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Przegląd / Review

Selected aspects of undercover production of explosives and explosive devices in 1939-1945
Wybrane aspekty konspiracyjnej produkcji materiałów i wyrobów wybuchowych w latach 1939-1945

Tomasz Sałaciński

Institute of Industrial Organic Chemistry, 6 Annopol, 03-236 Warsaw, PL
https://orcid.org/0000-0002-4376-4081
E-mail: salacinski@ipo.waw.pl

Abstract: *In this paper are presented:*
a) contemporary limitations in research opportunities,
b) raw material sources and technological background,
c) human resources,
d) organization of production,
e) locations of manufacturing facilities (armouries),
f) diversification of explosive devices and explosives applied in their underground production, as well as support from abroad,
g) production quality and research capabilities,
h) contemporary forms of commemoration of people and places associated with the clandestine production of explosives and explosive devices in occupied Poland during the Second World War.
The purpose of the analysis is to show how big and diverse was this activity, as well as, the importantance of this topic in our times.
Streszczenie: *W pracy zaprezentowano:*
a) współczesne ograniczenia możliwości prowadzenia badań,
b) zaplecze surowcowe i technologiczne,
c) zaplecze kadrowe,
d) organizację produkcji,
e) lokalizacje wytwórni,
f) zróżnicowanie produkowanych w podziemiu wyrobów oraz materiałów wybuchowych stosowanych do jego produkcji, jak też wsparcie zagraniczne
g) jakość produkcji i możliwości badawcze,
h) współczesne formy upamiętnienia ludzi oraz miejsc związanych z konspiracyjną produkcją materiałów i wyrobów wybuchowych na terenach okupowanej Polski w czasie II wojny światowej.
Celem podjętej analizy było wykazanie jak duża i jak zróżnicowana była ta działalność oraz jak ważny jest to temat dla współczesnych Polaków.

Keywords: *Second World War, explosives, cheddite, potassium chlorate(V), arming, production, memorial*
Słowa kluczowe: *II wojna światowa, materiały wybuchowe, szedyt, chloran(V) potasu, uzbrojenie, produkcja, pomnik pamięci*

Nomenclature:

AK Home Army (*pl. Armia Krajowa*)
AL People's Army (pl. *Armia Ludowa*)
AN Ammonium nitrate(V), NH_4NO_3
BBT Bureau of Technical Studies (pl. *Biuro Badań Technicznych*)
BCh Farmers' Battalions (pl. *Bataliony Chłopskie*)
DNB Dinitrobenzene, $C_6H_4(NO_2)_2$
ET-40 Hand grenade produced by **ZWZ-AK**, often called „*Filipinka*"
EX(s) Mixture(s) and/or substance(s): secondary and primary explosives and pyrotechnical, respectively
EXDs Explosive and pyrotechnical devices, respectively
GL People's Guard (pl. *Gwardia Ludowa*)
GL-AL **GL** and/or **AL**, respectively
MF Mercury fulminate, $Hg(ONC)_2$
NC Nitrocellulose
PBX Plastic Bonded Explosive(s)
PC Potassium chlorate(V), $KClO_3$
PRL Polish People's Republic (pl. *Polska Rzeczpospolita Ludowa*)
PWP National Factory of Gunpowder and Explosives in Pionki (pl. *Państwowa Wytwórnia Prochu w Pionkach*)
R-42 Hand grenade produced by **ZWZ-AK**, often called „*Sidolówka*"
RDX Hexogen, $C_3H_6N_6O_6$
PETN Pentrite, $C(CH_2ONO_2)_4$
TNT Trinitrotoluene, $C_6H_2(CH_3)(NO_2)_3$
WW2 Second World War
ZWZ Union of Armed Struggle (pl. *Związek Walki Zbrojnej*)
ZWZ-AK **ZWZ** (1939-1942) and/or **AK** (1942-1944), respectively
Ø Diameter [mm]

Supporting Information (Tables S1-S4 and Figures S1-S8) is available at:
http://www.wydawnictwa.ipo.waw.pl/materialy-wysokoenergetyczne/materialy-wysokoenergetyczne10/HEM_0171_SI.pdf

1. Introduction

1.1. Contemporary limitations in research opportunities

The extraordinaryness of the Polish underground armament industry in the period 1939-1945 is that it was the sole activity of all resistance movements which operated throughout the occupied territories involved in **WW2** [1]. However, there are few scientific monographs on the clandestine manufacture of **EXs** in occupied Poland. Although present in those works, none of them is focussed on the technologies of the synthesis of **EXs** or on the development of **EXDs**. The reason is obvious, keeping **EXs** alone doesn't enable fighting to take place, *i.e.* the struggle against an enemy demands a lot of **EXDs**. In other words, the need to analyze the manufacture of **EXs** and **EXDs** is important but not crucial for many researchers studying the clandestine armament industry. It is justified because the achievements of Polish gun constructors from **ZWZ-AK** and **BCh**, are much better documented as well as being much more spectacular than the production of **EXs**. Finally, much more emphasis is put on successes in the field of developing and clandestine production of – essentially, homemade, even though professional technologies were used – machine guns [1-3], not to mention the continuation of underground manufacture of the pre-war pistol VIS [4]. Moreover, the clandestine machine guns contained solutions at the world-class technical level known during **WW2**, in some cases even exceeding this.
Descriptions of the manufacture technologies of **EXs** produced in underground facilities are not generally

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available. It appears that the main source of data is that detailed by Heger on clandestine production of **EXs**, recalled among the references used in Satora's monograph [2]. Heger was involved in the production of **EXs** and **EXDs** (see Table 1), so was very competent in this field. The questions are, if mentioned in [2] do the details cover all apects of the topic or are there other sources which could confirm Heger's statements.

As will be shown, in the field of secondary **EXs** the first and only place is taken by cheddite (**PC**-based **EX**, of very variable chemical composition). Taking into consideration that development of cheddite was stopped after **WW2**, *i.e.* other **EXs** practically displaced cheddite from the market, one can make an assumption that knowledge about cheddite before and after **WW2** (*e.g.* in 1979, as regards to Heger's monograph [5]) is very close to the level of know-how used in the clandestine facilities.

Another situation is in the field of primary **EXs**. However, the list of primary **EXs** available during **WW2** is well known, *i.e.*: **MF** (in use since 1815), lead azide (synthesised in 1910) and lead(II) 2,4,6-trinitroresorcinate (preparation established in 1919) and tetrazene (synthesised in 1919). Because of the huge importance of inventory activities during **WW2**, technological know-how of primary **EXs** production could be significantly different after **WW2**, compared with the state-of-art before 1939. However, primary **EXs** are extremely dangerous so far reaching changes in manufacturing technologies seemed to be excluded. The reason is obvious, basic processes of these technologies had to optimized at the beginning. Other solutions, *i.e.* choosing processes which are not optimised, have resulted in so many accidents that such technologies had to be abandoned. Confirmation of this theory is, for example the synthesis of lead azide, described in p. 3.4.2. In 1931 in Poland and in 1942 in the USA, both synthesis routes were based on the reaction of sodium azide with a salt of lead(II). The difference was that the lead(II) salt in Poland was nitrate whereas in the USA it was acetate. Lead(II) acetate is poisonous, so finally, in 1979 Heger [5], chose the synthesis route with lead(II) nitrate.

There are many sources (papers, *e.g.* [6], and websites, *e.g.* [7, 8]) that freely admit that the source of their knowledge is those two monographs, [1, 2], so they cannot be regarded as independent confirmation of other sources. It happens, that data presented in the secondary sources does not agree with common knowledge. It will be shown further using the example of cheddite. In general, however, it is not possible to verify extraordinary or atypical data. There are many reasons, *e.g.* witnesses of contentious situations are dead and/or do not leave verifiable memories. The standard situation is the lack of documentation, photographs and reports. Any such evidence when taken by the enemy was like death sentence for many people. It is possible, that there are unpublished documents, *esp.* in the Warsaw Uprising Museum [9], however this museum was opened in 2004 and has since been gathering many thousands of artefacts from this period. Before publishing, these have to be analyzed, thereby taking time to evaluate all museum's resources, and – as stated above – manufacturing of **EXs** and **EXDs** is not the most important topic.

Finally, the aim of this paper is to prepare a background, *i.e.* collecting data and show how big, diverse and important is the interest in the topic of manufacture of **EXs** and **EXDs**.

1.2. Forgotten history

A quick comparison of the data published on the Internet, in Polish and in other languages, *esp.* English, proves that the scope of information available in Polish significantly differs from the scope of information presented in other languages. It could be the language barier which prevents verification and supplementation to our „domestic" state of knowledge with the help of the international scientific community. A clear example of something like self-limitation of Polish researchers is knowledge presented on the **BCh** webpage. At the end of 2018, the English version [10] was developed on the basis of only 3 references, however the Polish version [11] was based on 31 sources. Moreover, only in the Polish is there a chapter about weapons and armaments used by **BCh** troops; not to mention the fact that also presented only in the Polish version, is information about cooperation between **BCh** and **AK** troops in the intelligence coup resulting in the delivery of 13 elements of the V-1 and V-2 rockets to the Western Allies.

One can regard the above-mentioned facts as evidence that there is no need to worry about the knowledge about the discusssed themes surviving in society for future generations because the information is still available,

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so it is only a question of disseminating the information. However, this thesis seems to be controverersial. There is no work prepared by foreign researchers, so undercover production can be regard as a local niche, not important for the assessment of final outcome of the **WW2**. Without new forms of popularization, there will be no stimulae for sustaining the interest of future generations. According to our findings, there are no monographs or review papers in foreign languages focussed directly on clandestine production of **EXs** or **EXDs**, so the basic step, to make this topic international, is to attract foreign scientists. The lack of interest by international circles seems to be caused by:

a) huge dispersal of information, as well as its incompleteness or even existence of contradictory data,
b) very few original scientific and popular science works and, at the same time, a significant number of secondary works; finally, this same data is multiplied, so, if false, can led to misinterpretation or even loss of knowledge about the true course of events; moreover, the possibility exists that information presented in the original works can be undermined by information direct from participants of the events described, as in [12],
c) very few historical artefacts, which could attract the youth to explore this subject,
d) an almost total lack of possibility of verifying the testimonies of witnesses and participants of the events which took place 70 years ago.

Presented in this review are examples of overcoming the above-mentioned problems, if not at a professional level then at least to show how great the public interest is in Poland regarding this aspect of the history of **WW2**. How great is the need to remember underground activities in occupied Poland is underlined by the fact that for over 50 years (until 1990s) of **PRL**, general knowledge about clandestine activity was restricted. One has to remember that because of a lack of comparable achievements of other organisations, the only one organisation which could be appreciated was **ZWZ-AK**. It was impossible for the leftist governments, which even for many years after **WW2** were trying to destroy **AK** members and their legacy, to ignore. Because of this, it seems necessary to tell the story of those who survived **WW2** and were trying to live for a better future in the post-war reality (see Table 1), as well as those about whom we know almost nothing (Table S1).

Importance of the subject undertaken in this work was obvious for those, who were struggled during **WW2** within the troops of the Underground State. One can hear it in the poem composed during Warsaw Uprising (August 1, − October 3, 1944) and entitled "Żądamy amunicji" (eng. "*We demand ammunition*") by Zbigniew Jasiński (1908-1984), as a soldier of **ZWZ-AK**. Jasiński expressed in his poem the biggest desire of those, who were abledare to fight with naked hands. Ammunition was the only one thing that they really needed, as a help from the Polish Government-in-Exile in London. Lack of the combat means was significant obstacle in the acitivties of the whole resistance movement (see Table 2). This problem was the key factor at the end of **WW2**. It came from sudden increase in a number of underground soldiers of **AK**. This number increased mainly because of incorporating new soldiers whose came to **AK** from other resistance movements, especially from **BCh**. In general, *ca.* 40,000 people of total numer of *ca.* 112,000 **BCh** members [11] had strengthen the **AK** troops, of overall number of *ca.* 300,000 soldiers [39]. **BCh** troops were not well armoured, so it seems to be possible assumption that the number of weapons not increased adequately. For example, in February 1944, over 40,000 grenades were in the armouries of **AK** Kraków District, *i.e.* for *ca.* 17,400 soldiers (officers, petty officers and cadets) [21]. In the middle of 1944, almost this same number of grenades had to ensure needs of 90,000 soldiers of this District. Importance of the number of possessed **EXDs** is clear also upon the following comparison. During the whole **WW2** period, **AK** activities were assesed to counted to be *ca.* 230,000 actions [39]. In comaprison, total number of actions executed by **BCh** is assesed to be *ca.* 5,700 [40], while – as it was stated above – overall number **BCh** soldiers was at from one-third to one-sixth part (*ca.* 112,000) [11] of **AK** resources.

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Table 1. Achievements of some activists of the clandestine explosives industry

Person	Before **WW2**	During **WW2**	After **WW2**	**Ref.**
Gokieli, Witold (1904-1956)	Graduate of Warsaw Technical University (mechanics, 1926). 1927 – yearly studies at Sorbone in Paris. 1927-1930 employee of aviation industry comapnies. 1930-1939 employee at executive positions in State Plant of Armaments (pl Państwowa Wytwórnia Uzbrojenia) in factories localized in Radom, Skarżysko-Kamienna, Kraśnik.	1942 Leader of *Conspirational Production Department* (pl. *Oddział Produkcji Konspiracyjnej*) in Headquartes **AK**. He was active in the team for elaboration of 10-years plan of reconstruction of Poland after the end of **WW2**. He supervised production of grenades in Kielce. During Warsaw Uprising, *e.g.* he coordinateg work on the insurgents' mortar from Warecka street.	1945-1947 employee as technical director in Central Board on Armament Industy (pl. *Centralny Zarząd Przemysłu Zbrojeniowego*). 1948-1949 member of Advisory Board in Polish Standardization Committee. In 1949 he was arrested and tried *e.g.* for continuing conspiratorial activity, aimed at forced changing the **PRL**'s system. In 1954 he was released from prison and started to work as a lecturer in the faculty of Mecanical Engineering of Warsaw Technical University.	[13-15]
Heger, Ludomir (1913-1992)	Graduate of Warsaw Technical University (explosives, 1939), 1939 employee of Ammuntion Factory no. 2 in Rembertów.	Leader of underground manufacturing sites of **ZWZ-AK**, among others of: a) **MF**, b) tetryl, c) incendiary and smoke grenades. During Warsaw Uprising he was the Commander of *"Leadership"* (pl. *Szefostwo*).	Organizator of research structures on **EXs** in: a) Institute Technical of Armaments (pl. *Instytut Techniczny Uzbrojenia*) , b) Institute of Precision Mechanics (pl. *Instytut Mechaniki Precyzyjnej*), c) Institute of Industrial Organic Chemistry (pl. *Instytut Przemysłu Organicznego*). Author or co-author of many patents and research articles.	[16-19]
Krasnodębski, Miron (1904-1979)	Graduate of University of Warsaw (chemistry, 1933).	Leader of **ZWZ-AK** manufacturing site in Milanówek of **MF**.	Owner of a cosmetic factory (1945-1953) and further researcher, lecturer and author of many publications (also patents and books) in the field of natural silk.	[20]
Nieczuja-Ostrowski, Bolesław (1907-2008)	Second Lt. (1931), Lt. (1934) and since 1936 lecturer and instructor in Polish Army.	One of the leaders of Polish resistance in Lwów (1940-1941). Commander of clandestine structures for assembling of armament (*e.g.* guns and grenades) and production and **EXs** in Kraków District of **AK** (1941-1943). Commander of **AK** Inspectoriate in Olkusz, Miechów and Pińczów Districts (1943-1944). Commander of 106 Infantry Division of **AK** (1944). He took part in battles in Republic of Pińczów.	Together with about 100 comrade-in-arms he moved in 1945 to the vicinity of Elbląg and he started common life. He became the Manager of Gardening and Apiculture Cooperative in Elblag, however because of his former activity in **AK**, he lost job in Cooperative and in 1949 he was arrested and sentenced to death in 1953 for his activity against the PRL. After 9 months in death cell, the sentence was changed into life imprisonment, but upon the basis of amnesty in 1956 he was released from prison. Until retired he worked in Gdańsk. He wrote several books, *esp.* about **AK**.	[21-26]

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Person	Before **WW2**	During **WW2**	After **WW2**	**Ref.**
Słoń, Marian (1909-1987)	Graduate of Warsaw Technical University (technology of **EXs**), Untill **WW2** – employee of Warsaw Technical University; co-worker of Prof. T. Urbański – together, they presents in French Academy of Science (1936) the first in the world works on nitroparafins. In 1930s - employee of Military Institute of Armament in Rembertów.	He produced **MF** for **ZWZ-AK**.	First president of Kielce city (1945-1946). Director of many companies. Researcher in the field of bisphenol A.	[16]
Smoleński, Dionizy (1902-1984)	Graduate of Warsaw Technical University (Chemistry, 1926), 1929-1939 employee of military research institutes (in Toruń, Rembertów and Zielonka near Warsaw), 1932-1939 assistant in Warsaw Technical University.	Deputy director of armament branch in Hedquarters **AK**. Commander of clandestine fire range in Zielonka. Lecturer of mathematics in underground Warsaw Technical University.	a) Technical University in Wroclaw: – 1946-1960 Scientific researcher in the field of explosives (professor since 1948), – 1952-1960 Rector; b) Scientific researcher in Wroclaw University, c) Warsaw Technical University: – lecturer (parallelly with work in Wroclaw), – 1965-1969 Rector; d) Military University of Technology in Warsaw: – 1951/1952 lecturer of internal ballistics, – 1960-1965 – leader of the Cathedra of Combustion Theory and Internal Ballistics Member of Parliament of the **PRL**. Member of Polish Scientific Academy. Author of many books and articles.	[16, 27]
Szypowski, Jan (1889-1950)	1918 – joined the Polish Army, also as an employee of Ministry of Militarry Affairs (pl. *Ministerstwo Spraw Wojskowych*) 1925-1927 delegate of Polish Military Mission in Paris Director of organized Ammunition Factory in Nowa Dęba, within the frame of Central Industrial District (pl. *Centralny Okręg Przemysłowy*).	Leader in Hedquarters **AK**, responsible *e.g.* for production of **EXs** and **EXDs** in the whole territory of occupied Poland. Commander of insurgents troops during Warsaw Uprising.	After 2WW, he was a member of a commission which secured, stocktaked and acquired ordnance and **EXs** factories for **PRL**.	[2,28-35]
Szabatowska, Janina (1899-1977)	Graduate of Technical University in Lwów. 1933-1939 emplyee of Central Laboratory of Coal-Mines in Pszczyna.	Leader of manufacturing sites *"Kinga"* and *"Dyehouse"* (1943-1944), *e.g*: of cheddite and ammonite.	Researcher in the field of chemical coal processing (Assistant Professor in Instytucie Chemii Ogólnej (eng. Institute of General Chemistry) in Warsaw – today Industrial Instytut Chemii Przemysłowej (eng. Chemistry Research Institute).	[36-38]

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Table 2. Exemplary quantities of **EXs** and **EXDs** which were in dispositon of various underground structures

Underground structure	**AK**				**BCh**
Locality	Cracow District		Polesie District	Warsaw District	Sandomierz District
Number of soldiers	50 (a partisan unit)	17,400	(whole District)	(whole District)	3,750
Period of time	1943 or 1944	February 1944	1943	1 Maj 1944	End of **WW2**
TNT [kg]	–	nd[a)]	A few	nd[a)]	nd[a,e)]
Cheddite [kg]	–	nd[a)]	60	nd[a)]	nd[a,e)]
PBX [kg]	80	nd[a)]	A few	118.5	Several dozen
Grenades [pcs.]	60 + 10[b)] (British)	40,000	30 (Russian defensive grenades)	518[c)] + 307[d)]	Several hundred of defensive grenades
Thermite bombs	–	nd[a)]	YES	nd[a)]	nd[a)]
Armour piercing guns [pcs.]	–	nd[a)]	–	9 anti-tank guns (360 projectiles)	3 PIAT launchers (200 grenades)
Anti-personnel mines [pcs.]	–	nd[a)]	–	550	nd[a)]
Detonating cords [m]	50	nd[a)]	–	nd[a)]	nd[a)]
Primary **EXDs** [pcs.]	Total *ca.* 180 (different types)	nd[a)]	–	nd[a)]	nd[a)]
Ref.	[41]	[21]	[42]	[43]	[11, 44]

[a)] no data; [b)] in [41] are listed 60 British grenades and, separately, 10 Gammon grenades; [c)] hand grenades; [d)] anti-tank grenades; [e)] precise data are not available, however total amount of **EXs** *from British airdrops was described as "Several dozen"*

In fact, manufacturing of **EXs** (*e.g.* synthesis, crystallization) is something else than manufacturing of **EXDs** (as common threads, at least *e.g.* mixing of components, melting, pressing of **EXs** charges further elaborated into **EXDs**). Moreover, if there is something in the literature about manufacturing of **EXDs** usually there is nothing said about parallel synthesis of **EXs.** One can concluded from the above, that manufacturing of **EXs** has to be analyzed as a quite different topic than manufacturing of **EXDs**. Despite this obvious conclusion, in this paper are taking into consideration both topics, however in the field of **EXDs** the only one aspect *i.e.* manufacturing of grenades. It is because of the following data:

– analysis of constructions of grenades' ignition chains allows to point out what **EXs** were used,
– black powder could be produced in places where grenades were assemblied [45]: however, during manufacturing of grenades in Lublin, **MF** delivered from Milanówek (a city nearby Warsaw) was applied, as well as **TNT** was crushed to the powder form by hamering **TNT**'s sapper cubes placed in leather bag. Manufacturers fro Lublin (by the way, only 4 people and, among them, Władysław Pankowski (1902-1980) – see Table S1, [2, 16-18, 20-33, 36-38, 45-53]) produced charcoal as well as applied it further in manufacturing process of black powder for delay paths in grenade fuses. Clandestine production of charcoal and black powder was also carried out in Warsaw [2],
– both synthesis of **EXs** and manufacturing of **EXDs** ought to be regard as of this same importance beacuse of similar threats: in the case of occupied Polish territories during **WW2**, unmasking of any kind secret production could cause death not only for manufacturers, but also for many others. Even if unmasking, the threats of accidental explosion was always present in this activity. Moreover, in the conspiracy, working conditions were so extremely difficult, and during Warsaw Uprising it was done under almost constant enemy fire. Accidents happened during the whole **WW2**. Taking into consideration that access to full data that presents full picture of the clandestine armament industry, it seems to be woth to remember also those

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just filled in *e.g.* incendiary bottles. On the other hand, it is necessary to underline that incendiary bottles were produced by **ZWZ-AK** in many places since 1940 and the total number of the bottles produced before Warsaw Uprising can be assessed as *ca.* 10,000 [43].

In the year of 100 anniversary of the recovery of independece, it cannot be ommitted the question, if will survived in future generations of Poles the knowledge about the clandestine industry. So, the main goal of this review is the attempt to present this piece of the underground struggle from the point of view of the history they dealt with, as well as, to show if their word still exists in our times.

2. Resources of EXs and EXDs

2.1. Raw materials and technological background

One has to remember that use of cheddite wasn't a new discovery in clandestine factories in **WW2**. Properties of cheddite were used in Poland for comparison with other **EXs** at least in 1935 [54]. Those time, maximum detonation velocity of cheddite was 3,000 m/s, the Trauzl number was 255 cm^3 and impact sensitivity for 2 kg fall hammer was 30 cm. The methodologies are not described in [54], however related values for **TNT** were given, *i.e.* 6,660 m/s, 290 cm^3 and 150-160 cm, respectively. There are many examples of **EXs** based on **PC** (Tables 3, S2 and S2 based on [2, 16, 55-60]), and sodium chlorate(V), $NaClO_3$ (Table S4 – based on [55-57, 60]).

Significant technological use of cheddites became at the ecd of XIX century. Cheddite, under the trade name Rack-a-Rock, was aplied in blasting works since XIX century [59], *e.g.* during building of East River channel in 1885 in the USA and in China for first railway constructions. Because of the *in situ* technology of manufacturing, *i.e.* soaking with nitrobenzene the made-of-cotton containers with **PC**, Rack-a-Rock is assigned to so called „Sprengel explosives", see [55]. In France, in 1897 [61], when the French *Commissiondes Substances Explosives* commenced its first investigation and concluded that the Cheddites (*i.e.* **EXs** manufactured at Chedde in France in *Poudrerie de Vonges*) are [56]:

– less sensitive to shock than No. 1 dynamite (75% guhr dynamite),
– when exploded by a fulminate cap they show a considerable brisance which however is less than that of dynamite, because of their lower velocity of detonation.

Finally, only two types of Cheddite, No. 1 (see Table 3, cols. 4 and 5) and No. 4 (see Table S2, col. 8), were approved for manufacture in France [60]. According to [56], Cheddites were manufactured by melting nitro compounds in the castor oil (phlegmatizer) at 80 °C and mixing thoroughly with, adding little by little, the pulverized **PC**. The warm mixture was emptied out onto a table, and rolled to a thin layer which hardens on cooling and breaks up under the roller and was then sifted and screened.

During the first World War, except **TNT**, cheddite was the second **EX** used in French grenade F-1 [62, 63]. Cheddite used in French grenades and mines was known under the designations, Minelite B and Explosif O No. 6B [56]. Total number of F-1 grenades (manufactured by over 6 countries all over the world since 1915 till 1940) is over 60,000,000 [63].

According to [56, 64], influence of density on velocity of detonation of **PC**-based and $NaClO_3$-based **EXs**, in respect to material of tube diameter 22 mm is shown Figures 1, 2, S1 and S2. Chemical compositions of **EXs** presented in Figures 1, 2, S1 and S2 are shown in Tables 3 and S2-S4. Vertical line segments depict densities for which full detonation didn't occured. Trend lines, obtained in standard procedure in MS Excel, and which describe influence on velocity of detonation of density of selected **PC**-based and $NaClO_3$-based **EXs** and are shown in Figures 1, 2, S1 and S2 and in Table 4.

In the USA, in 1942, cheddite was composed maliny of up to 80% **PC**, nitronaphthalenes and castor oil [59].

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Table 3. Examples of **PC**-based **EXs** with at least 80% **PC**, known before 1960[a)]

Component	Cheddite[c)]	Chlorate **EX**	Explosif O No. 1 Formula 41	Explosif O No. 1 Formula 60 *bis*[a)]	Steelite No. 5	Steelite No. 7	Minélite C	Minélite B	Minélite A	Explosif P	Cheddite		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
PC	80	80	80	80	83.33	87.50	89	90	90	90	90-92[a)]	91[d)]	95[e)]
Aromatic nitrocompounds or naphthtalene	5	–	–	–	–	–	–	–	–	–	–	–	–
Fat	15	–	–	–	–	–	–	–	–	–	–	–	–
Paraffin	–	–	–	–	–	–	5	7	7	10	–	6	–
Vaseline	–	–	–	–	–	–	4	3	–	–	–	3	–
Oxidized resin[b)]	–	20	–	–	16.67	12.50	–	–	–	–	–	–	–
(Mono)nitronaphthalene	–	–	12	13	–	–	–	–	–	–	–	–	–
Castor oil	–	–	8	5	–	–	–	–	–	–	–	–	–
Dinitrotoluene	–	–	–	2	–	–	–	–	–	–	–	–	–
Aluminum	–	–	–	–	5.00	–	–	–	–	–	–	–	–
Pitch	–	–	–	–	–	–	2	–	–	–	–	–	–
Heavy petroleum oil	–	–	–	–	–	–	–	–	3	–	–	–	–
Nitrocompounds or paraffin	–	–	–	–	–	–	–	–	–	–	8-10	–	–
Sugar	–	–	–	–	–	–	–	–	–	–	–	–	5
Ref.	[2]	[55]	[56, 57]	[56, 57]	[56]	[56]	[56]	[56]	[56]	[56]	[5]	[2]	[2]

a) - Refs. [57] (col. 4 and 5) and [5] (col. 12) were published after 1960 − [57] is cited only, as a confirmation of data presented in [56], and [5] – as a confirmation of the tendency that high content of **PC** *in clandestine chedddites was preferred (Heger – the author of [5] − was involved in this production) b) in French – Résidée; c) cheddite produced by* **AK** *according to a brochure from 1943; d) cheddite produced in Kraków by* **AK;** *e) cheddite produced during Warsaw Uprising by* **AK**

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Figure 1. Influence of density on velocity of detonation for **PC**-based **EXs** in copper tube (Ø 22 mm) with trend lines and − marked with vertical line segments − densities for which not-full detonation occurred: - -□- - − Cheddite 60(4th), -■- − Minelite A, -○- − Minelite B and ▲ – Minelite C

Figure 2. Influence of density of Explosive P on velocity of detonation, with trend lines and − marked with vertical line segments − densities for which non full detonation occurred, in respect to material of the tube (Ø 22 mm): -■- – copper,- -□- - – paper

Table 4. Trend lines describing influence of density of **PC**-based **EXs** and $NaClO_3$-based Explosive S on velocity of detonation, in respect to material of the testing tube (all tests performer in testing tubes with diameter of 22 mm)

EX		Testing tube made of	Trend line (MS Excel)	R^2	Graphic presentation in Figure
Name	Density [g/cm³]				
Cheddite 60(4th) (fine grain)	1.08-1.19	P	$y = -21000x^2 + 56110x - 3451$	1.0000	S1
	0.87-1.39	C	$y = -3074.6x^2 + 8102.1x - 2183.6$	0.8650	1
Cheddite 60(4th) (original form)	0.84-1.62	C	$y = -3074.6x^2 + 8102.1x - 2183.6$	0.9335	S1
Explosive P	0.87-1.39	C	$y = -6088.8x^4 + 22195x^3 + 30224x^2 - 3318.2$	0.9943	2
	1.08-1.19	P	$y = -23061x^3 + 75061x^2 - 78786x + 29165$	0.9944	
Minelite A (fine grain)	0.87-1.39	C	$y = -69793x^4 + 308313x^3 - 509775x^2 + 375489x - 101333$	0.865	1
Minelite B (fine grain)	0.97-1.38	C	$y = -5763x^2 + 15044x - 6655.6$	0.7945	
Explosive S	0.81-1.54	C	$y = -22298x^4 + 101217x^3 - 171910x^2 + 130589x - 34974$	0.9884	S2
	1.05-1.29	P	$y = -4090.9x^2 + 10023x - 3678.6$	1.0000	

[a] *C – copper;* [b] *P – paper*

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2.2. Domestic resources during WW2

Chemical synthesis of pure substances was not the main source of **EXs**, because the Germans controlled all activities and it was not possible to keep such installations undercover. Throughout **WW2**, resistant movement acquired **EXs** and raw materials for their production, as well as **EXDs** (*e.g.* grenades, ammunition) from the following sources [1, 13, 43]:

a) purchasing of chemicals on legal market in chemist's shops, drugstores and wholesalers, also based on fake coupons,, *e.g.* in this way **ZWZ-AK** bought 15,000 kg of **PC**, in Kraków in 1943 [65];
b) retrieving Polish Army weapons hidden following the invasion in 1939, as well as collecting off the battlefields, *e.g.*:
   (i) at the turn of the year 1940/1941, the origin of 20% of weapons possesed by **BCh** was collected in this way [11],
   (ii) in **AK** armouries there were 43,154 grenades as well as guns with ammunition (over 5,000,000 bullets, including 4,489 armor-piercing bullets) collected after the invasion, however, because of improper storage in magazines, only 30% of the weapons and **EXDs** collected in this way were servicable at the end of **WW2** [66];
c) collecting weapons left by Russian Army in 1941;
d) incorporation of private collection into the weaponry, even heirlooms coming from the January Uprising (1863-1864);
e) purchasing on the black market **EXs** and **EXDs** from German soldiers or soldiers from satellite armies, like Austrians, Romanians, Italians, Hungarians, Slovakians, *e.g.* **ZWZ-AK** obtained 136 hand grenades in this way [11];
f) taking over German resources, as a result of:
   (i) disarming actions or armed skirmishes, *e.g.* in the period 1943-1944, 493 hand grenades were obtained by **AK** in this way,
   (ii) train robbery of both purchasing from specialized railway thieves and by own actions, *e.g.* however information is not precise as in both sources it is claimed it was a wagon only, an example is a wagon of **TNT** was taken over by the **AK** in Kielce, in 1944 [67], as well as one of an unknown **EX**, taken over by **AL** in Lublin in 1943 [68],
   (iii) stealing by Polish workers from factories controlled by Germans (*e.g.* Skarżysko-Kamienna and Częstochowa [13]), warehouses and magazines (*e.g.* Toruń [69]), especially metal components of **EXDs**, as well as blasting means from coal mines [70] and quarries [67], as well as:
      – in this way the **ZWZ-AK** obtained over 500,000 rounds despite it not producing ammunition and only sometimes assembling it [13],
      – on May 27, 1943, with the aim to ensuring continuity of production of cheddite, **ZWZ-AK** gained 21 barrels (possibly, a few hundred kilograms) of **PC** were obtained this way from the only factory which was in Generalgovernment (pl. *Generalne Gubernatorstwo*), and which produced **PC**. The factory was named *Kijewski, Scholtze i Spółka,* and was situated in Warsaw at 6 Siarczana street [71];
g) taking over the allied airdrops (see p. 2.3).

2.3. Foreign resources

From technical point of view, one has to remember that co called "the Polish question" was not a subject of the arrangements between Russians and West Alliances. Moreover, cooperation between Polish Government-in-Exile and the Western Allies was full of diplomatic and strategic unfavorable circumstances [72]. On the other hand, one has to remember that supporting of Polish armed act by by airdrops encountered obstacles also from the Rossians, who did not agree to landing, for long time, the allied aircrafts at their territory when the crews had to fly back after executing the airdrops at the territory of occupied Poland. Finally, airdropping was regarded as the only one possible way to supply Polish troops with armament. It was not found the explanation, why the Western Allies prefered airdropping connected with dangerous flights over enemy's territory, instead of delivery

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the aid for **ZWZ-AK** with help of the Soviet Union, *i.e.* with use of the transportation through the USSR territory. It would be much easier and more effective to deliver the aid to Asian part of the USSR, transport it its the European part, and finally – even if with use of the airdropping – deliver the aid to Polish resistance movements. One has to remember that under the Lend-Lease Act, much bigger, than for **ZWZ-AK**, quantities of **EXs** and **EXDs** were transported from the USA to the USSR.

Foreign aid caused that for **ZWZ-AK** the airdrops were comparable in importance source of **TNT** in comaprison to resources hidden by Polish Army in 1939 [13]. Flights were executed mostly by the British 148th Squadron and the Polish 1586th Squadron for Special operations. Also the 205th Bomber Group, consisting of the British 178th Squadron and the South-African 31st Squadron, were active during the Warsaw Uprising. Polish people appreciated the dedication of pilots, who died during these actions, *i.e.* totally, the crews of 34 planes. They were commemorating by monuments and memorial plaques – *e.g.* shown in [1] – in Kiełpin, Michalin, and 6 of them, in Warsaw.

The importance of the lack of support from the Soviet Union to the airdropping actions can be shown upon the basis of the outstanding achievement in airdropping for the clandestine forces was a daytime flight on September 18, 1944. This day Russians allowed to land the allied planes at their airports in Ukraine. It was carried out by 110 Americans B-17 ”Flying Fortress” and some fighter planes. In this action, 1284 containers were dropped containing, among others [73]:

– 7,000 grenades (significant number of them was the No. 82 Mk I „Gammon Bomb”),
– 2,000,000 pieces of ammunition, and
– 7,000 kg of **EXs**.

Unfortunately, most of the cargo sent on September 18, 1944 (*ca.* 65-80% of sent containers) didn’t reach the insurgents. According to [3], during the Warsaw Uprising, 3,400 kg of **EXs** were received by the insurgents. This was 40% of the amount sent in this period (8,400 kg). In general, further researches have to be carried out, as far as total quantity of the airdropped **EXs** is taking into consideration. The total number of delivered **EXs** could be much bigger than 7,000 kg. Further research needs to be conducted, because it is not clear if it has to be added also the amount of secondary **EXs** present in **EXDs**, like grenades and projectiles. It is known that there were airdropped also empty (not elaborated) greandes and, separately **EXs** for their filling in. Differences can be significant because each of Gammon grenade may additionally be *ca.* 1 kg of **PBXs**.

The USA and Great Britain started to support the **AK** by airdrops in 1941 and executed over 800 flights [73]. Of this number, 184 flights were executed during Warsaw Uprising. Finally, of this 184 flights only 83 airdropping operations were finished with successfull delivering of the aid. There were airdropped armaments, munition, **EXs**, radio stations, *etc*. as well as 316 trained officers, so called Polish rangers or The Silent-Dark Ones (pl. *cichociemni*). 27 of them were trained in manufacturing of homemade **EXs** [74].

Russian could much easily executed airdrop operations. However, it is obvious that in the occupied Poland, Russians suported solely, if any, the leftist resistance movements like **AL** (1944) [75] and its predecessor **GL** (1942-1944) [76], however there are two contradictory oppinion about the scale of the Soviet’s help. On one hand, there are information that Russians’ airdrops were so big that each member of supported by Russian underground troops could have 2 machine guns for himself [77], but on the other hand, there are also known asks for help in arming their partisans, sent by Polish communists to Russians in 1944 because they didn’t had weapons for their partisans [76]. Assessing the importance of allied airdrops, one have to take into consideration, that The airdropped aid was passed to clandestine structures in the whole occupied Poland. Finally, locally, the quantities of **EXs** and **EXDs** were not so huge, as it is show in Table 2. As it can be seen from Table 2, **ZWZ-AK** used Russian grenades, as well as airdropped West-Allied weapon was used by other resistance movements. Airdrops dedicated to **ZWZ-AK** could be picked up by **BCh** troops or a part of them could be forwarded by **ZWZ-AK** to **BCh** as reward for help in airdrops protection [78].

According to [3], it was sent to occupied Poland *ca.* 40,124 kg of **PBXs**, but, out of this, only 79% (31,820 kg) were supplied successfully. Despite big number of losses, Americans assessed that the final result of airdrops was quite good, *i.e.* those 30,000 kg of armour, ammunition and other equipment were accounted to be *ca.* 1/3 of overall supply from Western allied forces for Warsaw.

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3. Clandestine production of EXs and EXDs

3.1. Organization of production

As it was discussed earlier, **AK** was the only one significant producer of **EX** in occupied Poland. Secret production of **EXs** and **EXDs** was led by:

a) Col. Franciszek Niepokólczycki (1900-1974). Since Autumn 1942, Niepokólczycki was co-organizer of new **AK** division for current battle, so called *Kedyw* (pl. ***Kierownictwo Dywersji***). Since January to September 1943, as a Deputy Commandant of *Kedyw*, Niepokólczycki directed all activities of the Production Department of Combat Means. In 1943 he left "*Kedyw"* and, once again, he was appointed the head of Sapper Department of 3rd Branch (Operational and Training) of Headquarters **ZWZ-AK**. Niepokólczycki led the whole production of **EX**, grenades and incendiary bottles (Molotov coctails) during Warsaw Uprising [79].

b) Col. Jan Szypowski (see Table 1). As the Second Deputy Chief of Staff of Headquarters **AK** he led the 4th Branch *Służba Uzbrojenia,* codename "*Leśnictwo",* since its beginning in 1940 to the end of its activity. In the range of the whole occupied Poland, in addition to production of **EXs** and **EXDs**, Szypowski, as the Chief of the Forestry Branch, was responsible also for [13]:
   - developing plans to cover needs, in the range of armaments, of underground armed forces,
   - collecting and analysis of data on quantities and types of armaments belonging to **AK**,
   - collecting and analysis of data on Germans' factories and on technical characteristics of armament produced by Germans,
   - carrying shopping on the black market,
   - executing security measures during allied airdrops,
   - technical super visioning of gun magazines.

c) Lt/Col. eng. Zbigniew Lewandowski (1909-1990) [80-83]. He was the commander of sapper trops for railway's actions of **AK** Warsaw and further the chief of **BBT**. Headcount of BBT was *ca.* 30 people. He was responsible for:
   - adaptation for use **EXs**, remained after the September Campaign 1939,
   - developing and testing devices for sabotage and diversion,
   - elaborating of instructions and training instructors for sabotage and diversion operations,
   - testing and adapting for the requirements of conspiracy equipment and materials coming from air-drops.

3.2. Examples of clandestine EXDs

Data on activity of other than **AK** underground organizations are very rare. It is because:

- the Polish Underground State, so in fact **AK** troops, took over almost the entire pre-war resources of specialists, knowledge and technologies, so there was nothing left for others organizations,
- cooperation with organizations associated with Soviet Union were regarded as collaboration with the second occupant,
- the need to have their own weapons was quite different because of number of soldiers, *e.g.* **AK** is estimated at 400,000 people (or between 200,000 and 600,000) in 1944 [84], while the **AL** structures had not more than 60,000 members in that time [75]. **BCh**, with up to 170,000 members, had much bigger needs than **AL**, however **BCh** operated mainly in rural areas so **BCh** hadn't suitable facilities. Finally, **BCh** put his contribution into underground production, however its importance in struggle was very small, *e.g.* **BCh** constructors develop exceeding its time machine gun, but only 11 guns were manufactured [11, 78]. It is possible that **BCh** assemblied own grenades in Broniszowice [78].

Total number of grenades produced by other structures than **ZWZ-AK** is estimated as 6,000 pieces [2]. Therefore, it is not surprising that at the beginning of Warsaw Uprising, in the Central Armament Laboratory of the People's Army (pl. *Centralne Laboratorium Uzbrojenia Armii Ludowej*), at 76 Obozowa street in Warsaw, there were „*some amounts of own manufactured grenades and incendiary bottles, as well as different chemicals,*

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petrol, and explosives" [85]. More information about achievements of **AL-GL** is presented in [86]. It is known, that **GL** developed in 1943 a grenade which was as large as pocked torch [87]. Selected technical data of the most popular underground grenades are presented in Table 5 and schematic appearance of their explosive chains are shown in Figures 3 and 4.

Table 5. Selected technical data of the most popular underground grenades

Grenade	Delay time [s]	Range [m]	Total mass [kg]	Explosive charge [kg]	Height of shell [mm]	Diameter of shell [mm]	Ref.
ET-40	0[a)]	>10	0.3	0.15	95	Variable, up to 52	[2, 3, 88-90]
	–	–	–	*ca.* 1[b)]	–	–	[90]
„Karbidówka"	3	20	0.9	0.2	126	70	[89, 91]
„Granat Woreczkowy"	5	20	0.3	0.15	75	60-70	[89]
R-42	4-4.5	>10	0.31	0.15	150-165	55	[2, 3, 89, 92, 93]

*[a)] – immediate inertial fuse; [b)] – there were also produced short series of ET-40 grenades with enhanced force, with **TNT** or **PBX**.*

(a) (b) (c)

Figure 3. Schematic layouts of the explosive elements of clandestine hand grenades: (a) **ET-40** grenade (1 – incendiary primer, 2 – **MF**, 3 – **TNT**, 4 – secondary **EX**), (b) **R-42** grenade (1 – incendiary twine, 2 – incendiary primer, 3 – phosphorous composition, 4 – black powder path, 5 – powder amplifier, 6 – **MF**, 7 – **TNT**, 8 – cheddite with metal pieces), (c) grenade manufactured in Łódź (1 – ignition knob, 2 – black powder path, 3 – black powder); Note: schemes not to scale

According to [3], the most commonly known two types of underground grenades, **ET-40**, commonly known as «*Filipinka*» (eng. Phillippine) (Figure 3(a)) and **R-42**, commonly known as «*Sidolówka"* (meaning similar to English *"Sidol's"*, where *"Sidol"* was the trade name of Henkel's cleaning agent for metals of those times) (Figure 3(b)), were produced both in Warsaw and Kraków and, also, **ET-40** in Rudniki nad Sanem [2] and **R-42** – in Lviv (pl. *Lwów*), after **WW2** in the USSR and since 1991 in Ukraine, in the Veterinary Academy at 67 Kochanowskiego street [2]. Grenades were produced also in Kielce, Radom, Lublin, Mościce (since 1942, in the pre-war Factory of Nitrogen Compounds [94, 95]) and in Vilnius (pl. *Wilno*), after **WW2** in USSR and since 1991 in Lithuania.Within the period from September 1943 to February 1944 there were produced 20,000 grenades in **AK** Lublin District and the production of 20,000 grenades begun in Wilno District [2]. The overall number of all types of underground hand grenades produced during **WW2** is estimated to about 400,000 [13],

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however this number can be significantly different. Except lower quantities, there are also calculations that total number of manufactured grenades **ET-40** and **R-42** was *ca.* 550,000. One of the reason of uncertain data are widespreading of manufacturing sites and secrecy rules. Separate issues is how many **EXDs** were used. Many of manufactured grenades were lost, *e.g.* taken over by Germans from exposured magazines in Warsaw in 1944, *e.g.* 78,000 hand grenades in July [43] and 50,000 grenades in February [2]. Diversification of hand grenades, schematically shown in Figure 3, is presented to convince the reader that developed constructions were of both kinds, extremely very simple as well as very advanced.

a) Offensive grenade **ET-40** [3] (Figure 3(a) and Table 5) was elaborated upon the basis of pre-war grenade ET-38 [49]. It was developed in 1940 and production started in 1941. Until the end of 1944, there were produced *ca.* 200,000 grenades, including dozens of thousand produced during Warsaw Uprising in Warsaw [89]. **AK** transfered to the Jewish organizations in the Warsaw's Ghetto a few hundred (total number of transfered grenades is estimated to be 600 [47]) of **ET-40** grenades [90], however **AK** sent to the Ghetto also cheddite and **TNT** [47].

   History of **ET-40** revealed not common aspect how much was done to hide the truth about the origin of this grenade. Thank to that, there were more chances that Germans had not expected how big was the production of **EXs** and **EXDs**. The way to misled Germans were the common names of **ET-40** grenade, mostly:
   - *"Filipinka":* However, in Polish, "*Filipinka"* means a term of a woman coming from the Phillipines (Phillippine), but in this case, it comes from the name Philip, taken from the pseudonym (pl. "*Filip Tarło"*) of its constructor Edward Tymoszak (see Table S1),
   - *"Perełka"* (eng. small pearl),
   - *"Wańka"* (eng. Vanka or Wanka): This name was used strictly to convince Germans that **ET-40** is not Polish construction but it is supplied by Russian, because "*wańka"* is a part of Polish name of Russian roly-poly toy (pl. *"wańka-wstańka"*) [96]. Moreover, to reinforce the misleading association with Russian's origin, some lots of grenade were marked on theirs' housing with Russian letters.

b) Grenade **R-42**, called *"Sidolówka"*, (Figure 3(b) and Table 5), was introduced for the production at the end of 1942 [3, 92] however one can find data that it could be only designed in summer 1943 [89]. Greater compliance is in the case of total production scale. According to both sources [3, 89], over 350,000 **R-42** grenades were produced. In general, cheddite (Figure 3(b), (8)) was applied as the secondary **EX** [3], however also **TNT** was used in assembly sites (at least 4) during Warsaw Uprising [89]. According to [89], cheddite was composed of **PC** and **MF**. Because of the presence of primary **EX**, it seems to be very doubtful and need further investigations. On the other hand, composition of **PC** with **MF** were used those times but as percussion compositions [64].

Except **ET-40** and **R-42**, commonly known grenades, there were also other grenades manufactured by **AK**, *e.g.* a grenade constructed and produced by "*Wyzwolenie"* (eng. Liberation) NOW-AK in Łódź [2], in service since 1942 to 1943 or 1944 (Figure 3(c)). Distinguishing feature of this grenade was that its shell was made of die-cast aluminum.

Third place after **ET-40** and **R-42**, in respect to the volume of production takes the grenade constructed by **GL-AL**, called *"Karbidówka"* (eng. Carbide lamp or Acetlene gas lamp) (see Table 5), *i.e.* the name of the grenade was this same as of a lamp, commonly used those time. Scale of production, started in 1943, is difficult to be estimated but it likely was less than a few hundreds. Cheddite was applied in *"Karbidówka"* grenades, too. Fuse was not developed during **WW2**, but it was a pre-war Polish delay fuse GR-31, produced in Kielce [97]. Distinguishing features of *"Karbidówka"* were both [2, 89]:

- it was developed and produced by the leftlist part of Polish resistance movement (**GL**), in clandestine workshops operated in Warsaw,
- shell of *"Karbidówka"* was a modified housing of an acetylene (carbide) lamp, usually a brand called Zenith, so it was also easy to hide the grenade as – broadly used in comon life – an acetlene gas lamp,

"Karbidówka" grenade was cheap (shell was commonly available because it was) but not easy to handle. The truth about the origin of *"Karbidówka"* needs more research, however mentioned below information that *"Karbidówka"* was produced in Kraków by **AK** seems to be very doubtful. Nieczuja-Ostrowski, the leader of

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AK production of grenades in Kraków, in footnotes in his book focused of his further activity [98] used names of *"Sidolówka"* (**R-42** grenade) and *"Karbidówka"* interchangeably. Moreover, in his further book [41] Nieczuja-Ostrowski has recall – once, so maybe by mistake – also the name *"Karbitówka"*.

During Warsaw Uprising, there were constructed and manufactured other kinds of grenades, like launching grenades (Figure 4). Insurgent constructions were produced in very small series, because they were in service a few weeks and were dedicated to a given kind of armour, counted in a few pieces. Of course also material possibilities were limited. How simple were firing paths in uprisings' constructions, show examples of:

– incendiary grenade, Figure 4(a), for grenade launcher developed at 4/6Warecka street; it had delay time 5-8 s; ignition followed after contact of knob (1) with sulphuric(VI) acid (H_2SO_4) [2],
– 75 mm fragmentation mortar grenade, Figure 4(b). Ignition path was developed by Heger (1913-1992) (see Table 1) [13, 19]. When fired, an igniter consisted of elements of hunter's ammunition was ignited, (1) and (2). Ignition impulse after passing through the fire channels (3) caused ignition of the safety fuse (4). The fuse transferred the fire impulse to a detonation primer (5) and the booster made of pressed **TNT** (6). Finally, the charge of amatol (7) was detonated [2].

(a) (b)

Figure 4. Schematic layouts of ignition train elements of clandestine launching grenades: (a) 75 mm mortar fragmentation grenade (1 – ignition cup (hunter's), 2 – gun powder (hunter's), 3 – fire channels, 4 – safety fuse, 5 – sapper cup, 6 – pressed **TNT**, 7 – amatol; (b) incendiary launching grenade: 1 – igniter (**PC** with sugar), 2 – incendiary mixture, 3 – ampoule with concentrated sulphuric(VI) acid, H_2SO_4; Note: schemes not to scale

Bag grenade (pl. *Granat woreczkowy*) (Table 5) – other name of this grenade, however it is not exactly translation, can be: a rag (pl. s*zmaciak*). This kind **AK** grenades were developed and produced during Warsaw Uprising in 3 localizations: – Sienna street (first place), – Zgoda street (further) and finally – Mokotowska street). There were manufactured *ca.* 24,000 [89]. "*Bag grenade*" was composed of two bags. The first bag (inner) was filled mostly with **TNT**. Outer bag was filled with metal fragments, pieces of sheet metal *etc*. Each of the bags was fixed separately to friction igniter P-42 [99], with use of copper wires. An archetype of "*Bag grenade*" could be the British No. 82 Mk I „Gammon Bomb", filled in with **PBX** – up to 0.9 kg [62] or 1.5 kg, according to Polish sources [3]. According to **AK** instruction [43], total weigh of Gammon grenade was 0.5-1.5 kg. As similarity to "*Bag grenade*", Gammon grenade was provided with a stockinet bag and – when used as antipersonnel grenade – instead of one half of **PBX** it was filled in with gravel, nails or scrap metal. Gammon grenades were used before (see Table 2) and during Warsaw Uprising, in a number of a few thousand pieces, and was supplied within

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the alliance airdrops [3].
Underground production of grenades was not limited to Warsaw. In 1942, in Kraków District of **AK** was operated Chiefship of Cladestine Weapons Production (pl. *Szefostwo Produkcji Konspiracyjnej Broni*) code-named "*Insurance Office*" (pl. *Ubezpieczalnia*), under the charged of Major Bolesław Nieczuja-Ostrowski (1907-2008) (see Table 1) [21]. "*Insurance Office*" operated in over 20 localizations, *e.g.* grenades assembling points were in Piotrkowice Wielkie, Przesławice and Słomniki [41], as well as in Tonie nearby Kraków [2]. According to [21], within the period September 1, 1943 – February 29, 1944, "*Insurance Office*" produced and mounted 36,000 grenades for Kraków District and 19,000 grenades (shells without cheddite [2]) for **AK** Śląsk District. Total number of grenades produced in Kraków is assessed to be ca. 60,000 [100]. However other value of total amount of grenades cannot be excluded, like 100,000 [98]. In the remaining explosive assortment of "*Insurance Office*" in Kraków District of **AK**, can be pointed out also 100 mines [100].

3.3. Manufacturing of secondary EXs

3.3.1. Manufacturing technology of cheddite

Vaseline was the second main component of cheddite manufactured in Kraków [15], however, there is no confirmation of presence of vaseline according to [2] (see Table 3, cols. 2, 13 and 14). It is possible, that cheddite with vaseline was present in grenades manufactured in Kielce and Lwów, because Cracovians' cheddite was sent there as a train cargo (6,000 kg each cargo) [65]. It seems that not all cheddite was produced with vaseline or there were very different types of it. This come from the other significant feature of cheddite produced in Kraków, *i.e.* of its colour. It was yellow and it left yellow smudges [101]. It is only assumption, becasue there is nothing said about nitrocompounds in [101], however yellow color suggests presence of an organic nitrocompound, *i.e.* cheddite prepared only of **PC** and vaseline couldn't be yellow. Possibility of presence of nitrocompounds is confirmed by [2] (see Table 3, col. 2). **PC**-based **EXs** which contain aromatic nitrocompounds have higher velocities of detonation and are more brisant than those whose carbonaceous material is merely combustible [56]. On the other hand, cheddite mentioned in [101] was in powder form, but cheddite manufactured in Warsaw was stabilized with fat (see Table 3, col. 2) and it was used in the form of granules and shavings. It means that cheddite in the form of powder couldn't be stabilized with fat [1]. On the occasion of a story presented in [101], one can find out that grenades with cheddite, if a fuse was not violated, could be insensitive to bullet overshooting. Other advantages of **PC**-based explosives presented in p. 3.1, Explosifs P and the Minelites, is that they burn while the flame of a Bunsen burner is played upon them but, in general, go out when the flame is removed [56].
Presented in 1970's by Heger (Table 1), chemical composition of cheddite was 90-92% of **PC** and 8-10% of nitrocompound or paraffin [5]. Composition recalled by Heger is very similar to compositions known before **WW2** (see Table 3). It can assure as that as high as possible content of **PC** was preferred in clandestine chedddites. The manufacturing process based on the following processes:
– **PC** was pour into a heated bowl with melted nitrocompound or paraffin,
– thorough manual mixing, with use of wooden ladle,
– after cooling down, composition was rubbed through a sieve with appropriate defined mesh number.
Rubbing through a sieve was dangerous. It could lead to explosion. The most important advantages of cheddite, claimed by Heger [5], are the lack of decomposition during storage and it is not hygroscopic.

3.3.2. Localizations in Warsaw

The following secondary **EXs** were manufactured in the facilities commanded by Jan Szypowski, before Warsaw Uprising [1, 13]:
a) **cheddite,** total production in Warsaw is assessed to be between *ca*. 65,000·kg and *ca.* 70,000 kg [71], in private buildings, at the following addresses [61]:
   – 15 Asfaltowa street (Figure S3), codename "*Asfaltowa*"; operation time April 1941 – January 1943. One can easily know from the inscription, that there were 2 leaders. One of them was tortured and died on

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January 1943 in Germans prison called in Polish *Pawiak* [102]. The second leader was arrested on April 1943, tortured in *Pawiak*, and executed by shooting, on May this same year. Except the leaders, there were working 11 people.
- 103 Solec street (Figure S4), codename "*Kinga*"; operation time 1943 – April 1944 [51, 103]. The manufacturing site was hidden in a basement of a private house where detergents were produced. The crew of "*Kinga*" was 17-19 people.
- 40 Twarda street (since May 1940),
- 56 Wolska street, codename "*Wola*",

b) **amonit** (mixtures of **AN** and **TNT**), total production was *ca*. 4,000 kg, was produced in Warsaw at:
- „*Kinga"* (main facility) [51] (Figure S4),
- "*Dyehouse*" at Krochmalna street [36] (Figure S5),
- a drugstore at the intersection of Mariańska and Pańska streets [39].

c) **tetryl**, total production was *ca.* 300 kg, was produced in the *Inspection* site at 18 Polna street. There was an installation, usually running twice a week, with capacity of 1.5 kg of tetryl [16].

It cannot be excluded, that cheddite or other **EXs** (*esp.* pyrotechnic compositions, like black powder) could be occasionally processed or manufactured before Warsaw Uprising in the following workshops, commanded by Jan Szypowski, where hand grenades were assembled:
- 14 Królewska street (Figure S6), Officially, there was a trade school at this localization, during **WW2**. Contemporary, these building doesn't exist.
- nearby to the intersection of Okopowa and Powązkowska streets, codename *Powązki* (common name of a cementary in Warsaw),
- 14 Pułtuska street.

AN was produced illegally in the city of Warsaw [7].

During Warsaw Uprising, the most important place was at 51 Hoża street, codename the "*Egg-warehouse*" (pl. *Jajczarnia*). Besides many other functions [8, 104, 105], in the "*Egg-warehouse*" there were also produced **EXs** within the insurgent structure called "*Plant*" (pl. *Wytwórnia*). Within the assortment of the "*Plant*" there were also assembled incendiary bottles and grenades, manufactured by a few women served in Military Service of Women (pl. *Wojskowa Służba Kobiet*), as well as fuses, manufactured by 3 men. When safety fuses were consumed, chemical initiator (concentrated sulphuric(VI) acid, H_2SO_4, in a glass ampoule) was in use [8]. According to [8, 104, 106], also cheddite is claimed as filling material for grenades, however in this case, this cheddite was composed of milled sugar and likely of **AN**. In *"Jajczarnia"*, except **EXs** for grenade elaboration, there were also produced fuses and incendiary bottles [106]. Grenade shells were manufactured of water pipes as well as, when other resources of zinc were consumed, of zinc recovered from roofings. Taking into consideration such conditions, as well as accompanying constantly battlefield operations and other activities at this site, it is hardy to believe, however according to [104], during 2 months of the Uprising, there were produced a few tens of thousands grenades, usually 200-300 grenades daily [8].

A conspirational structure of **AK**, with codename "*Inspection*" (pl. *Inspekcja*), was localized during occupation in Warsaw *e.g.* at 34 Pius XI street, and it was dealt with getting **EXs** form unexploded ordnance [13]. During Warsaw Uprising, "*Inspection*" was placed at the corner of Marszałkowska and Świętokrzyska streets. There were placed laboratories for deelaboration of unexploded German ordnance and for elaboration of **ET-40** grenades. These grenades were filled, among other, with **PBXs** obtained from allied air-drops (*ca.* 100 grenades were elaborated in this way) [16]. In this same building, the "*Inspection*" manufactured cheddite, too.

3.3.3. Localizations outside Warsaw

Except Warsaw, cheddite was manufactured also in Kraków. According to [21], within the period September 2, 1943 – February 29, 1944, the "*Insurance Office*" in **AK** Kraków District produced 15,000 kg of cheddite. Cheddite was produced in Kraków at 28 Paulińska street and total amount of production was 17,000 kg [100].

It cannot be excluded, however cheddite, or other **EXs** used in the grenades, could be produced also in Mościce

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[95]. For sure, cheddite was used in Mościce for manufacturing of grenades [95]. As it was stated before, production of black powder was the must when grenades were produced. Because of it, one cannot excluded that this kind of production was executed by **ZWZ-AK** also in:

- Białystok (Sienkiewicza street) and in Niemczyn (33 km from Białystok). Both facilities were placed in forges [39]. Starting from 1941 or 1942 were produced, except incendiary bottles, also 3,000 [107] or 15,000 [108] grenades.
- Lublin, since 1942 there were produced 36,000 grenades, mainly **R-42**, most of all for planned uprising in Warsaw [45, 68].

3.4. Production of primary EXs and EXDs

3.4.1. Scope of production

Analysis of the literature shows that in the field of primary **EXs**, and much more when primary **EXDs** (*esp.* fuses) one can find much less data than those devoted to manufacturing of secondary **EXs** and **EXDs**. As it was stated above, factories in Kielce were the main source of fuses. According to [74], one of the tasks realized by Kedyw was production of fuses.

3.4.2. Manufacturing technology of primary **EXs**

Synthesis routes of primary **EXs** based on the following processes

a) **MF**: During **WW2**, synthesis route for **MF** was as follows [109]:
   $3Hg + 8HNO_3 = Hg(NO_3)_2 + 2NO + 4H_2O$
   This route was preferred also after **WW2**, *e.g.* [110], so, changes ought to be not significant. Because of it, it seems to be appropriate to recall the route from 1979, described by mentioned before Heger [5]:
   - dissolving of mercury in 62% nitric(V) acid (HNO_3), with small amounts of hydrochloric acid ($HCl_{(aq)}$) and copper shavings,
   - pouring in the solution into 96% ethanol at *ca.* 50 °C and removing toxic gases,
   - separation of solid mercury fulminate on a piece of a cloth,
   - washing with cold water.

b) **lead azide**: As above, it seems to be appropriate to recall the route for synthesis of lead azide, from 1979, described by mentioned before Heger [5]:
   - precipitating of lead azide from a water solution of sodium azide and lead nitrate in 18-22 °C,
   - filtrated product is washing with water, alcohol or gasoline with 5% of paraffin.

One of first attempts of use lead azide in Polish detonators were reported in 1931 [111]. Reported in [111] synthesis route of lead azide was as follows (Reactions 1a-1c):

$$Na + NH_3 \longrightarrow NaNH_2 + H \quad (1a)$$

$$2NaNH_2 + N_2O \longrightarrow NaN_3 + NaOH + NH_3 \quad (1b)$$

$$2NaN_3 + Pb(NO_3)_2 \longrightarrow Pb(N_3)_2 + 2NaNO_3 \quad (1c)$$

According to [111], in those times, the most usefull method of NaN_3 synthesis was Wislicenus method – reactions (1a) and (1b). In reaction (1c), instead of lead(II) nitate ($Pb(NO_3)_2$) it was possible to use lead acetate, *e.g.* in the USA [109, 111]. However, in Poland, after **WW2**, synthesis with lead(II) nitate was preferred [110]. The reason could be the high toxicity of lead(II) acetate.

c) **lead trinitrorezorcinate:** Taking into consideration [5], synthesis route could based on the reaction of styphnic acid ($C_6H(OH)_2(NO_2)_3$), with lead nitrate and sodium bicarbonate ($NaHCO_3$). Product is washing with water and gasoline with 5% of paraffin. Pre-war synthesis route of lead trinitroresorcinate (2) given in [111] had to be known in Polish industry, *e.g.* in Factory "*the Projectile*" (pl. *Zakłady Pocisk*):

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$$C_6H_4(OH)_2 \xrightarrow[H_2SO_4]{HNO_3} C_6H(NO_2)_3(OH)_2 \xrightarrow{Na_2CO_3} C_6H(NO_2)_3(ONa)_2 \xrightarrow{Pb(NO_3)_2} C_6H(NO_2)_3O_2Pb \quad (2)$$

d) **tetrazene:** Taking into consideration [5], synthesis route could based on the reaction of guanidine bicarbonate ($CN_4H_6HCO_3$), sodium nitrate(III) ($NaNO_2$) and nitric(V) acid at elevated temperature.

3.4.3. Localizations of manufacturing sites

MF was the basic primary **EX** manufactured by clandestine facilities. It was used in detonating fuses. The first, homemade, attempts to develop the technology of **MF** were done in Rembertów, nearby Warsaw. Target production was held first in Rembertów and further in Milanówek [1, 112]. Manufacturing of **MF** in private flats in Warsaw at Wronia and Lwowska streets was also executed, however both sites ended their activity probably in 1943 because of exposure caused by accidental explosions [2]. Also two accidental explosions were in Rembertów, however this time, it did not result in exposing [2]. Production of **MF** in the laboratory of Central Experimental Silk Station (pl. *Centralna Doświadczalna Stacja Jedwabnicza*) ended at the beginning of Warsaw Uprising. In the period 1942-1944, one person – Miron Krasnodębski (1904-1979), see Table 1, produced over 80 kg of **MF** [112], and during a few months before Warsaw Uprising, together with a few associates produced next a few tens kg of **MF**. Total quantities of primary **EXs** are not known, however, *e.g.* in the period March 1 – August 31, 1943, armories of Headquarters **AK** produced 260,000 primers [113].

3.5. Manufacturing facilities for pyrotechnical compositions

Clandestine assortment concerned also pyrotechnical compositions and **EXDs**, *e.g.*:

a) black powder was produced in many places, like in the Insurance Office in Kraków District of **AK** [114] and Lublin [45]; during Warsaw Uprising it was manufactured at 11 Krucza street (150 kg), 51 Hoża street and 40 Tamka street and it was used in grenades instead of cheddite,
b) nitrated solvent naphtha was produced at 15 Krochmalna street (overall, *ca.* 1,000 kg of nitrated product was obtained) [2, 36],
c) thermite bombs (called „Morwitankami") were produced in Kraków in 1940. After an accident (a fire in Flat chich was the manufacturing site), workers were moved to Warsaw [113]. Thermite bombs with delay fuse were produced in two places in Warsaw, at 15 Krochmalna street (today [36] – Al. Jana Pawła II 26a) codename „*Dyehouse*" (pl. *Farbiarnia*) and 40 Hoża street;
d) incendiary bottles constituted the most important part of manufactured **EXDs** – especially during Warsaw Uprising, but also significant amounts could be produced by Jewish organizations in 1943 [46-48] (see Michał Klepfisz, Table S1). Petrol with addition of concentrated sulfuric(VI) acid (H_2SO_4) was used as fuel. Clandestine incendiary bottles were more complicated than common Molotov cocktails, because Molotov cocktails were first ignited and further thrown but incendiary bottles were permanently sealed and they had own incendiary fuse. The fuse was prepared from a composition containing grounded sugar and **PC**, placed at the inner side of a label placed around the bottle [13].

Total quantities of pyrotechnical devices are not known, however, *e.g.* in the period March 1 – August 31, 1943, armories of Headquarters **AK** produced 380 signal flares and 20 smoke candles [113]. Total number of smoke candles produced by **ZWZ-AK** (since 1940 till August 1944) can be assessed to a few hundred [43].

Chemical delay fuses were produced by **GL**, *e.g.* for suitcase bombs [2]. Other elements of the explosive chain in the suitcase bombs were **EXDs** (4 grenades for 46 mm grenade launcher connected with detonation cords and primers).

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4. Production quality and research capabilities

One can read that in the case of all the most important grenades (**R-42**, **ET-40** and "*Karbidówka*"), there were cases that detonation didn't occurred or delay times didn't meet the requirements [3]. There are known accounts that even tenth **R-42** grenade didn' explode. It was despite the consent for the start of manufacturing processes of **EXs** and **EXDs** had to be preceded by comissional tests. Only if test results were positive, the technolology could be accepted and executed, *i.e.* technological documentation had to be prepared and accepted [45]. Tests were carried out by **BBT** were executed in specially selected and prepared places (like secret fire ground in Józefów nearby Warsaw), however the production itself took place in existing, and practicaly impossible to be changed, conditions [3, 89]. Each explosion could caused exposuring by Germans so it was quite impossible to perform quality tests in manufacturing sites, as well as performing the research and development works on new or corrected items in the firing range tests. Despite such severe obstacles, during standard production of grenades, 5 of each 100 fuses were always tested with the aim to confirm the delay time [2].

There was no problem with keeping the conspiracy rules during Warsaw Uprising, however prodction was conducted in much more provisional conditions. The best example of conditions is insurgent facility "*Egg-warehouse*". In an area of a few buildings, under enemy fire, beside the biggest place of assembling of **EXDs** and manufacturing of **EXs**, there were also operated a gunsmith's workshop, constructed by the insurgents a power station and a radio station, as well as field hospitals and a drilled well for insurgents and civilians [105].

On the other hand, because of lack of own stocks, **EXs** taken from unexploded German ordnance were used for production. One have to remember, that in many countries, resistance movements and forced laborers itself did sabotage actions in German ordnance factories, also in occupied Poland, among others in Kielce [67] and Bydgoszcz [115]. Finally, the quality of **EXs** derived from unexploded **EXDs** was unknown.On the others hand, also own cheddite become different and more dangerous. Needs of battlefield and the pressure of direct threats caused that insurgering's manufacture technology of cheddite was shorten as much as possible and it was used in the form of not stabilized and dusty form [1]. Finally, quality tests of **EXDs** were preceded in the battle.

Vertical lines in Figures 1, 2, S1 and S2 are pointing out the densities of cheddites for which detonation failed (non full detonation occurred). Usually, density of clandestine cheddite was 1.3 g/cm^3. As it can be seen form Figures 1, 2, S1 and S2, this density assures almost maximum detonation velocity, however it is very closed to the range where both, detonation velocity decreases and the effect of detonation failure can be observed. Arrangements in the clandestine grenades were different than those (tubes), used in the test of which results are shown in Figures 1, 2, S1 and S2, however the vertical lines reveals the possibility that the reason of explosion failure of some grenades could be too high density of cheddite.

5. Contemporary forms of commemoration

5.1 Commemorating clandestine manufacturing activities

Polish underground activities in presented topic have been commemorated, among others, in the form of memorials (Figures 5, 6 and S3-S8). For a wider perspective of present forms of commemoration of an armed act from the years 1939-1945, it is worth to remember that with this purpose are also both movies in the Internet, like [116, 117], as well as stickers with the symbol of fighting Poland on cars. Memory board presented in Figure S7 is placed on the façade of the headquarters of Polish Federation of Engineering Associations (pl. *Naczelna Organizacja Techniczna*) [118, 119] and is dedicated to the "memory of all engineers and technicians who struggled and died for free and independent Poland". More focused on production of **EXs** and **EXDs** is the memorial presented in Figure 5, because it was founded strictly to commemorate Polish underground arms industry [39]. There is the text on the opposite side of the monument – translation from Polish according to [120]: "*In tribute to the soldiers of the Polish underground state working in the underground armouries in 1939-1945, producing sniper rifles, explosives, grenades, ammunition and other means of sabotage combat.*".

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(a)

(b)

(c)

Figure 5. Memorial at Grzybowski Square in Warsaw, dedicated to the memory of all who worked in the underground armouries in 1939-1945: (a) front, (b) back and (c) its locality (fot. T. Sałaciński, 2018)

In Figure 5 is shown not only the front side (Figure 5(a) and 5(c)) but also the backside (Figure 5(b)). It is because, in present time − in general − the inscription at the backside is very hard to be seeing because of bushes. It has to be assessed solely by each reader if is it just in advertently that important part of this monument is practically invisible, and, finally, it can be regard as a sculpture. The problem is posed because in the photo presented in [1], so not older than from 2005, there are no bushes around the monument ...., so the desire to commemorate the soldiers was much better visible (no bushes) in the past.

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(a) (b)

Figure 6. Plaque commemorating of the location of **AK** production of **EXDs** during the Warsaw Uprising, *e.g.* grenades and incendiary bottles, at 51 Hoża street in Warsaw, called "*Jajczarnia*": (a) memorial plaque and (b) its locality (fot. T. Sałaciński, 2018)

5.2. Comemorating of people

Except mentioned above actions focused on general subjects, one can find signs of commemoration of individuals, like – Lt. Col. (during **WW2**) and Col. (after **WW2**) – Jan Szypowski (1889-1950), *alias Leśnik* (eng. Forester), (Figure S8 and Table 1). Memorial plaques and monuments (Figures 4-6 and S3-S8) are not the only one form that allows to consolidate and transfer to future generations the knowledge about clandestine production of **EXs** and **EXDs**. The best examples are actions commemorating Jan Szypowski and Bolesława Nieczuja-Ostrowski (see Table 1), like:

a) internet websites, presenting achievements of a given people and their biographies prepared by the state centers specialized in the field of interest, like Warsaw Rising Museum [30], Polish Army Museum [31], or other, generally focused on selected aspects of **WW2** [33] – even on a unveiling of a memory board [121] or on social actions [7]. Many pieces of information are available in general sources, *e.g.* [32],
b) local meetings with co-workers and associates of the honored people, *e.g.* in Nowa Dęba [29],
c) runnings, *e.g.* a running in Jan Szypowski memory is organized yearly since 2016 in Słupca (the city where he was born) [32, 122],
d) naming facilities: in Nowa Dęba (the city where Szypowski was working before **WW2**):
   – hotels: *Szypowski Hotel* (in 2005) and *Szypowski Strefa* (eng. Szypowski Zone) (in 2010/2011) [123-125],
   – street: at the Szypowskiego street are localized mentioned above hotels and the Zakłady Metalowe "Dezamet" SA. (a factory producing ammunition),
   – military center: *Ośrodek Szkolenia Poligonowego Wojsk Lądowych* (eng. Training Ground of Ground Forces) (in 2004) [126];
e) naming parks: in Jan Szypowski memory in Warsaw (Figures S8(a) and S8(b)) and in Nowa Dęba as well as, in Bolesław Nieczuja-Ostrowski memory in Elbląg [23],
f) dedication of a year: Town-Council in Elbląg established a year 2017 as the year of general Bolesław Nieczuja-Ostrowski [23],
g) granting honorary citizenship: Bolesław Nieczuja-Ostrowski is a honorary citizen of Wolbrom, Elbląg,

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Miechów and Kraków [23],

h) decorations: Bolesław Nieczuja-Ostrowski was awarded, among others, a medal "*Polonia Mater Nostra Est*" a s well was honorized in 2006 with the *Krzyż Komandorski z Gwiazdą Orderu Odrodzenia Polski* (eng. Comander's Cross with Star of Order of the Rebirth of Poland) [23],

i) military promotion: Bolesław Nieczuja-Ostrowski was in 1991 to the rank of Brigadier general [23].

5.3. Museum activities

As it was stated before, teh most import ant facilities for production of **EXs** were located in Warsaw and Krak**ów**w. Because of it, especially the two museums in Warsaw – Warsaw Rising Museum (pl. *Muzeum Powstania Warszawskiego*) [9] and Polish Army Museum (pl. Muzeum Wojska Polskiego) [127], as well as the Museum of Home Army in Kraków [128], are predestinated to popularizing the history of the topics, discussed in this review. It has to be underline, that all over Poland one can find museums which presents remnants of the wartime history of **EXs** and **EXDs**, like Allied drop hoppers in the Historical Museum of Zamojski Inspectoriate of Home Army (pl. *Muzeum Historycznym Inspektoratu Zamojskiego **AK***) [129].

The main form of exposure of this topic in the mentioned above museums in Warsaw and Kraków are presentations of grenades, incedniary bottlers and their launchers, as well as photos from clandestine facilities, *e.g.* at the webpage of Warsaw Uprising Museum. The reason of lack of ther exhibits seems to be obvious, *i.e.* documents, as well as equipment used in the facilities were destroyed. Despite such obstacles, museums undertake numerous Rother forms of popularization. There are , *e.g.*:

a) organized meetings with veterans [130],

b) organized scientific conferences [131],

c) published monographs [3],

d) elaborated and shared on-line published biographical data bases on underground soldiers, among them those who produced **EXs** and **EXDs** (see Tables 1 and S1).

6. Summary

In paper are presented first attempts to collect very distributed data on some aspects related to the clandestine production of explosives and explosive devices, *esp.* grenades and incendiary bottles, in the occupied Polish territory during the second war world. The reason of including of explosive devices was that there are some data that in the assembly workshops also some explosives (*esp.* black powder) were produced. On the other hand, incendiary bottles were not simply a bottle with flammable liquid, but pyrotechnical mixture was applied as chemical fuse.

Analysis of origin sources of weapons used by underground troops is presented, mostly like the Allies' air-drops and domestic actions – even purchasing on the black market. Comparison of a few type of the firing paths in underground grenades is undertaken as an example of cleverness in development, *i.e.* use of pre-war resources as well as both, very simple and very sophisticated, own constructions. Also unimaginable efforts to hide the clandestine production (even common names of grenades were given with this aim) and to executed the rules of quality control in manufacturing of grenades is pointed out.

Analysis of collected data assure us that despite there are many different occasional publications (newspaper articles as well as internet films and websites) many of them are multiplication of very limited number of original works (museum's exhibitions and conferences, scientific papers and books). However sometimes, even the original works are based on suppositions and incomplete data. Moreover, contradictory information are also published. The reasons are explained in paper, however the secrecy rules in those times are not the most important factor. The essence of things is combating people (*esp.* former soldiers from **AK**) and knowledge about their achievements for many years of – dependent form Russia – Polish authorities, including secret services. Finally, in present time, despite this obstacle has been removed the possibility to known the whole truth seems to be lost. It is because many of witnesses of events that took place in the period 1939-1945 died many

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years ago, and even they are still alive their memories cannot be verified.
Because there is significant lack of information about the period 1939-1945, some kind of interpolation was applied. This is why context is presented in this paper, *i.e.* human resources as well as material and technological background coming from the period before 1939. Also information taken from the period after **WW2** are included. It is applied to synthesis routes of mentioned in this paper **EXs**, presented by Heger (a manufacturer in clandestine facilities) and Urbański (well known researcher from pre-war and after-war periods). In Table 1 and in Supplementary Information, short data about the fate of some underground manufacturers before 1939 and after 1945 are added. Taking into account the need to preserve for future generations even a rudimentary knowledge, contemporary forms of commemoration has been appreciated by adding photos of contemporary look of some commemorating places located in Warsaw.
In this review has been shown how close to us is so extraordinary history of underground production of **EXs** and **EXDs** and how many activities and technological achievements were done to sustain combat abilities of occupied but not defeated Poland within the period 1939-1945. There are only a few source data, usually – even officially confirmed – which are cited literally (word by word) by all other references. The main intention of citing these secondary references is to show how many centers are in public, interested in the underground armor industry.
Very important question undertaken in this paper is also the future of the knowledge about Polish undercover facilities and their crews. Taking this into consideration, some concern was put also on contemporary social and cultural phenomena existing in the public space. Next research has to be undertaken.

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