately injected unsterile fluid is worse.

The solvent. In September 1937 the S.E. Massengill Company dissolved sulfanilamide in diethylene glycol and sold it as Elixir Sulfanilamide. The FDA History Office account gives 71 adults and 34 children dead, 105 in all, across 15 states, from kidney failure. Investigators recovered 228 of the 240 gallons made. The last victim died on 31 October 1937. The chemist, Harold Watkins, killed himself. The company had broken no law, because the product contained what it said. **The drug was correct. The thing it was dissolved in killed the patients, most of them children.**

9. Sulfanilamide: easier to discover, not easier to make

Gerhard Domagk at I.G. Farben found in 1932 that the red azo dye Prontosil rubra, synthesised by Mietzsch and Klarer, protected mice against streptococcal infection although inactive in the test tube, and published in February

1935 (Ellis 2014). Within weeks the Pasteur Institute group under Fourneau showed the active part was the sulphanilamide fragment, made by Paul Gelmo for a Vienna doctorate in 1908 and therefore unpatentable. Ronald Hare argued in 1970 that this is why the 1932 results waited until 1935.

The clinical effect was large and replicated. Leonard Colebrook and Méave Kenny at Queen Charlotte's published on Prontosil in puerperal fever in *The Lancet* in 1936: 38 almost hopeless cases with three deaths, then 26 treated without a death (Ellis 2016). Colebrook and Purdie's 1937 series of 106 women gave 8 deaths, 3 directly from puerperal fever, with daily doses of 8 to 12 g in severe cases and 3 to 6 g in less severe. Ward mortality fell from 93 per cent in 1932 to 27 in 1936 and 1937, although Colebrook attributed the earlier fall to antibacterial handwashing (Embryo Project).

This report does not give the acetanilide route, and the reason is not squeamishness. Chlorosulfonic acid reacts violently with water, is very toxic by inhalation, causes severe burns, reacts violently with alcohols and finely divided organic matter, and must not be fought with water in a fire (NOAA CAMEO Chemicals). It is handled in plants designed for oleum, and a hamlet with a still cannot hold it. The intermediate steps need a controlled-temperature reaction vessel, acid-resistant plant, fume handling, and a way to establish that the product is the compound intended. Then comes the step 1937 is about: even granted the right compound, it must be given in something that does not kill.

Sulfonamides carry their own toxicity: crystalluria, oliguria and anuria, agranulocytosis, thrombocytopenia, haemolytic anaemia in G6PD deficiency, and hypersensitivity rising with dose. Hydration is the main preventive measure for the kidney effects, with a target urine output of 1,200 to 1,500 ml a day (Merck Manual). **I could not find period incidence figures** for agranulocytosis or crystalluria from the 1930s and 1940s, and I will not estimate them.

Sulfanilamide powder packets were issued to every American soldier from 1941, and in July 1944 the Surgeon General determined they were not appropriate for field wound treatment and recommended suspension of issue (med-dept.com). The Pearl Harbor experience was that enthusiasm for the powder led surgeons to skip debridement and wounds became infected, though British wartime accounts were more favourable. **Powder in a wound does not replace cleaning the wound, and believing it does kills people** (THRIVING library, WO-02).

10. Phages: the most feasible and the least reliable

D'Herelle named bacteriophages in 1917 and treated a boy with severe dysentery in Paris in 1919. Giorgi Eliava, who had observed bactericidal action in the Mtkvari in Tbilisi, met him at the Pasteur Institute and founded a bacteriological institute in Tbilisi in 1923. D'Herelle worked there in the mid 1930s. Eliava was executed as an enemy of the people in 1937.

D'Herelle's 1927 Punjab cholera work reported 8.1 per cent mortality among treated against 62.9 per cent untreated, and the Indian Medical Service replicated it in Assam with 8 to 11 against 60 to 80 per cent. These are the figures phage advocacy quotes. **The Punjab control group consisted of people who refused treatment** (secondary encyclopedia source [VERIFY]). That is not a control group. Three other investigators reported complete failure in the same period. A randomised placebo-controlled WHO-sponsored trial in East Pakistan in the 1960s found a high phage dose matched tetracycline in reducing vibrio excretion but gave no convincing clinical improvement.

Myelnikov's 2018 history is the best account of the Soviet record. By about 1940 a network of institutes made phage, Moscow making cholera phage and Tbilisi dysentery, intesti- and pyo-phages. Yermolyeva produced it locally in a Stalingrad basement in 1942 when bombers destroyed the train carrying it from Moscow, with no figure recorded for how many received it. The best-quantified trial is Mel'nyk's in the Donbass between 1929 and 1935: **282 treated against 1,059 controls, mortality halved, and 55 per cent of treated discharged within four days against 19 per cent of controls.** Myelnikov himself calls this promising but not foolproof. Against it stand Krueger and Scribner in *JAMA* in 1941 finding no consistent evidence of efficacy, and Florey calling much of the Soviet work

"Impressionist" science. Critically, Soviet production used generic polyvalent mixes rather than matching phage to the patient's own strain.

The matching problem is quantified in modern work. Against collected isolates, Pyophage and Intestiphage each lysed 81.7 per cent of 142 ESBL-producing *E. coli*. Against isolates straight from patients the figures collapse: in 118 clinical urine samples tested against the Pyo preparation, 24 per cent of strains were sensitive, 16 per cent moderately sensitive and 60 per cent resistant, improving after adaptation to 41 and 34 per cent. Georgian regulation, inherited from Soviet practice, requires commercial preparations to be checked against newly emerging strains at least every six months. **A phage preparation not matched to the bacterium in front of you is, more often than not, water.**

Schooley and colleagues reported in 2017 the treatment of a 68-year-old diabetic man with necrotising pancreatitis and disseminated multidrug-resistant *Acinetobacter baumannii*. Nine phages in three cocktails were used, from environmental samples including raw sewage, screened against the patient's own isolate, with two laboratories finding active phages within 10 days. Doses were of the order of 10^9 plaque-forming units, and even after purification the preparations had to be diluted to meet the 5 endotoxin units per kg per hour limit. **Phage resistance emerged in an isolate collected about eight days into therapy, stepwise, to all eight original phages**, and a ninth phage plus minocycline was needed. He went home on day 245.

The largest modern series is Pirnay and colleagues in *Nature Microbiology* in 2024: 100 consecutive cases across 35 hospitals in 12 countries, clinical improvement in 77.2 per cent and eradication in 61.3 per cent, with **eradication 70 per cent less likely when no concomitant antibiotic was used** (odds ratio 0.3). It is an uncontrolled retrospective series. The controlled trials are weaker: PhagoBurn randomised 27 burn patients and was stopped early for insufficient efficacy, and Wright's 2009 double-blind trial in 24 patients with chronic otitis cleared the infection in only 3 of 12.

11. What a bench buys, and the arithmetic of a village

The Oxford cylinder-plate assay, described by Heatley in the *Biochemical Journal* in 1944 (38:61-65, which I could not read), works on a simple principle. A known organism is seeded evenly over a plate, measured volumes of test and standard material are placed in wells or cylinders, the plate is incubated, and the diameter of the clear ring is read against a curve made from the standard. Florey's group used *S. aureus* at 37 degrees C for twelve to sixteen hours. The same geometry underlies the modern disc-diffusion test, standardised by WHO in 1976 and taught for district laboratories in *Basic laboratory procedures in clinical bacteriology* (Vandepitte et al 2003).

Such a bench can Gram-stain pus and say whether the organism is a Gram-positive coccus in clusters or chains or a Gram-negative rod, which changes treatment more than any homemade antibiotic would. It can test whether a salvaged, expired or unlabelled antibiotic still has activity, the highest-value use of a plate after the Fall (THRIVING library, IN-05). It can test susceptibility, and whether a phage lyses the patient's own isolate. And it can show, by the absence of any zone, that a crude preparation has no useful activity, stopping a programme before it wastes a year. It cannot measure endotoxin or mycotoxin, establish sterility to injectable standard, or convert a zone diameter into an injectable dose without a calibrated standard.

The arithmetic below is my own, from sourced figures [VERIFY]. The library's epidemiology report gives a village of 300 roughly 13 child pneumonia episodes a year, under one case of newborn sepsis, a maternal death about once in twenty years, and a steady background of wound infection (THRIVING library, IN-01). Call it 20 to 30 courses a year that would change an outcome. At 50,000 to 1.5 million units a course, mid value 400,000, that is **8 to 12 million units a year for the village** and **80 to 120 million for a district of 3,000**. At Oxford's demonstrated 2,000 litres per septic case, 25 cases need **50,000 litres**, which at 500 litres a week is **two years of full-time work by six people plus a laboratory**. At the best wartime strain and medium, 900 units per millilitre, the village's need falls to about **11,000 litres** before extraction losses. The village has neither the strain, the medium nor the extraction. The Soviet figure is the reality check: two plants staffed by a state institute made 500 million units a year, enough for

300 to 400 patients, so **a district of 3,000 would need roughly a fifth of the entire Soviet national penicillin capacity of 1945.**

Evidence grades

Thing	Tradition	Record	Modern inference	Grade
Injected purified penicillin for sepsis, osteomyelitis, puerperal fever	Not traditional	Oxford 1941, Tripoli 1943, worldwide after	Transformative, dose-dependent	**A**
Sulphonamides for puerperal sepsis	Not traditional	Colebrook 1936 and 1937: 38 cases 3 deaths, then 26 with none, 106 cases 8 deaths, ward mortality 93% to 27%	Replicated across countries	**A**
Crude mould filtrate on conjunctivitis	Mouldy bread on sores	Paine 1930-31: 4 cures in 5 eye patients, 0 of 3 in sycosis barbae, no controls	Plausible, unquantified, sensitising	**D**
Mouldy bread or jam poultice on a wound	Egypt, Quebec, Devon, Kansas, Asia	No counted series anywhere	Some moulds make penicillin, some patulin, none distinguishable by eye	**D**, and **X** for any deep wound
Injecting crude broth of any kind	Nobody ever claimed this	Pyrogenic rigor in the first recipient at Oxford	Endotoxin, mycotoxin and contamination all uncontrolled	**X**
Sulfanilamide powder in a field wound	Issued to every US soldier from 1941	Issue suspended July 1944, associated with skipped debridement	Does not substitute for cleaning	**X** as a substitute for debridement, **D** as an adjunct
Phage matched to the patient's own isolate, with an antibiotic	Soviet and Georgian practice	Pirnay 2024: improvement 77.2%, eradication 61.3%, uncontrolled	Eradication 70% less likely without a concomitant antibiotic	**B**
Unmatched commercial phage cocktail	Soviet polyvalent mixes	24% of 118 clinical urinary isolates sensitive before adaptation	Matching is the whole problem	**D**

Thing	Tradition	Record	Modern inference	Grade
Phage for cholera	Punjab claim, 8.1% against 62.9%	Controls were people who refused treatment, and the WHO-era randomised trial showed no clinical benefit	Not established	**X** for the Punjab claim as evidence, **D** for the practice
Plate assay to test a salvaged antibiotic	Not traditional	Oxford 1941-44, WHO district standard since 1976	Reliable for presence or absence, needs a standard for potency	**B**
A district penicillin programme from scratch	Internet folklore	Soviet state effort 300-400 patients a year, Delft under occupation zero, Kunming "experimental"	Yield, not chemistry, is the barrier	**X** at hearth and hamlet, **D** at district

Means ledger

Rung	Penicillin	Sulfa	Phage	What it changes
Hands and knowledge alone	Nothing. Recognise the infections antibiotics treat and the ones they do not, and know that mouldy bread is not a drug	Nothing	Nothing	Prevents the fatal error of delaying drainage while waiting for a poultice
Hearth (fire, clean water, salt, honey, vinegar, cloth, knife)	Nothing safe. Growing mould is easy and useless: the product cannot be measured, dosed or kept	Nothing	Nothing	Cleaning, drainage, honey or sugar dressing and fluids save more lives here than any improvised antibiotic (WO-02)
Garden and still (ethanol, soap, scale, pressure cooker, forge)	Nothing injectable. A pressure cooker gives sterile dressings and instruments, not sterile drugs. Ethanol antiseptics belong here (IN-07)	Nothing. Chlorosulfonic acid and oleum are not hamlet chemicals at any price	Nothing, without a way to identify the bacterium	Sterile instruments and antiseptics. The rung at which surgery becomes survivable

Rung	Penicillin	Sulfa	Phage	What it changes
Village dispensary (300, lay healer, salvaged stock, microscope)	Use and ration salvaged stock (IN-05). Gram-stain pus. Do not attempt production	No	No	The right salvaged drug, given as a full course, beats any local synthesis
District infirmary (3,000, nurse or doctor, sterile room, ten beds, lab bench)	Plate assay of salvaged stock, disc sensitivity, Gram stain, a maintained reference culture. A production attempt can be started and will almost certainly fail: the ceiling is Oxford's, about one septic patient a month at 1941 doses, after one to two years of work by several trained people	No. The chemical plant required is a different civilisation	The most plausible of the three. Phages can be isolated against a specific organism and tested against a patient's own isolate. What a district cannot do is remove endotoxin to injectable standard, so topical and gut use is the ceiling	A bench that tests is worth more than a bench that manufactures. The assay saves the salvaged stock. The production attempt consumes the district
Hospital before the Fall	Industrial fermentation, pennies a dose	Dozens of sulphonamides	Regulated magistral preparations in a few countries	The reference, and it is not coming back

Hearth to garden-and-still changes wound outcomes through cleanliness and sterile instruments, not drugs. Garden-and-still to village changes outcomes through correct use of salvaged drugs. Village to district changes outcomes through diagnosis. **No rung below the pre-Fall hospital changes outcomes through manufacture.**

Harm test

Crude mould preparation, injected. Kills by pyrogenic shock, mycotoxin, injected sepsis or solvent. No dose is safe. Signs it is going wrong: shaking chills one to three hours after the injection, high fever, collapsing blood pressure, falling urine output, jaundice at two to ten days. What to do: stop, give fluids by mouth or rectum, keep the patient warm, and expect to lose them. Historical case: Elva Akers, Oxford, 1941.

Crude mould preparation, topical. Risks mycotoxin absorption through broken skin, bacterial contamination, and contact sensitisation that may make a future life-saving injection fatal. Never on a deep wound, a joint, a body cavity, a burn of more than small area, or an uncleaned wound. Never on an infant, and never in pregnancy. Signs it is going wrong: spreading redness, increasing pain, rash beyond the dressing, itching and weeping at the site. What to do: remove it, wash copiously, do not reapply, and record the exposure, because that record may matter years later.

Mouldy bread swallowed. Aflatoxin from *A. flavus* causes acute hepatic failure. Kenya 2004: 317 cases, 125 deaths, about 39 per cent case fatality, children heavily represented. Makueni 1981 killed 12 of 20. Patulin and citrinin damage kidneys. Who must never: everyone, and especially children and the pregnant.

Sulphonamides. Crystalluria, oliguria and anuria, especially in the dehydrated. Agranulocytosis. Thrombocytopenia. Haemolytic anaemia in G6PD deficiency, common in malarial regions. Severe skin reactions. Hypersensitivity

rises with dose. Prevention of the kidney effects is fluid, with a urine output of 1,200 to 1,500 ml a day, and no dehydrated patient is dosed before rehydration. Signs it is going wrong: falling urine output, blood or gravel in the urine, flank pain, sore throat and fever with mouth ulcers, rash with blisters or mucosal involvement, sudden pallor with dark urine. What to do: stop the drug, push fluids by mouth, do not restart. Historical case of harm: Elixir Sulfanilamide, 1937, 105 dead including 34 children, from the solvent and not the drug.

Phage preparations. Crude lysates contain the broken remains of the bacteria they killed, which is to say endotoxin, so injecting one is injecting a pyrogen. Signs it is going wrong: rigor after dosing, no improvement after 48 to 72 hours, improvement then relapse.

The error common to all three. A weak, unmeasured dose of something that is nearly an antibiotic breeds resistance without curing anybody. Florey said so at Tripoli in August 1943: bacteria become resistant following under-dosing, so adequate dosage should be given at once.

Red flags

Signs the patient will die or be disabled without what the village cannot give, and what to do anyway.

1. **Spreading redness advancing hour by hour, fever above 38.5 C, pulse above 110, confusion.** Sepsis. The pre-antibiotic record gives 82 per cent mortality for staphylococcal bacteraemia (Skinner and Keefer 1941, secondary citation [VERIFY]). Do anyway: open and drain any pus, irrigate, elevate, give fluids by mouth constantly, and if a salvaged antibiotic exists give a full course and not a part of one.
2. **Pain out of proportion to the wound, skin crackling under the fingers, foul sweet smell, dusky skin.** Gas gangrene, for which modern doses reach 72 million units a day and no village preparation touches. Do anyway: open widely, excise dead tissue, and consider amputation above the involvement while the patient can survive it (WO-02).
3. **Newborn who will not feed, floppy or stiff, cold or hot, grunting or breathing fast.** Neonatal sepsis, whose case fatality fell from 16.6 to 2.8 per cent in Gadchiroli when village workers were trained and given antibiotics (IN-01). Do anyway: warmth skin to skin, expressed breast milk by drops, and any salvaged oral antibiotic the dosing section allows.
4. **Jaw stiffness, arched back, spasms on noise or touch.** Tetanus, where antitoxin and not an antibiotic is what is missing. Do anyway: dark quiet room, minimal handling, fluids, honest comfort.
5. **Shaking chill within three hours of any injection.** Pyrogen or injected contamination. Do anyway: stop, warm, fluids, and never give that preparation to anyone again.
6. **A rash that blisters, or involves mouth, eyes or genitals, on any sulphonamide.** Stop immediately. This can be fatal and no village rung treats it.
7. **A bone that stays tender with a sinus that will not close over weeks.** Osteomyelitis, which needed large intravenous doses even at Tripoli. Do anyway: drainage, dressing, nutrition, and plan for disability.

Honest comfort in all of these: tell the family early that the thing which would save this person is not available, that the village is not withholding it, and what will be done instead. The worst outcomes come from delay in drainage while waiting for a drug that is not coming.

The case against

The strongest case against this report's pessimism is that the district rung is dismissed too fast because the hearth rung is hopeless. The record contains real improvised successes. Yermolyeva's nine-person department had a production line in a little over a year. The Delft group under occupation, using milk bottles, reached 50 per cent purity. Paine cured four of five eye infections in 1930 with a filtrate no chemist could purify. These people were not magicians: what they had was knowledge, a trained team and persistence.

The case still fails at the numbers. Each success was embedded in an industrial civilisation. Yermolyeva had state backing, the published Oxford methods, Florey's own handover of culture and media methods, and two chemical plants, and her programme still treated only 300 to 400 patients a year while imports exceeded domestic production about 83 to 1. Delft had a fermentation factory and treated its first patient after liberation. Paine's four cures were on eyes, and nobody since has shown how to dose a filtrate.

Named critics. Milton Wainwright, who rescued Paine's records and has argued most sympathetically for mycotherapy, is also the co-author who says the active principle in folk mould remedies may be patulin, and whose 2015 paper would confine any use to extreme situations with a pure culture of known composition. Howard Florey dismissed much of the Soviet phage literature as "Impressionist" science. Nikolai Burdenko publicly refuted the claim that Soviet penicillin beat the Western product, and prevailed. Elena Sherstneva's archival work shows the Soviet success story was substantially propaganda, and that imported penicillin saved Soviet lives. Krueger and Scribner found no consistent evidence of phage efficacy in 1941. The PhagoBurn investigators stopped their own trial for insufficient efficacy.

Against the opposite error: the book must not use this evidence to dismiss the district laboratory. A district that cannot make penicillin can still test whether the penicillin in the cupboard works, tell a staphylococcus from a Gram-negative rod, test whether a phage lyses this patient's organism, and keep records that let the next generation do better. **The romance to avoid is not only the jar of mould. It is also the belief that because manufacture is impossible, the laboratory bench is useless.**

10-line summary

1. The hard part of penicillin was never growing the mould but extracting, purifying and stabilising it, which defeated Fleming, Raistrick, Ridley and Craddock between 1928 and 1932.
2. Oxford's whole department at full stretch in 1941 produced enough for about one septic patient a month, at about 2,000 litres of culture fluid per case.
3. Albert Alexander received 220,000 units over five days in February 1941, improved, ran out of drug and died on 15 March 1941. That total is a single small injection by modern standards.
4. The wartime yield increase, from about 4 to about 900 units per millilitre, took a national laboratory, two universities, a genetics institute, 21 companies and a war government.
5. The best improvised programme in the record, Yermolyeva's, reached a national capacity of 500 million units a year, enough for 300 to 400 patients, while imports exceeded domestic output 83-fold.
6. A village of 300 would need an estimated 8 to 12 million units a year and a district of 3,000 some 80 to 120 million, a fifth of the entire Soviet capacity of 1945 [my arithmetic].
7. Moulds from ordinary spoiled food do make detectable penicillin, and some make patulin at the same time, and nothing visible distinguishes them.
8. The only documented clinical success with crude filtrate is Paine's, four cures in five eye infections in 1930 and 1931, with no controls and failures in everything else he tried.
9. Crude broth is never injected. The first human given Oxford's own material had a pyrogenic rigor within three hours.
10. Phage is the most feasible of the three at a district bench and the least reliable in the body: it must be matched to the patient's own organism, resistance emerged within eight days in the best-documented modern case, and eradication was 70 per cent less likely without a real antibiotic alongside.

Open questions

- **What was the Oxford broth's actual strength?** Raper's recalled 4 units per millilitre is the only number I could source, and it is an oral history given decades later.

- **Was krustozin more potent, and did it cause fevers?** Rufanov said yes, Burdenko said no, and the 1945 instruction treated both producers identically. The fever claim traces to TASS by way of VOA, not to an archival document.
- **Does a crude filtrate have a defensible topical use at all?** Paine's four eye cures are the whole evidence base, unrepeated under any control in ninety-five years.
- **What mycotoxin exposure comes from a poultice on broken skin?** I found no measurement of transdermal absorption of patulin or aflatoxin.
- **Can a district bench isolate a phage against a local organism and use it safely?** The isolation is plausible, but the endotoxin problem beyond topical or oral use is unsolved at that rung.
- **Is there a middle path**, such as keeping a known pure penicillin-producing strain as a village heirloom against the day a district laboratory exists? I found no discussion of this anywhere.

Sources to read in full

1. **Sherstneva (2019), *Remedium* 12:16-20.** Archival, specific, numerate, and it demolishes the most seductive myth in the field.
2. **Wainwright and Swan (1986), *Medical History* 30:42-56.** The whole evidence base for crude filtrate.
3. **Alnaimat et al (2015), *Saudi Journal of Biological Sciences* 22:600-603.** The modern test of the folklore, with the patulin finding.
4. **Myelnikov (2018), *Journal of the History of Medicine and Allied Sciences* 73:385-411.** The honest history of phage, the trials that worked and the ones that did not.
5. **Pirnay et al (2024), *Nature Microbiology* 9:1434-1453.** The modern ceiling for phage.
6. **Schooley et al (2017), *Antimicrobial Agents and Chemotherapy* 61:e00954-17.** What it actually takes to treat one patient with phage.
7. **Lax, E. (2004). *The Mould in Dr Florey's Coat*.** The standard history of the Oxford effort. **Not read.**
8. **Lesch, J.E. (2007). *The First Miracle Drugs*.** The standard history of sulfa. **Not read.**
9. **Vandepitte et al (2003), *Basic laboratory procedures in clinical bacteriology*, WHO.** Written for the district rung this book describes.
10. **Strathdee and Patterson (2019). *The Perfect Predator*.** The Patterson case from inside. **Not read.**

At the bedside after the Fall

The household

Minimum viable version: none. There is no household version of making an antibiotic. The household's contribution is to know the difference between an infection that needs cleaning and one that needs a drug, and to get the second to the dispensary before it kills.

What it needs to start: clean water, soap, cloth, honey or sugar, a boiled knife, the knowledge in WO-02, and a written record of every antibiotic any family member has reacted to.

The first failure to expect: somebody puts mouldy bread on a wound because they heard it works, and the wound worsens while the chance to drain it passes.

The village of 300

Minimum viable version: a dispensary that can Gram-stain pus, keeps and rations salvaged stock under lock, gives full courses or none, and never attempts production. The honest village experiment is not to make a drug but to test one.

What it needs to start: a microscope and the skill to use it, stains, agar or a substitute, plates, a maintained test organism, a heat source holding about 37 degrees C overnight, a record book, and one person trusted to say no.

The first failure to expect: the test organism dies or is contaminated and nobody notices for a month, so every result in that month is worthless.

The district of 3,000

Minimum viable version: a bench that tests rather than manufactures. Gram stain, disc sensitivity, potency assay of salvaged stock against a kept reference, phage matching if a phage programme is attempted, and a register of every organism, drug, dose and outcome. If after three years the district still wants a penicillin programme, it should start knowing the ceiling: about one patient a month at 1941 doses, after one to two years of work by several trained people, and topical only.

What it needs to start: everything the village needs, plus a reference preparation of known strength (the most precious object in the district), a sterile room, a pressure vessel, someone who can read, calculate and keep records, and a rule on the wall about what is never injected.

The first failure to expect: the reference degrades, because benzylpenicillin in solution is not measurable after about eight days even cold, and the assay silently becomes meaningless.

Protocols

Protocol 1: The rule that is never broken (every rung)

1. Nothing grown, brewed, steeped or fermented in this village is ever injected into a person, under the skin, into a muscle, a vein, a joint, the eye, the belly or a deep wound.
2. Nothing of unknown composition goes to a pregnant woman, an infant under one year, or a person not passing urine.
3. Any preparation that causes a shaking chill within three hours is destroyed, the batch is destroyed, and the fact is written in the register with the date.
4. Write this rule on the dispensary wall and read it aloud to every new helper.

Protocol 2: Deciding whether this infection needs an antibiotic at all (village, 10 minutes)

1. Take temperature, pulse and breathing rate. Record them.
2. Press gently for fluctuance. **If there is pus, the first treatment is to open and drain it, not to give a drug** (WO-02).
3. Mark the edge of the redness with ink and write the time. Re-measure in four hours.
4. Red flags for an antibiotic if one exists: redness or hardening advancing more than 5 cm from the wound edge, temperature above 38.5 C, pulse above 110, confusion, a newborn who will not feed, a woman febrile within six weeks of giving birth, or breathing faster than 50 a minute under one year.
5. If an antibiotic is given, give the whole course. **Half a course is worse than none**, because it breeds resistance without curing.
6. Record the drug, dose, times and outcome at 48 hours and at discharge.

Protocol 3: Testing whether salvaged stock still has activity (district bench)

1. Prepare plates of nutrient agar and seed them evenly with the test organism, the same organism every time. Oxford used *S. aureus*.
2. Incubate at **37 degrees C, tolerance plus or minus 2 degrees**, for **twelve to sixteen hours**, the Oxford window.
3. On each plate place equal measured volumes of the reference preparation of known strength and of the material under test, in wells or cylinders of the same size, at equal distances from the plate edge and at least 25 mm apart.
4. Run the reference at three or more strengths, each a fixed step from the last, so a curve can be drawn.

5. Measure each clear zone in millimetres to the nearest millimetre, across two perpendicular axes, and average them.
6. Plot the reference diameters against their strengths and read the test material's strength from that line.
7. **Repeat every test on a second plate on a second day.** If the two differ by more than about 15 per cent, discard both and find the error before trusting anything.
8. A zone of zero means no activity. Discard that stock and record it.
9. With no reference preparation, the test can only say "some activity" or "none". Record it that way and do not pretend to a number.
10. Keep the reference dry, cold, dark and sealed, never in solution. When a second reference is salvaged, compare the two before the first is exhausted and record the comparison. That is how a district keeps a scale across generations.

Protocol 4: If a district attempts a phage programme (district only)

1. Decide first which single bacterium the programme targets. A phage is useless against anything else.
2. Isolate the patient's own organism in pure culture before anything else.
3. Test every candidate against **that patient's own isolate** on a plate. If it does not lyse the isolate it is water. Only about 24 per cent of clinical urinary isolates were sensitive to an unmatched cocktail.
4. Re-test every stored preparation against newly collected local isolates at least **every six months**, the inherited Soviet and Georgian standard.
5. Use is topical or by mouth only. **Nothing from a bacterial lysate is injected at this rung**, because the lysate contains endotoxin the district cannot measure.
6. Review at 48 to 72 hours. No improvement, or improvement then relapse, means assume resistance has emerged, as it did within about eight days in the Patterson case, and stop.
7. Record every case, matched or not, improved or not.

Protocol 5: If someone has used a mould preparation anyway (village)

1. Remove it and wash the area copiously with clean water.
2. Write in the register: name, date, what was used, where it came from, and on what part of the body.
3. Mark the person's record **possible mould sensitisation**, and tell them and their family that this may matter if they ever need injected penicillin.
4. Watch 24 hours for spreading rash, itching away from the site, swelling of lips or face, or difficulty breathing. Any of these means never again, by any route.
5. If swallowed, watch for jaundice, dark urine and right-sided belly pain over the next two to ten days. Aflatoxicosis killed about 39 per cent of the 317 cases in Kenya in 2004.

Protocol 6: Go or no-go before a district starts a production attempt

All seven must be yes. If any is no, do not start.

1. Does the district already have a working assay, used routinely for a year, with a reference preparation? If no, stop: you cannot measure what you make, so you cannot dose it.
2. Can it spare several trained people full-time for two years without losing the testing service?
3. Does it accept that the product is **topical only** until an assay and a sterility regime exist?
4. Is there a written rule, enforced by someone with authority, that nothing produced will be injected?
5. Can it maintain a single pure strain of known behaviour rather than whatever grows?
6. Has it counted its need honestly? A district of 3,000 needs 80 to 120 million units a year. The Soviet national capacity in 1945 was 500 million.

7. Is there anything the same people and the same two years could do that saves more lives: clean water, attended births, drainage of abscesses, vaccination, nutrition? If yes, do that instead.

Numbers to carry

1. **600 mg of benzylpenicillin is one million units.** An Oxford unit is about 0.6 micrograms of pure drug.
2. **A course needs 50,000 to 1.5 million units**, depending on the disease (Soviet archival figure, 1945).
3. **Albert Alexander got 220,000 units in all, and died when it ran out.** That is a single small injection today.
4. **2,000 litres of culture fluid per septic case** was Oxford's figure in 1941.
5. **4 units per millilitre at Oxford, about 900 at the best wartime strain**, and it took a nation to close that gap.
6. **500 million units a year was the entire Soviet capacity in 1945: 300 to 400 patients.** A district of 3,000 needs roughly a fifth of that every year.
7. **Benzylpenicillin in water is gone in about eight days cold, and much faster warm.** Nothing can be stored as a solution.
8. **About 39 per cent died in the 2004 Kenyan aflatoxin outbreak**, 125 of 317 cases.
9. **105 people, 34 of them children, died in 1937 from the solvent, not the drug.**
10. **About 24 per cent of patients' own isolates were killed by an unmatched phage cocktail. Of matched modern cases 77 per cent improved, but eradication was 70 per cent less likely without a real antibiotic alongside.**

References

1. Ellis, H. (2016). "The birth of the antibiotic era". *British Journal of Hospital Medicine* 77(8):485. Read in full as PDF. https://storage.imrpress.com/IMR/hmed/application/10.12968/hmed.2016.77.8.485.pdf
2. Ellis, H. (2014). "Gerhard Domagk: a Nobel laureate pioneer of chemotherapy". *British Journal of Hospital Medicine* 75(4):231. Read in full as PDF. https://storage.imrpress.com/IMR/hmed/application/10.12968/hmed.2014.75.4.231.pdf
3. Museum of the History of Science, Oxford. "Back from the Dead" exhibition, Production page. Read online. Source of the ceramic vessel, bedpan and biscuit-tin details. https://www.mhs.ox.ac.uk/backfromthedead/exhibition/production/
4. Museum of the History of Science, Oxford. "Original Penicillin Culture and Penicillin Specimen (Recovered)". Read online. Source of the 2,000 litres per septic case figure, the 50 ml unit definition and Heatley's "less than 40 units per mg". https://www.mhs.ox.ac.uk/backfromthedead/exhibition/penicillin-culture-and-specimen/index.html
5. Bruggink, A. (2021). "Chemistry vs. bacteria, #20. Scaling up penicillin". Bio Based Press, 20 June 2021. Read online. Secondary. https://www.biobasedpress.eu/2021/06/chemistry-vs-bacteria-20-scaling-up-penicillin/
6. Bruggink, A. (2021). "Chemistry vs. bacteria, #28. The success of Bacinol". Bio Based Press, September 2021. Read online. Secondary, drawing on M. Burns (2005), doctoral thesis, University of Sheffield, which was **not read**. https://www.biobasedpress.eu/2021/09/chemistry-vs-bacteria-28-the-success-of-bacinol/
7. University of Wisconsin-Madison CALS News (2017). "D-Day invasion was bolstered by UW-Madison penicillin project". Read online. Source of Kenneth Raper's units-per-millilitre ladder, from an archived oral history. https://news.cals.wisc.edu/2017/06/05/d-day-invasion-was-bolstered-by-uw-madison-penicillin-project
8. Alfano, A. (2016). "Solving the problem of penicillin". Cold Spring Harbor Laboratory. Read online. Source of the 5,000 mutant strains and 504 candidates. https://www.cshl.edu/solving-problem-penicillin
9. United States Department of Agriculture, Agricultural Research Service. "Penicillin" timeline entry. Read online. Source of the Moyer corn steep liquor date and tenfold figure.

https://www.ars.usda.gov/oc/timeline/penicillin

10. Sherstneva, E.V. (2019). "Создание «советского пенициллина»: о чем молчали архивные документы" ("The silence of the archive: creation of Soviet penicillin"). *Remedium* 2019(12):16-20. doi:10.21518/1561-5936-2019-12-16-20. **Read in full in Russian.** Source of all Soviet archival figures, the February 1944 session, the Rufanov and Burdenko dispute and the May 1945 Instruction. https://remedium-journal.ru/journal/article/download/1172/4708
11. Martynyuk, L. (2023). "Fact check: Russia reinvents the inventor of penicillin". Voice of America, 13 September 2023. Read online, with K. Tarasava, "The Mother of Soviet Penicillin" (Substack essay, read online) for the popular Balezina account. Both secondary. https://voanews.com/a/fact-check-russia-reinvents-the-inventor-of-penicillin-the-great-soviet-scientist-ermolyeva-/7265664.html
12. Wainwright, M. and Swan, H.T. (1986). "C.G. Paine and the earliest surviving clinical records of penicillin therapy". *Medical History* 30(1):42-56. **Not read in the original.** Read through two secondary summaries: University of Sheffield, "Honour for Sheffield pioneer", and R. Fishman, "The Earliest Success of Penicillin" (Cogan Ophthalmic History Society, reposted on Ento Key, 6 January 2017). https://pmc.ncbi.nlm.nih.gov/articles/PMC1139580/
13. Alnaimat, S., Alharbi, N.S., Alharbi, S.A., Salmen, S.H., Chinnathambi, A., Al-Johny, B.O. and Wainwright, M. (2015). "Mycelium of fungi isolated from mouldy foods inhibits *Staphylococcus aureus* including MRSA: a rationale for the re-introduction of mycotherapy?". *Saudi Journal of Biological Sciences* 22(5):600-603. Read in full via PMC. https://pmc.ncbi.nlm.nih.gov/articles/PMC4537866/
14. Lobanovska, M. and Pilla, G. (2017). "Penicillin's discovery and antibiotic resistance: lessons for the future?". *Yale Journal of Biology and Medicine* 90(1):135-145. Read via PMC. https://pmc.ncbi.nlm.nih.gov/articles/PMC5369031/
15. Fletcher, C. Oral history extract, Royal College of Physicians history collections. Read online. Source of the Elva Akers rigor. https://history.rcp.ac.uk/collections/oral-history/extracts/charles-fletcher
16. Dayalan, S.A.J., Darwin, P. and Prakash, S. (2011). "Comparative study on production, purification of penicillin by *Penicillium chrysogenum* isolated from soil and citrus samples". *Asian Pacific Journal of Tropical Biomedicine* 1(1):15-19. Read via PMC. https://pmc.ncbi.nlm.nih.gov/articles/PMC3609156/
17. Centers for Disease Control and Prevention (2004). "Outbreak of aflatoxin poisoning, eastern and central provinces, Kenya, January-July 2004". *MMWR* 53(34). Read as a search summary of the MMWR item and associated PMC articles. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5334a4.htm
18. Embryo Project Encyclopedia, Arizona State University. "Leonard Colebrook's use of sulfonamides as a treatment for puerperal fever (1935-1937)". Read online. Source of the 106-case series, dose ranges and ward mortality figures. https://embryo.asu.edu/pages/leonard-colebrooks-use-sulfonamides-treatment-puerperal-fever-1935-1937
19. US Food and Drug Administration History Office, "Sulfanilamide disaster", with The Scientist, "The Elixir Tragedy, 1937" and the American Institute of the History of Pharmacy account. Read as search summaries. Source of the 105 deaths, 34 children, 15 states and 228 of 240 gallons recovered. https://www.the-scientist.com/the-elixir-tragedy-1937-39231 and https://aihp.org/sulfanilamide-and-the-food-drug-and-cosmetic-act/
20. NOAA CAMEO Chemicals. "Chlorosulfonic acid" chemical datasheet. Read as a search summary. Hazard data only. https://cameochemicals.noaa.gov/chemical/5911
21. Merck Manual Professional Version, sulfonamides entry. Read as a search summary. Source of the crystalluria guidance and the 1,200 to 1,500 ml urine output target. https://www.merck.com/mmpe/sec14/ch170/ch170n.html
22. Myelnikov, D. (2018). "An Alternative Cure: The Adoption and Survival of Bacteriophage Therapy in the USSR, 1922-1955". *Journal of the History of Medicine and Allied Sciences* 73(4):385-411. Read in substantial part via PMC. Source of the Mel'nyk Donbass figures, the Stalingrad account, Florey's "Impressionist" remark and the Krueger and Scribner *JAMA* 1941 assessment, none of which I read in the original.

https://pmc.ncbi.nlm.nih.gov/articles/PMC6203130/

23. Schooley, R.T. et al (2017). "Development and use of personalized bacteriophage-based therapeutic cocktails to treat a patient with a disseminated resistant *Acinetobacter baumannii* infection". *Antimicrobial Agents and Chemotherapy* 61(10):e00954-17. Read via PMC. https://pmc.ncbi.nlm.nih.gov/articles/PMC5610518/
24. Pirnay, J.-P. et al (2024). "Personalized bacteriophage therapy outcomes for 100 consecutive cases: a multicentre, multinational, retrospective observational study". *Nature Microbiology* 9(6):1434-1453. **Read as abstract and institutional summaries only.** https://researchportal.rma.ac.be/en/publications/personalized-bacteriophage-therapy-outcomes-for-100-consecutive-c/
25. Jault, P. et al (2019). PhagoBurn randomised trial, *The Lancet Infectious Diseases*. **Read as the CORDIS final publishable summary and secondary summaries only.** https://www.cordis.europa.eu/docs/results/601/601857/final1-phagoburn-final-publishable-summary-report.pdf
26. Wright, A. et al (2009). Randomised double-blind trial of a phage preparation in chronic otitis, *Clinical Otolaryngology*. **Read as secondary summaries only.**
27. Bionity encyclopedia entry on Félix d'Herelle. Read online. **Secondary**, and the source of the Punjab 8.1 against 62.9 per cent figures, the Assam replication, and the statement that the controls were people who refused treatment [VERIFY against a primary source]. https://www.bionity.com/en/encyclopedia/Felix_d%27Herelle.html
28. Electronic Medicines Compendium. Benzylpenicillin sodium Summary of Product Characteristics. Read as a search summary. Source of the modern dose ranges and the gram-to-mega-unit equivalence. https://www.medicines.org.uk/emc/medicine/108142/SPC
29. Health Products Regulatory Authority (Ireland), licence PA1122-038-003, benzylpenicillin. Read as a search summary. Source of 1 million IU equals 598.9 mg. https://assets.hpra.ie/products/Human/40741/Licence_PA1122-038-003_30012026144402.pdf
30. *Drug and Therapeutics Bulletin*, archived article on oral penicillins. Read as a search summary. Source of the statement that gastric acid destroys benzylpenicillin and only a small, inconsistent fraction is absorbed. https://dtb.bmj.com/content/5/7/28
31. Stability of benzylpenicillin in outpatient parenteral antimicrobial therapy (2024), *Antibiotics*. Read as a search summary via PMC. Source of the eight-day and buffered-stability figures. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11504374/
32. World Health Organization Expert Committee on Biological Standardization. "The second international standard for penicillin". PubMed 13082387. **Abstract only.** https://pubmed.ncbi.nlm.nih.gov/13082387
33. Inventing Europe. "Standardizing the magic bullet". Read as a search summary. Source of the 1945 International Unit value of 0.0006 mg. https://www.inventingeurope.eu/story/standardizing-the-magic-bullet
34. Heatley, N.G. (1944). "A method for the assay of penicillin". *Biochemical Journal* 38(1):61-65. **Citation located, article not read.** doi:10.1042/bj0380061
35. Vandepitte, J. et al (2003). *Basic laboratory procedures in clinical bacteriology*, 2nd edition. Geneva: World Health Organization. **Publication record read, manual not read in full.** https://www.who.int/publications/i/item/9241545453
36. Nelson, M.L., Dinardo, A., Hochberg, J. and Armelagos, G.J. (2010). "Brief communication: mass spectroscopic characterization of tetracycline in the skeletal remains of an ancient population from Sudanese Nubia 350-550 CE". *American Journal of Physical Anthropology*. doi:10.1002/ajpa.21340. **Read through press summaries only**, which are also the source for the Hummert and Van Gerven counter-finding. https://news.emory.edu/emory-report-archive/stories/2010/09/07/beer.html
37. New Zealand Electronic Text Centre, official history of New Zealand in the Second World War, surgery volume, penicillin chapter. Read as a search summary. Source of the Tripoli conference findings of August 1943 and Florey's remark on under-dosing. https://nzetc.victoria.ac.nz/tm/scholarly/tei-WH2Surg-pt1-c1-5.html
38. Robinson, G.H. and Wallace, J.E. (1943). "An inoculated penicillin dressing". *Science* 98(2545):329-330. **Ci-**

tation and a secondary summary read, article not read.

39. med-dept.com. "Class 9 items: drugs, chemicals and biological stains, sulfa drugs". Read as a search summary. Source of the July 1944 suspension of sulfanilamide packets and the Pearl Harbor debridement experience. https://med-dept.com/?p=81
40. Pépin, J. et al (2014). "Evolution of the global burden of viral infections from unsafe medical injections, 2000-2010". *PLoS ONE*. **Read through WHO and PAHO statements only.** https://www.paho.org/en/news/24-2-2015-new-who-policy-injection-safety-seeks-reduce-spread-disease-through-unsafe-practices
41. Xu, D. (2013). "Experimental production of penicillin in Kunming in the early 1940s". *Protein and Cell* 4(5):323-324. doi:10.1007/s13238-013-3801-7. **Metadata only, article not readable.** https://journal.hep.com.cn/pac/EN/1159767634227028707
42. Chu, C.M., Wong, Y.W., Fan, C.C. and Tang, F.F. (1945). "Experimental production of penicillin in China". *Chinese Medical Journal*. **Bibliographic reference only, not read.**
43. Wainwright, M. (1989). "Moulds in ancient and more recent medicine". *The Mycologist* 3(1):21-23. doi:10.1016/S0269-915X(89)80010-2. **Bibliographic record only, not read.**
44. Indiana Historical Society, "Commercial Solvents penicillin plant construction photographs" finding aid. Read as a search summary. Source of the 1943 to 1945 United States production totals. https://indianahistory.org/wp-content/uploads/commercial-solvents-penicillin-plant-construction-photographs.pdf
45. Understanding Animal Research. "Penicillin" history page. Read as a search summary. Source of the Ridley and Craddock failure and Fleming's instability conclusion. https://www.understandinganimalresearch.org.uk/human-diseases/penicillin
46. Period literature on penicillin hypersensitivity, 1943 to 1946 (*JAMA* and *Archives of Dermatology* items, including the 1946 review giving delayed reactions at about 1 in 1,500 to 1 in 2,000 courses, the ointment survey of about 350 patients, and the guinea-pig sensitisation study). **Read as search summaries only**, not in the originals.
47. Skinner, D. and Keefer, C.S. (1941), staphylococcal bacteraemia mortality. **Read only as a secondary citation** [VERIFY].
48. Studies of Georgian commercial phage cocktail coverage, including the 142 ESBL-producing *E. coli* panel and the 118 clinical urine samples before and after phage adaptation. **Read as search summaries only.** The 43 to 87 per cent adaptation figure comes from unrefereed conference material.
49. Lax, E. (2004). *The Mould in Dr Florey's Coat*. London: Little, Brown. **Not read.**
50. Lesch, J.E. (2007). *The First Miracle Drugs: How the Sulfa Drugs Transformed Medicine*. Oxford University Press. **Not read.**
51. Strathdee, S. and Patterson, T. (2019). *The Perfect Predator*. New York: Hachette. **Not read.**
52. THRIVING library, WO-02, "Cleaning the wound: irrigation, debridement, honey, sugar and the lessons of Ambroise Paré". Read in part.
53. THRIVING library, IN-01, "The great killers after the Fall". Read in part. Source of the village and district disease burden figures and the Gadchiroli neonatal sepsis case fatality.
54. THRIVING library, IN-05, salvaged antibiotics and stewardship. Referred to for the salvage question, not read.